Screening currents within the Eucard HTS dipole

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Summary

The EuCARD High Temperature Superconductor (HTS) insert is a **dipole magnet generating a self-field of 5.4 T** and designed to operate at **18 T within the FRESCA2 test facility**; it has just been successfully **tested in stand-alone configuration up to 4.51 T.**

To operate in such a large field, its winding is made of **12 mm HTS REBCO insulated stacked tapes conductor**; each conductor is composed of **four tapes in parallel** to achieve a large current of **2.8 kA**.

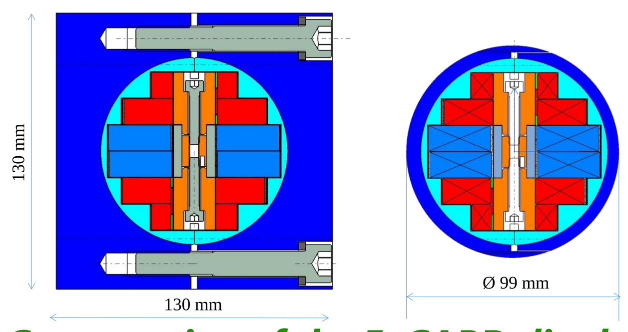
The drawbacks of using parallel HTS tapes are numerous: firstly, they are **very sensitive to orthogonal field** inducing screening currents loops within the tapes. Secondly, the use of tapes in parallel **imposes to transpose the conductor** to avoid current loops between tapes, induced from the parallel field. The screening currents in return generate a magnetic field (**Screening Current Induced Field**), opposed to the main one and consequently **lowering it and degrading the homogeneity.**

We have developed **a finite difference code** in order to simulate the **induced currents within a conductor** made of parallel tapes; we have calculated the SCIF and showed that the order of magnitude is non negligible compared to the main field.

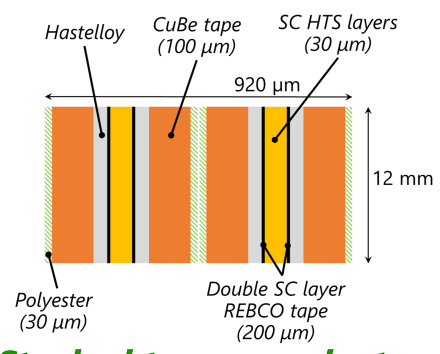
These computations have been **benchmarked against measurements** of the magnetic field performed during the stand-alone configuration tests.

EuCARD HTS insert

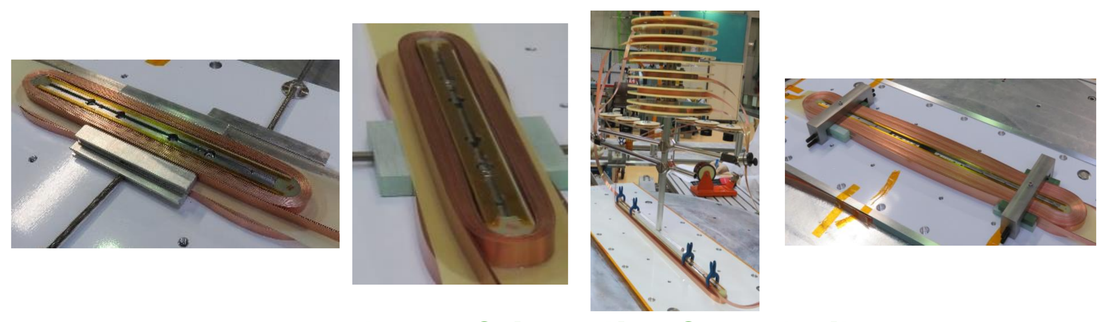
- The HTS winding is made of **three double-layer simple racetrack coils**. The two extrema coils are identical and made shorter than the central coil to decrease the magnetic field magnitude within the coil ends. They are assembled around **an iron pole.**
- The EuCARD HTS cable is a **stacked cable made of six co-wound ribbons.** Two of the ribbons are REBCO conductors, each made of two superconducting layers, soldered together on a copper matrix.



Cross-section of the EuCARD dipole



Stacked tapes conductor

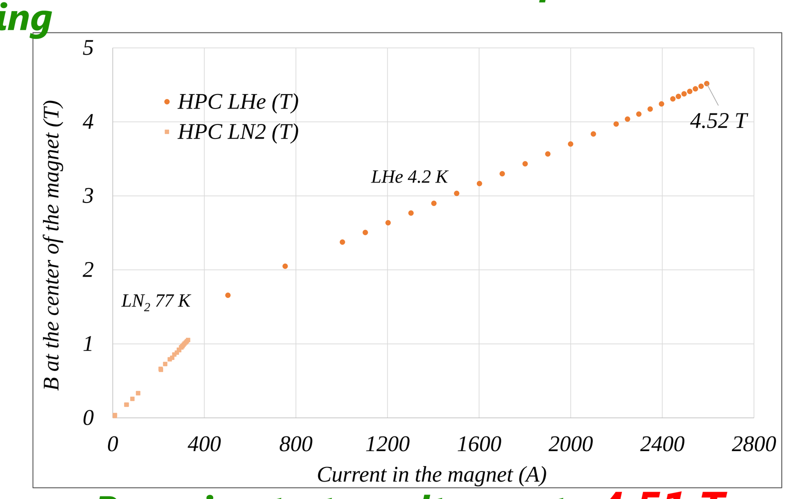


Views of the coils after winding

Magnet main parameters

Background field	T	0	13
Nominal current	A	2800	
Nom central field (no screening currents)*	T	5.38	
Expected central field (screening currents)	T	4.67	4.66
Temperature	K	4.2	
Winding current density @ I_n	A/mm^2	235	
Magnetic force F_x (one quadrant)*	kN/m	210	2750
Magnetic force F_y (one quadrant)*	kN/m	186	186
Magnetic force F_z (one end)*	kN/m	-	180
Self-stored energy	kJ	10.4	
Self-inductance	mH	2.7	
Estimated temperature margin	K	28	12
Estimated margin on the load line	%	45	30

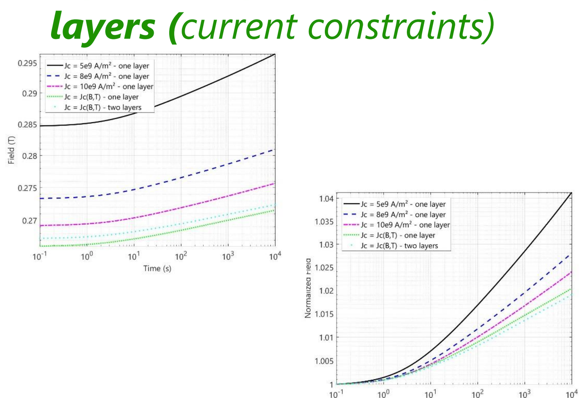
*Not taking into account persistent currents



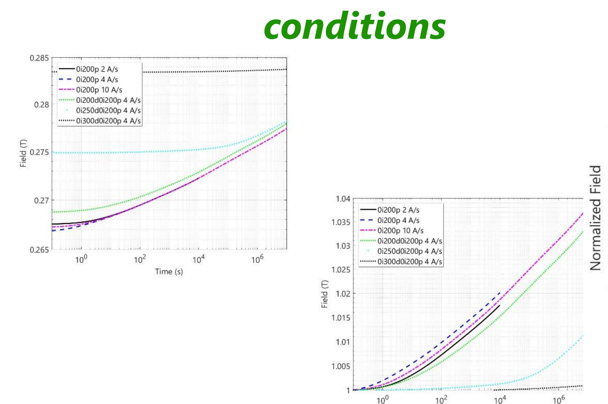
*Powering test results...up to **4.51 T***

SCIF sim. & meas. @ 77 K

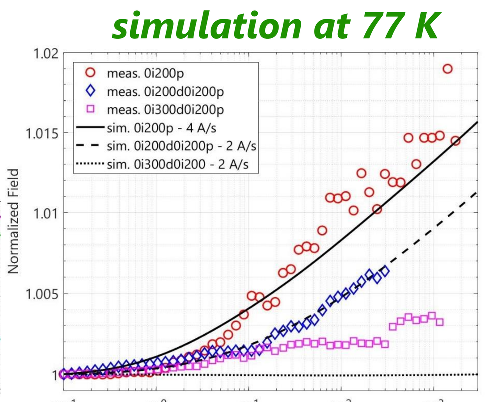
Influence of Jc and nbr of layers (current constraints)



Influence of initial conditions



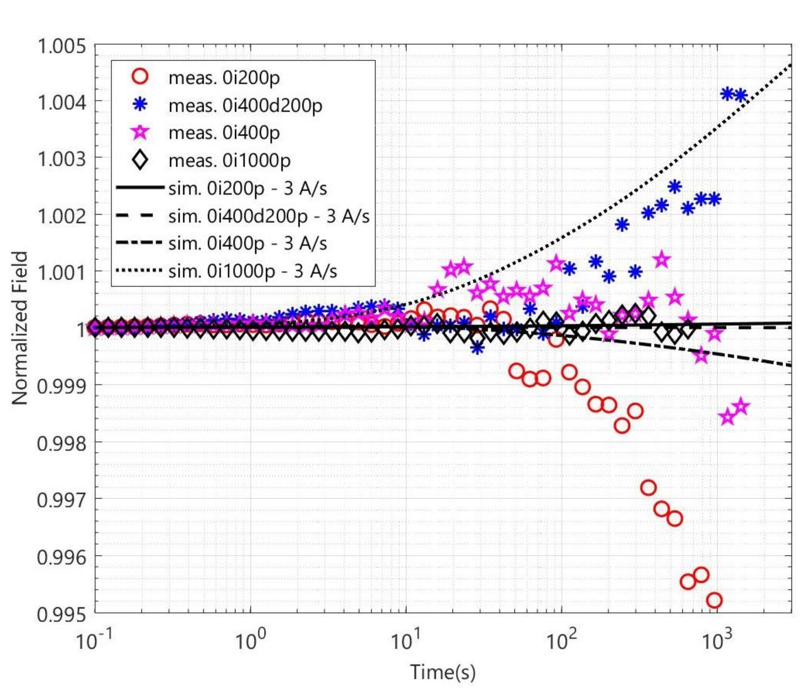
Measurements and simulation at 77 K



- **Decay** of the magnetization with **logarithmic** rate in time,
- Measurements and simulations show **initial conditions** preliminary to the plateau at 200 A have a **strong effect** on the magnetic field and its relaxation,
- **Same phenomenon** than in the **'overshoot' technique** used to remove the effects of the screening currents,
- **Good accordance** between **simulation and measurements.**

SCIF sim. & meas. @ 4.2 K

Measurements and simulation at 4.2 K

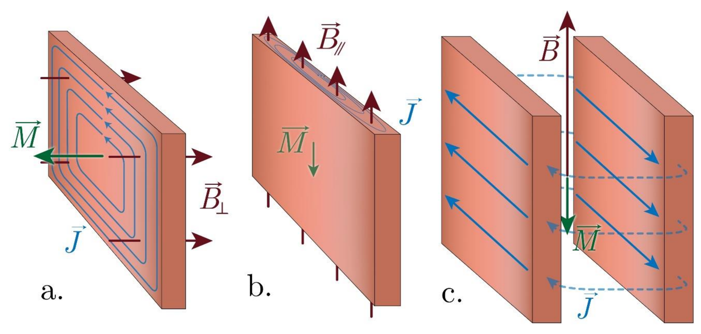


- Some measurements (and simulation) shows a **decrease of the total magnetic field**,
- This is due to the **particular conductor** of the EuCARD magnet and especially its **double SC layer ribbon**,
- The **relaxation** is not only due to the TAFC but also to the **redistribution of current between the two SC layers**,
- The phenomenon **time constant** depends on the **electrical resistance of the junctions**,
- **At 4.2 K**, the resistance are lower than resistances at 77 K and **the time constant is longer.**
- This could explains the **discrepancy between measurements and simulations at 4.2 K** (TAFC only taken into account in simulations).

SCIF

- **Screening currents** are induced when they are exposed to a magnetic field, generating in return an opposed field, referred as the **Screening Current Induced Field (SCIF) or magnetization**.
- The generation of the magnetization is **more intense** when the tape is exposed to a **perpendicular field** because the induced loops are wider as shown in right figure.
- For **two tapes**, a parallel field can induce high currents because the **loops can be very large** as the current can flow in one direction in the first tape and in the other direction in the second tape.
- The **relaxation** of these currents is very long and due to a phenomenon called **Thermally Activated Flux Creep (TAFC).**

Screening Current Induced Field generation



Simulation code

Faraday's equation...and its solution

$$\nabla \times \vec{E} = -\dot{\vec{B}} \Rightarrow \vec{E} = -\dot{\vec{A}} + \nabla V$$

$\vec{A}$ depends on J according to Biot & Savart law

$$M\frac{dJ}{dt} = G(J)$$

M is constant
G depends on J

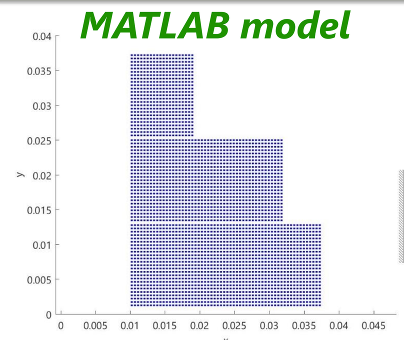
Power law and Jc fit

$$E = E_0\left(\frac{J}{Jc(B,\theta,T)}\right)^n$$

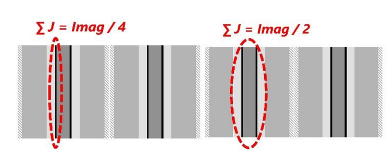
- A **difference finite method** is used.
- The **ODE** system is **stiff and highly non-linear** *(n # 20 to 30)*
- We solve it using the ode algorithm from **MATLAB.**

- *Jc(B,θ,T)* is computed from the fit of the critical surface of REBCO conductors made at CERN.
- ***n* is set to 25** for the computations.
- We assume the transposition is perfect: only a **quarter of the magnet** is modelized.
- Each tape is divided in 25 elements for a total of **6400 elements.**

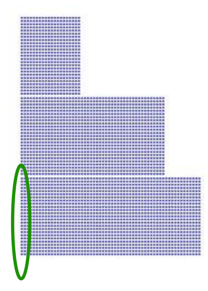
MATLAB model



current constraints



SCIF sim. @ 0 to 2800 A / 4.2 K



Tape #1