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Bologna, Italy
3rd-7th September

2-LP-HF2-11S

Design of 32+ T all-superconducting user magnets for EMFL

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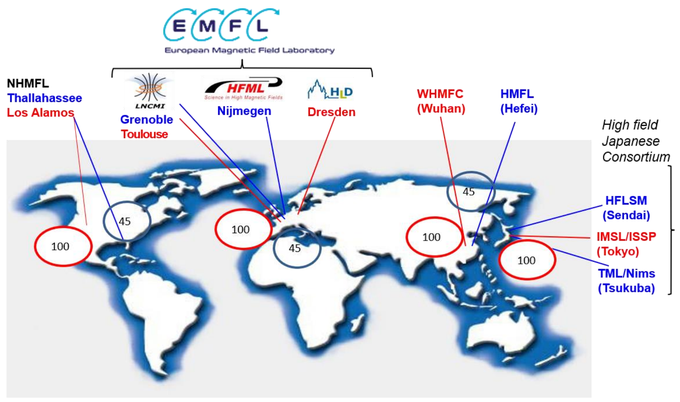
Background



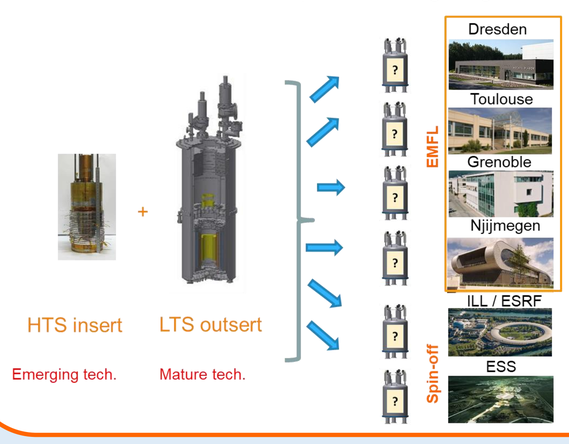
EMFL is gathering the European High Magnetic Field facilities producing pulsed fields up to 100 T and DC fields up to 45 T. The High DC Magnetic Fields are produced by resistive magnets requiring a large electrical and cooling power (e.g. for LNCMI-G 24 MW and 300 l/s of water).

HTS Superconductors for High Field - A change of paradigm

- Reducing drastically the energy to generate field
- Allowing long duration / low noise experiments

SuperEMFL concept and goals

A series of LTS + HTS superconducting magnets as new tools integrated within EMFL



Max field
Bore size
Geometry
Homogeneity

Compatibility with local instruments
- DC 50 mm
- Pulse 25 mm
- Beam line

Opportunities with local equipment
- Helium recovery
- Helium liquefier

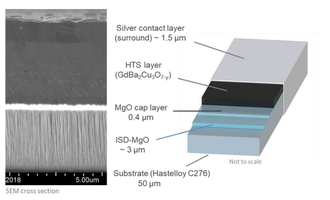
11 partners / Budget 2.9 M€
4 years / Started January 2021

Project features & challenges

Choice of tapes HTS conductor

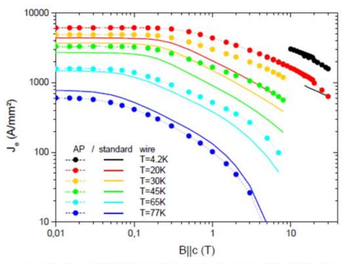
THEVA Pro-Line HTS Wire with APC

Basic wire architecture

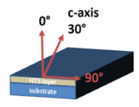


Simple, cost efficient, and robust

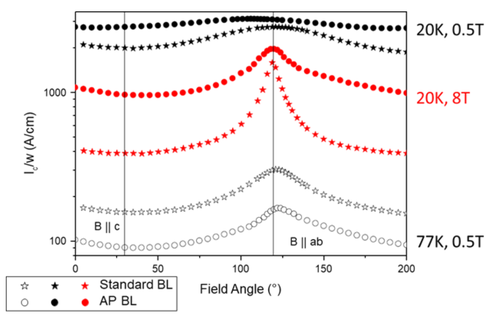
PVD surround stabilization
Cu up to 10 µm
Total: 65 µm

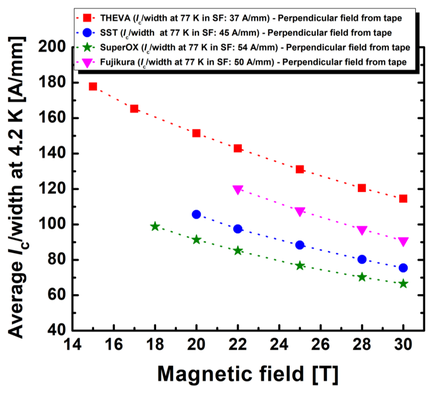


HF data from LNCMI Grenoble, Univ. Geneva, RRI Wellington
All values are $I_{c,min}$ values for B||c

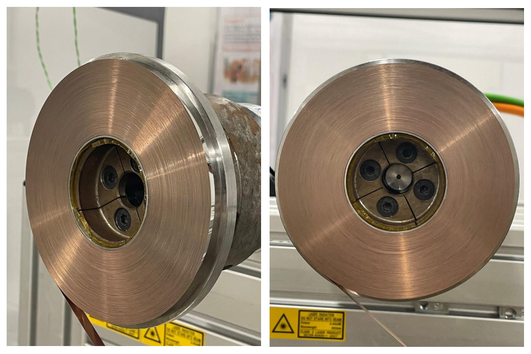


Due to ISD, the c-axis is tilted by about 30° wrt. the substrate normal. The tilt is always perpendicular to the tape length.





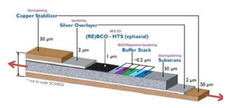
Current carrying capability per unit width at 90 degree from tape



Good winding uniformity & No winding deformation until target turns at a winding tension of 100 MPa

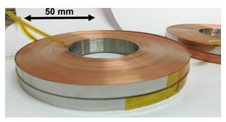
Starting point

- REBaCuO coated conductor



☺ High transport current under high magnetic field
☺ High mechanical strength due to Hastelloy

- Pancake coils

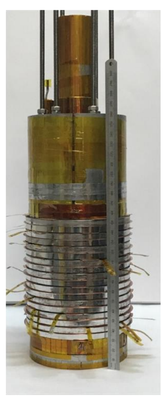


☺ Affordable for 100-200 m pieces

- Metal-as-insulation winding

☺ Best protection against quench

- Strained limited at 0.4 %



32.5 T
(18 T Ω + 14.5 T HTS)
in March 2019

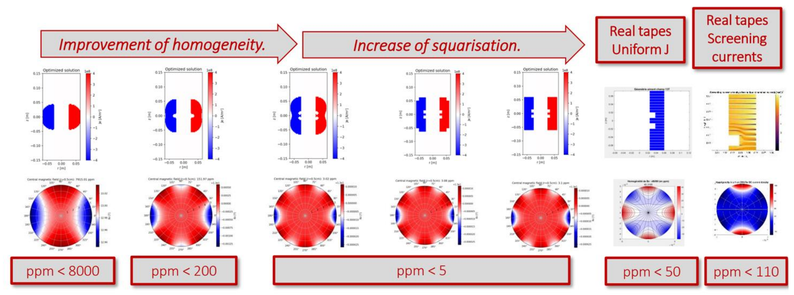
P. Fazilleau et al., Cryogenics **106** (2020) 103053
DOI: 10.1016/j.cryogenics.2020.103053

Specifications

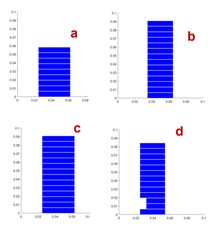
Parameters	Unit	Values
ID; OD	mm	50; 112
Height	mm	122.3
I_c DP coils @ 77 K	A	54.5 ~ 67.3
Number of DP		9
Turn per pancake		290
Total conductor length	km	~ 1.35
Stainless steel overband turns		44
OD after SUS overband	mm	119.0
Winding tension	MPa	92 ~100
Magnet inductance	H	0.825
Magnet constant	mT/A	44.5
Time constant (τ) at 4.2 K	s	23.06
Characteristics resistance (R_c)	mΩ	37
Contact surface resistance (R_{ct})	µΩ·cm²	103

Simulation/optimizations tools and preliminary design

32 T with 13 T from HTS magnet (19 T ousert)



Several numerical tools were developped and benchmarked to take into account screening current and metal-insulation features.

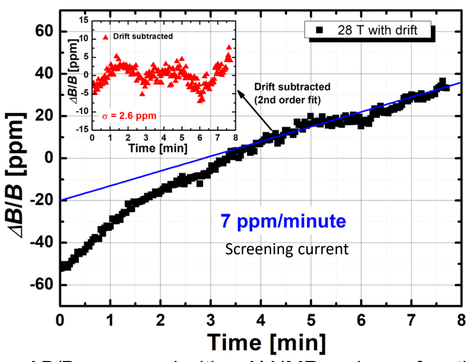


	Basic Design (a)	High Volume (b)	High Field (c)	High Homogeneity (d)
Design led by	Volume	Mechanics	Mechanics	Volume
Geometry				
Internal diameter (winding)	**50 mm**	**70 mm**	**50 mm**	**50 mm**
External diameter (winding+ob)	106 mm	132.6 mm	128.6 mm	106 mm
Number of DP	8	14	14	13
Turns per pancake	250	284	360	250/187
Total length	957 m	2495 m	2771 m	1510 m
Electrics				
SC Conductor			THEVA APC	
Nominal current	333 A	271 A	287 A	326 A
Critical current	472 A	454 A	422 A	468 A
Current margin on load line	29 %	40 %	32 %	30 %
Magnetics				
Magnetic field at center (HTS alone)	**13 T**	**13 T**	**18 T**	**13 T**
Homogeneity	2071 ppm	784 ppm	666 ppm	39 ppm
Inductance	0.5 H	2.18 H	2.56 H	0.88 H
Energy	27.9 kJ	79.7 kJ	106 kJ	46 kJ
Mechanics				
Winding tension			100 MPa	
Turns of over-bending			50	
Maximal hoop stress	**585 MPa**	**758 MPa**	**655 MPa**	**596 MPa**

Several designs are proposed depending on the purpose (high field, large bore, homogeneity

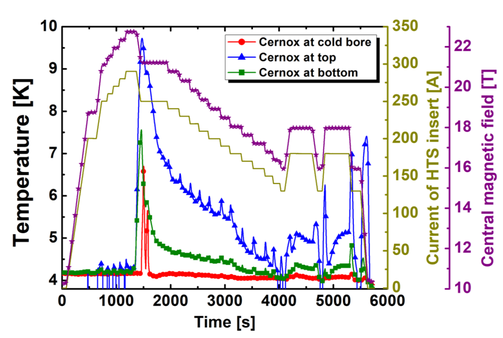
Some experimental results

Temporal stability



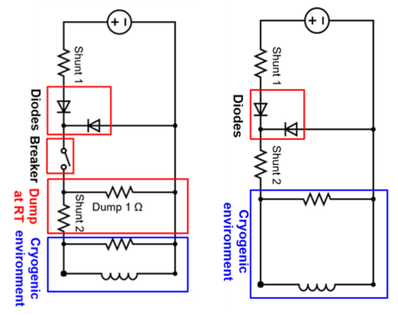
ΔB/B measured with a Al NMR probe as function of time at Btot= 28 T (18 T Ω + 10 T HTS) @ 4.2 K

Trapped helium bubble by grad(B²)

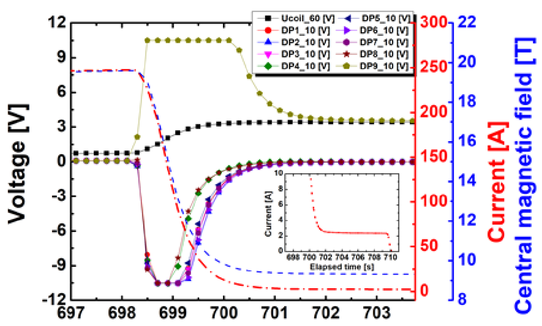


Temperature, current and field traces of the HTS magnet under Bext = 10 T @ 4.2 K

Simplified quench protection scheme using MI feature

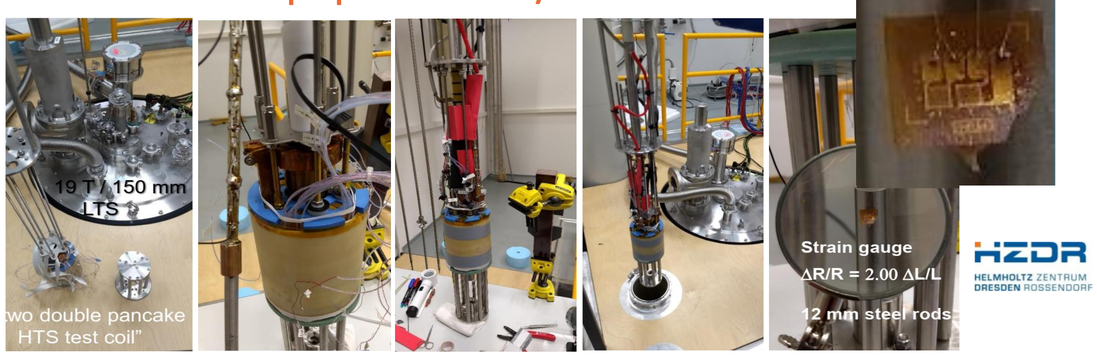


Protection schemes for HTS insert: (a) detect and dump and (b) PS voltage limitation style

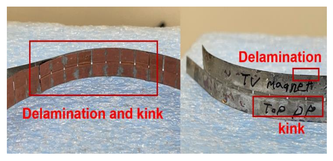


Quench behavior of the MI insert at Iop = 247 A at Bext = 9 T at 4.2 K without switch and dump resistor. Note that PS limitation was 3.5 V.

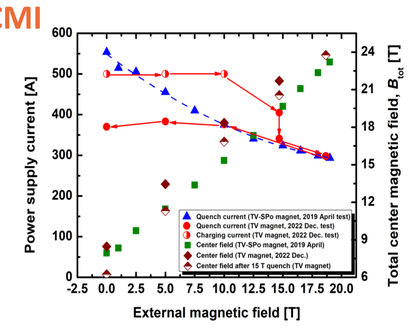
2 DP HTS coil test prepared in a 19T/150 mm Oxford Instr. LTS



2 DP HTS test coil at LNCMI



Example of an internal electrical junction between single pancakes after quench events.



Test results of TH-SP (2019) and all TH (2022) 2 DP test coils under various B_{ext} at 4.2 K

To be continued …

- **Good electrical performance (J_c >1000 A/mm²) under perpendicular field of 30 T from ab-plane at 4.2 K.**
- **For HF magnets, physical properties of REBCO tapes should be improved, i.e. delamination strength, and junctions reinforced.**
- **Tests of newly improved THEVA tapes are planned.**

Stay tuned …

SuperEMFL project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 951714. This work reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

See also in this conference :

- 3-LO-HT-03S Application of technical HTS wire in low-field and high-field magnets
- 3-MP-PR-06S A robust holder sample holder for ReBCO tape testing under extreme conditions
- 2-LP-HF2-11S Behaviour during quenches of a 40 T magnet constructed from LTS and HTS
- 3-LO-AL-02S Multi-physics modelling of metal-insulated REBCO magnets with screening currents