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DE LA RECHERCHE À L'INDUSTRIE

Quench propagation measurements on 2 km MgB_2 coil up to 4 T

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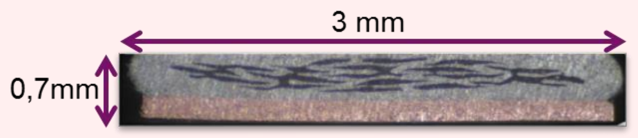
Experiment presentation

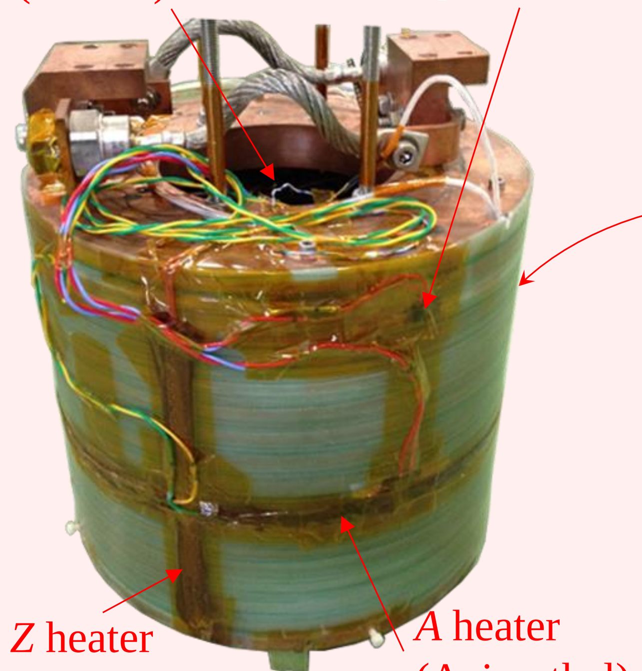


19 MgB_2 filaments in a Nickel matrix produced in 2014 by

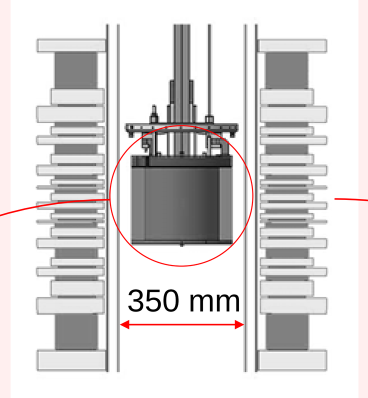
Columbus Superconductors

Parameters	Values	Units
Bar conductor dimensions	3.1 x 0.7	mm²
Insulation thickness	0.07	mm
MgB_2 cross section	0.31	mm²
Ni cross section	1.24	mm²
Cu cross section	0.62	mm²
Cu RRR	240	

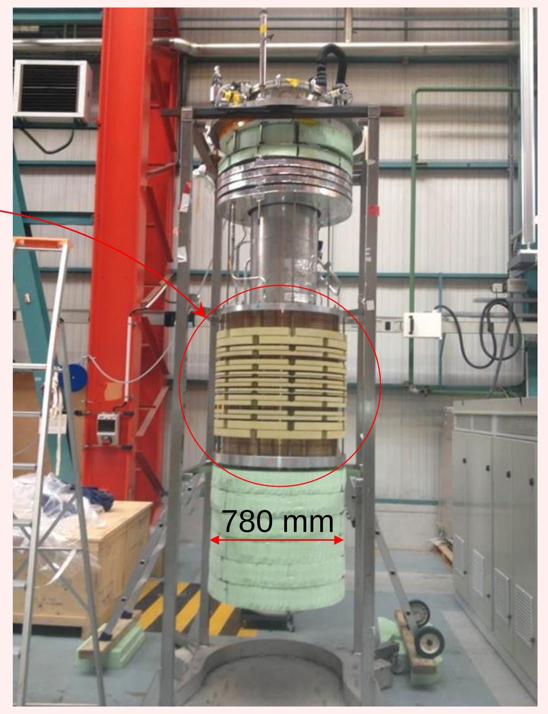
Main Conductor characteristics



1 T MgB_2 solenoid



Saclay MgB_2 test station:
- B < 3 T
- I < 600 A
- T ≥ 4 K.



3 T homogeneous solenoid

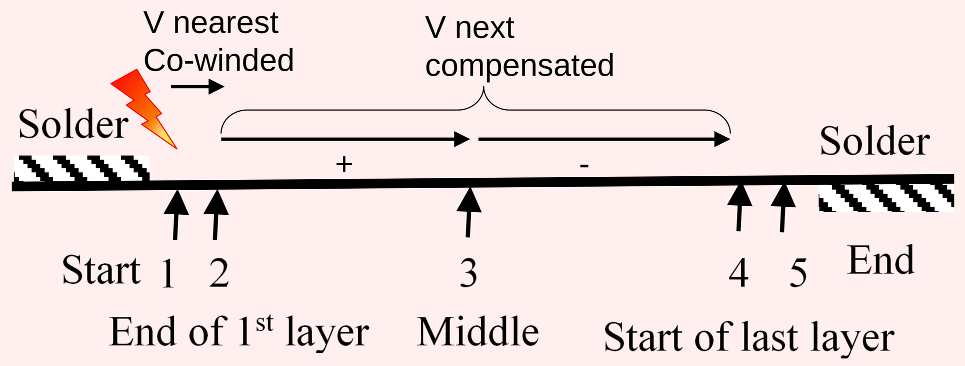
Parameters	Values	Units
Internal radius	100	mm
External radius	140	mm
Height	195	mm
Number of layers	44	
Nb. of turns/layers	60.5	
Number of turns	2662	
Conductor length	2	km
Inductance	1.14	H

Main solenoid characteristics

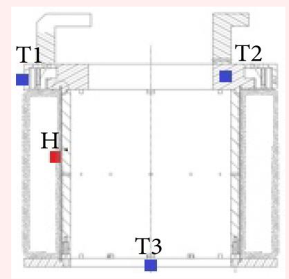
Names	Resistances (Ω)	Powers (W)	Surfaces (cm²)
M	18	55	1000
A	23	26	90
P	84	5	0.03
Z	8,05	72	20

Heater characteristics

The 1T solenoid is a dry magnet with only voltage taps and 3 Cernox as instrumentation.

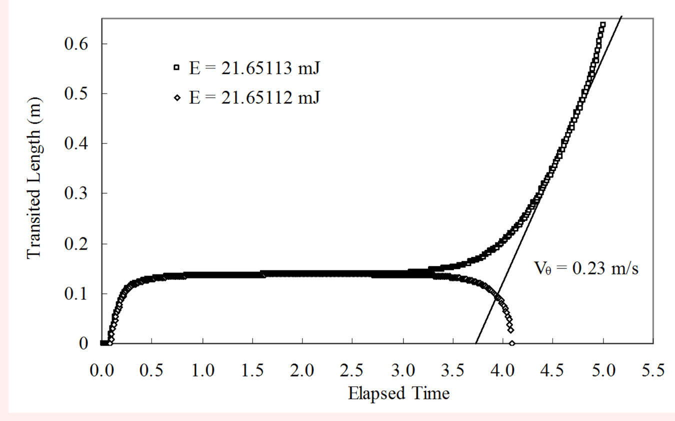


Voltage tap localization



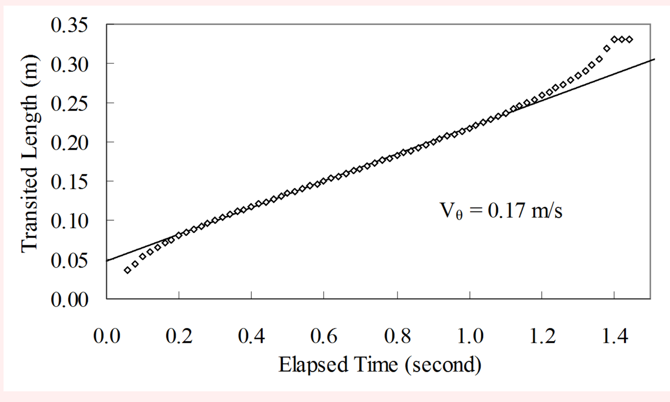
Temperatures & hot spot localization

Expected quench velocities calculated in 2013 [1]

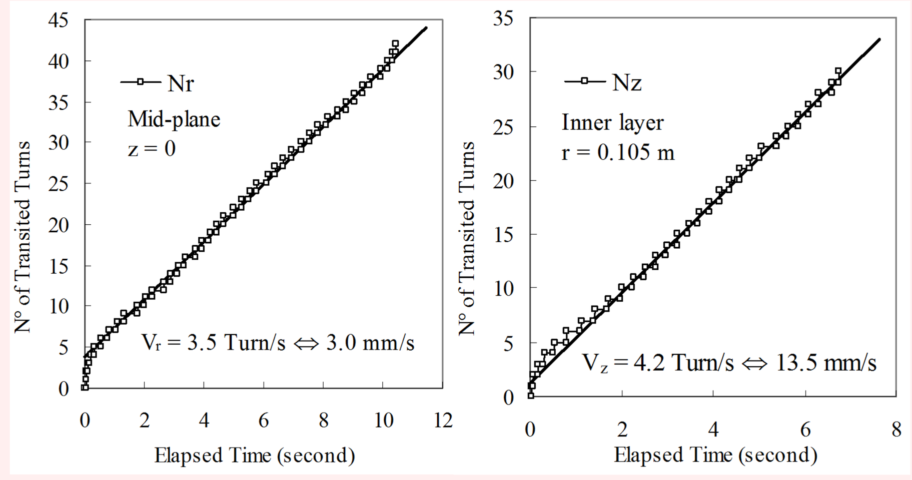


Stability of a single Conductor

A FEM studies have been performed to design the magnet and its protection. The entire coil is meshed. The computed MQE value equals 1 J. The MPZ value expressed in conductor length is 6.8 m and involves 40 adjacent turns. The quench velocities were also calculated:



Longitudinal quench velocity



Radial and axial quench velocity

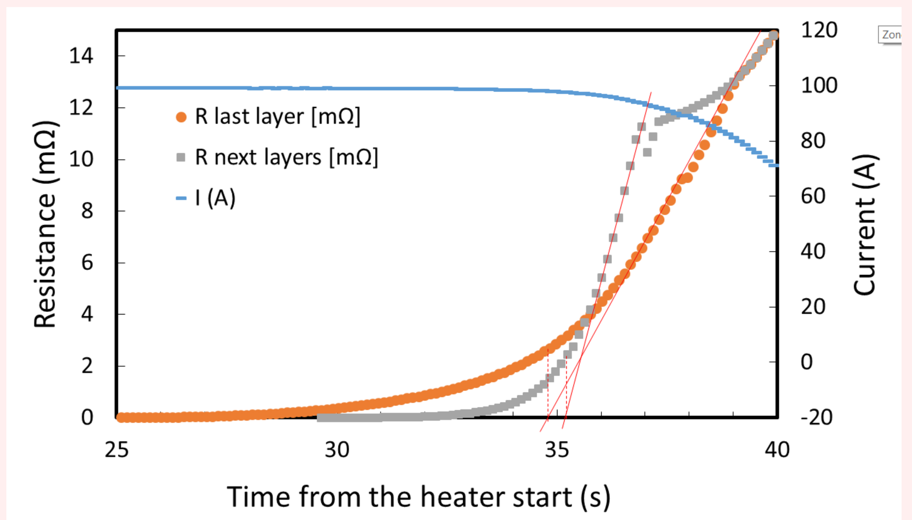
Name	Quench velocity	Delays or nb. of quenched turns before steady state	
Vr	3 mm/s	0.3 s	5
V_θ	170 mm/s	0.2 s	-
Vz	13.5 mm/s	2 s	1+2*3

Theoretical quench velocity

The nominal condition was set to : 100 A, 10 K, and 4.2 T and calculations were done without the mandrel and the fiberglass bulking.

[1] "The Preliminary Study of the Quench Protection of an MgB_2 Dry Magnet"; F-P Juster, *Adv. In cryo. Eng.* Vol.: 1573, p: 746-753; 2014

Resistance versus quenched length

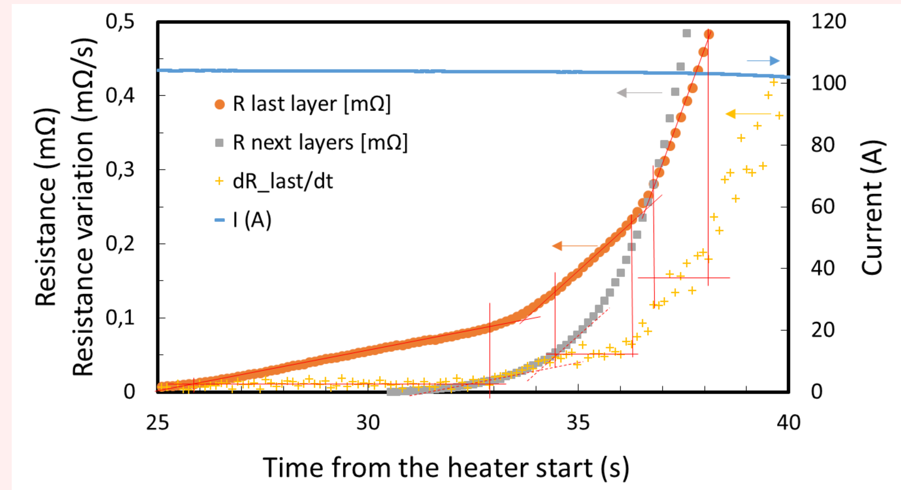


Quench with the axial Z heater @ 3 T, 99 A & 9.2 K

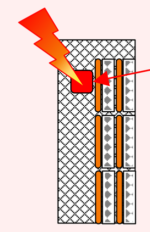
We calculated the value of the conductor linear resistance and corrected it roughly by the ratio of 17/11.5. This ratio gives the link coefficient between the resistance of the conductor and the quenched length: 0.20 mΩ/m at 3 T and 0.23 mΩ/m at 3.5 T.

After a quench initiated by the *Z* heater, the resistance curves show breaks when both azimuthal propagation fronts come together after a entire turn. The last layer and the rest of the coil reached the same resistance value at 39 s meaning that in both case, one entire layer is quenched. Notice that the 11-12 mΩ curve breaks do not correspond to a full resistance of one layer 17 mΩ as the current sharing of 13-14 K differs from the critical temperature of 21-23 K.

Experimental results



Quench initiated by the P heater @ 3 T, 104 A & 9 K



On the external layer, for a quench starting from the extremity corner, we can see up to 3 slops on the resistance curve. These slopes correspond to the number of adjacent quenched turns. The average quench length is directly obtained with the corresponding link coefficient.

Name \ Heater ref.		*P*	*P*	*A*	*A*
B @ quench	T	3.5	3	3,5	3
Initial current	A	94	104	93	107
Vr1	mm/s	0.1	0.1	0.3	0.2
Vr2	mm/s	1.2	2.2	0.81	0.46
$V\theta 1$	mm/s	23	55	-	-
$V\theta 2$	mm/s	53	83	-	-
$V\theta 3$	mm/s	-	152	-	-
Vz1	mm/s	0.2	0.37	1.2	0.93
Vz2	mm/s	0.69	1.0	1.6	1.9
Vz3	mm/s	-	1.9	2.4	-

Quench results at 9 K

Form various tests made at several initial conditions and with 2 different heaters, we can measure some quench velocities at the beginning of the quench propagation according to the rang of quenching turns or layers.

A correction must be applied to reset the velocities at the same initial conditions:

$$v_\theta \approx \frac{j}{\sum C_p} \cdot \sqrt{\frac{L_0 . T}{T_c - T}}$$

$$T_c = T_{c0} \cdot \left(1 - \frac{B}{B_{c20}}\right)^\gamma$$

With
- Vθ the longitudinal quench velocity
- j the current density in the stabilizer
- Cp the heat capacitance of all materials
- L0 the Wiedemann-Franz constant (2.44 10-8 W.Ω.K^{-2})
- T the working temperature
- Tc the critical temperature
- Tc0 = 35.2 K, the critical temperature at 0 T
- Bc20 = 15.5 T, the critical magnetic field at 0 K
- γ = 0.451

$$\frac{dv_\theta}{v_\theta} = \frac{dj}{j} + \frac{2T - T_c}{T_c - T}\frac{dT}{T} + \frac{\gamma T_c}{T_c - T}\frac{dB}{B_{c20} - B}$$

Correction from 18% to 33%.

Conclusion:

The longitudinal quench velocity is 2 time faster than expected probably due to the axial transvers velocity that is found to be 5 time less. The bulking and the presence of the conductor corners inducing a lower fiber contact could explain such difference.
The radial quench velocity was not measured because we were too fare from the asymptotic conditions.