Modelling of the pulsed field magnetization of a (RE)BaCuO bulk with a superconducting weld

***Rémi Dorget[1,2], Kévin Berger[1], Joseph Longji Dadiel[3], Kimiaki Sudo[3], Naomichi Sakai[3], Tetsuo Oka[3], Masato Murakami[3] and Jean Lévêque[1]**

[1] Université de Lorraine, GREEN, F-54000 Nancy, France

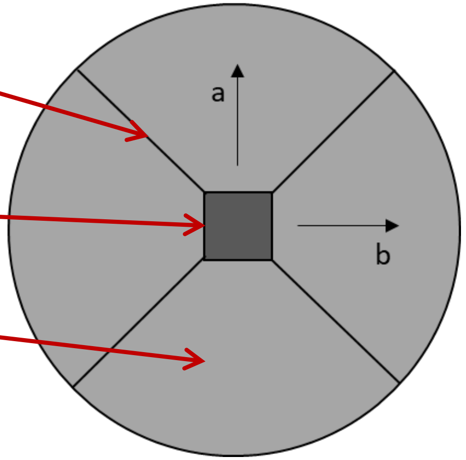
[2] Safran Tech, Electrical & Electronic Systems Research group, Rue des Jeunes Bois, Châteaufort, 78114 Magny-Les-Hameaux, France

[3] Shibaura Institute of Technology ,3 Chome-7-5 Toyosu, Koto, Tokyo 135-8548 - Japan

- Top seeded melt growth
- RE-Ba-Cu-O bulk welding process
- Description of the model
- Results

Top seeded melt growth (TSMG)

- Pellet of RE-Ba-Cu-O pressed then melted and slowly cooled to let the crystal grow
- The seed crystal (RE-Ba-Cu-O with higher melting point) give the crystal orientation
    - ❖Examples of seed crystals : Nd-Ba-Cu-O or Sm-Ba-Cu-O
- Several hours of oxygen annealing



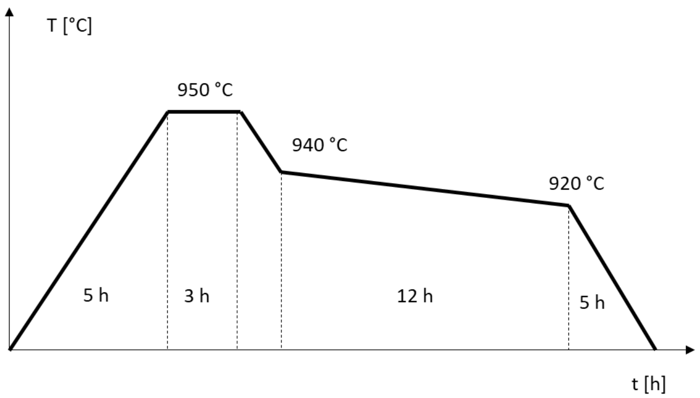
Growth sector boundaries

Seed crystal

Growth sector regions

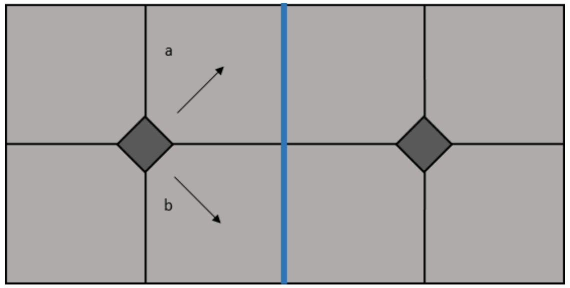
Bulk welding process

- Solder material: RE-Ba-Cu-O with low melting point
- Process similar to TSMG: The solder material is melted while the bulk body act as the seed

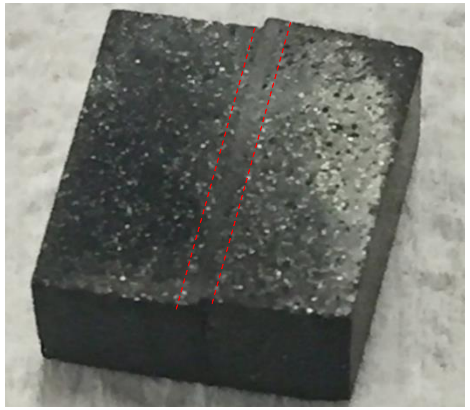


Example of the temperature process for joining Y-Ba-Cu-O + 10%Ag with Er-Ba-Cu-O + 10%Ag

Material	**Tp [°C]**
Y-Ba-Cu-O	1008 °C
Er-Ba-Cu-O	980 °C
Y-Ba-Cu-O + 10%Ag	956 °C
Er-Ba-Cu-O + 10%Ag	937 °C

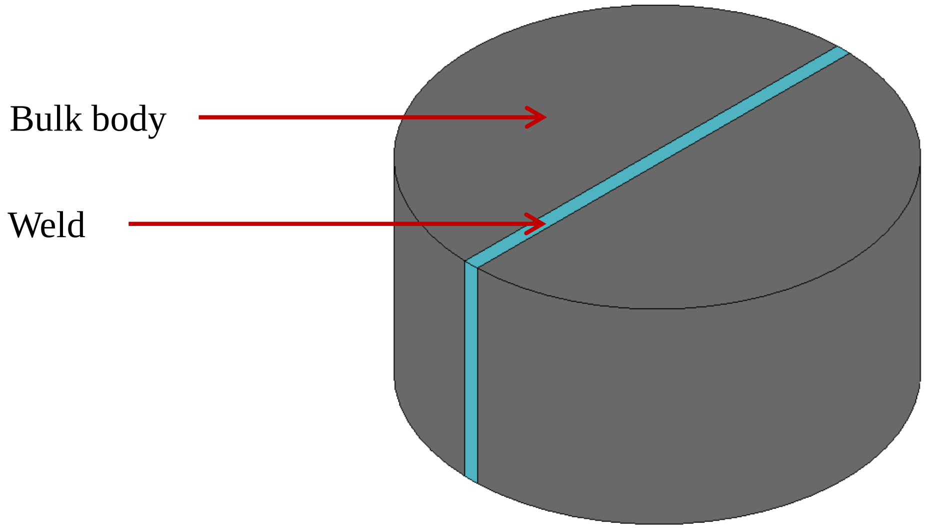


Good grain connection is obtain along the 110 plane



Case study

- Simulation of the weld behavior during pulsed field magnetisation (PFM)
- Bulk body:
  - ❖Radius : 30 mm
  - ❖Height : 15 mm
  - ❖Homogeneous superconducting properties
- Weld:
  - ❖Thickness : 1 mm
  - ❖Superconducting properties different from the bulk body
- Objective: study the magnetisation for different welds

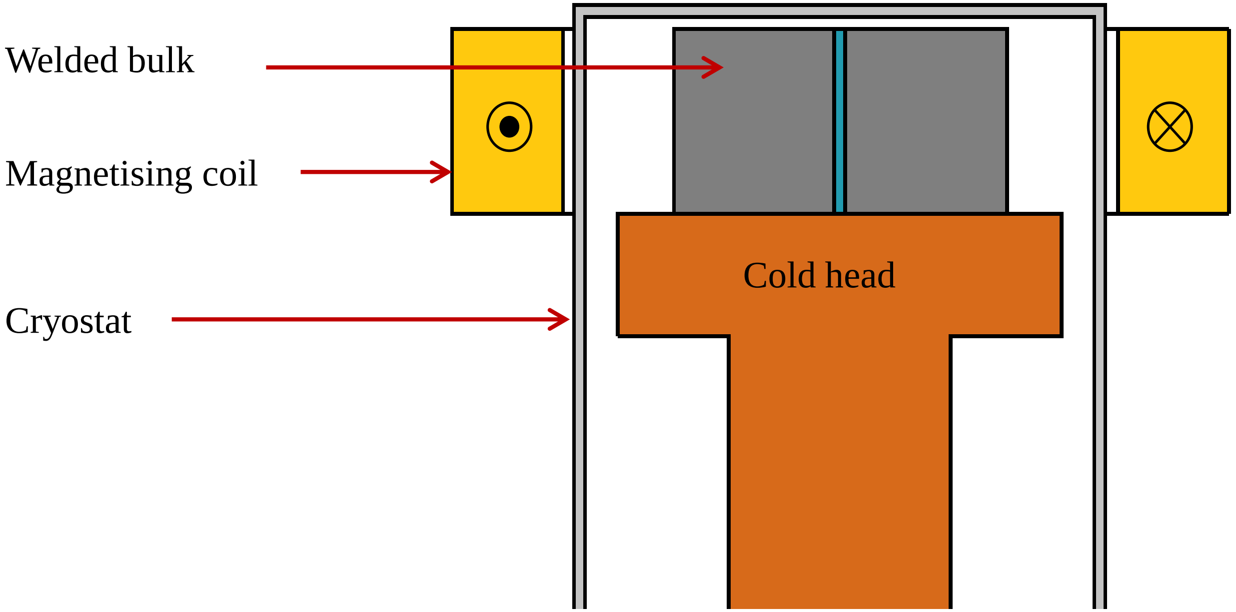


Simulated setup

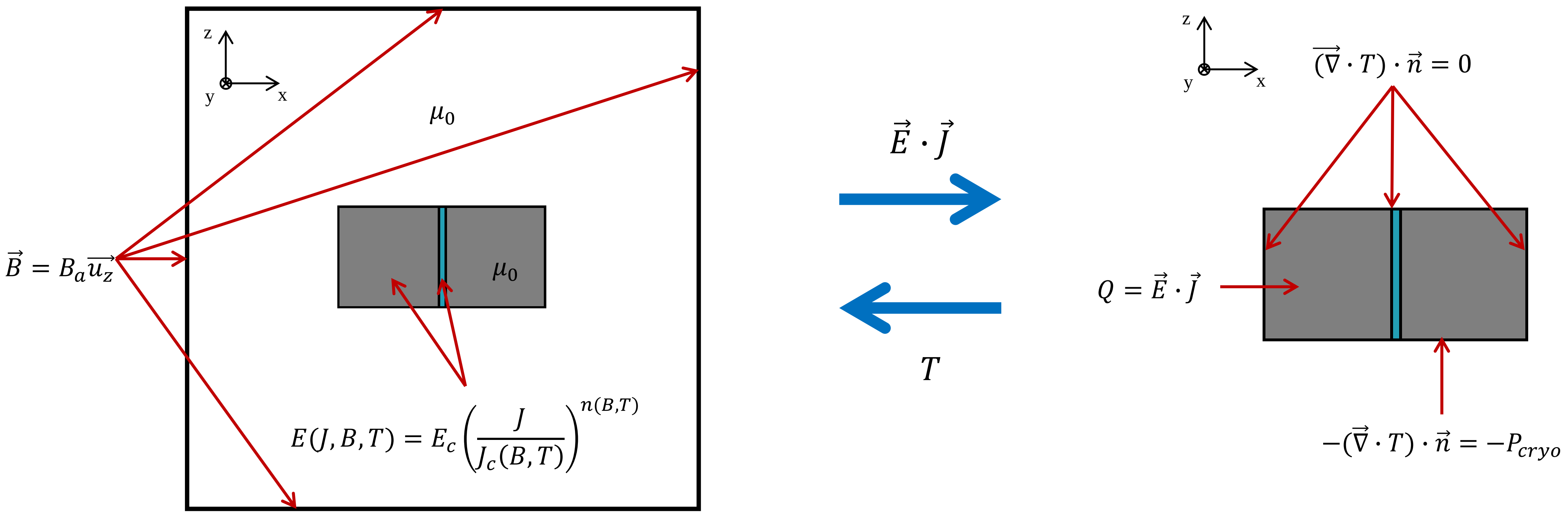
- Initial temperature :
  $T_a = 60$ K

- Cryocooler cooling power :
  $P_{cryo} = 50W$

- Applied magnetic field :
  $B_a = [0.5$ T : 9 T$]$



Electromagnetic and thermal models

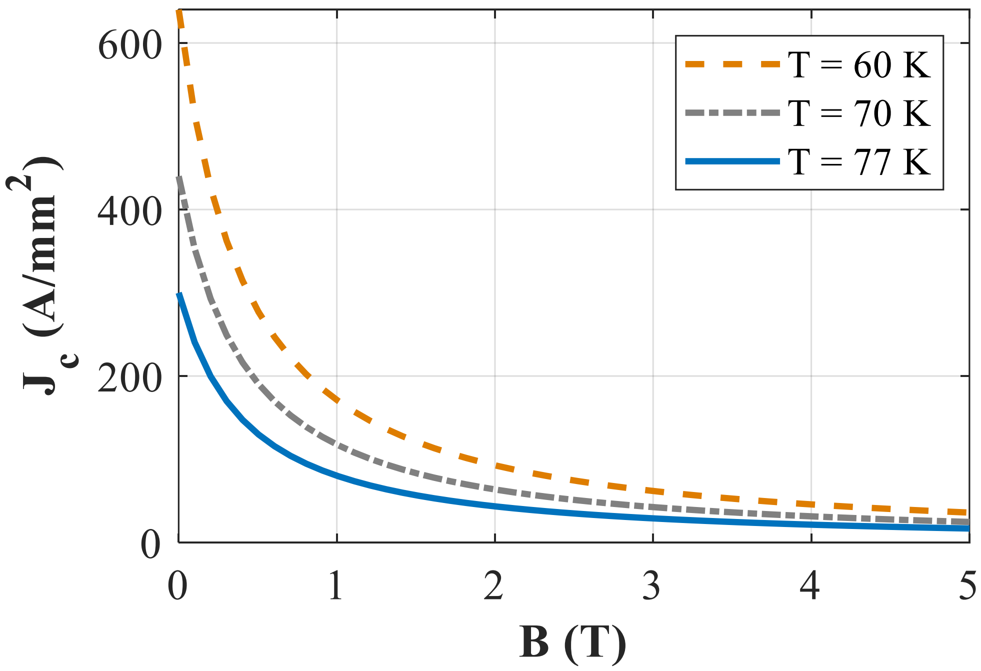


3-D Electromagnetic model

3-D Thermal model

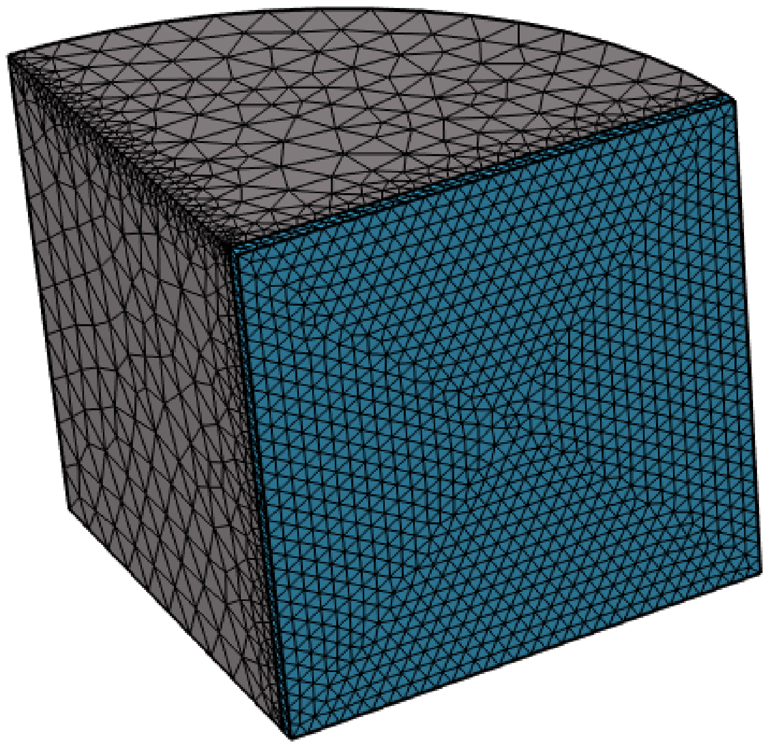
Electromagnetic model

- H-formulation
- $J_c(B,T)$:
  - ❖In the bulk body :
    $$J_{c1}(B,T) = \frac{J_{c0}}{\left(1+\frac{B}{B_0}\right)^{\beta}}\left(\frac{1-T/T_c}{1-T_0/T_c}\right)$$
  - ❖In the weld:
    $$J_{c2}(B,T) = \alpha J_{c1}(B,T)$$
  - ❖Weld to bulk body critical current ratio:
    $$\alpha = [0.25\,;0.5\,;0.75\,;1]$$
- $n(B,T) = \left(n_1 + \frac{n_0 - n_1}{1+B/B_0}\right)\frac{T_0}{T}$



Simulation parameters

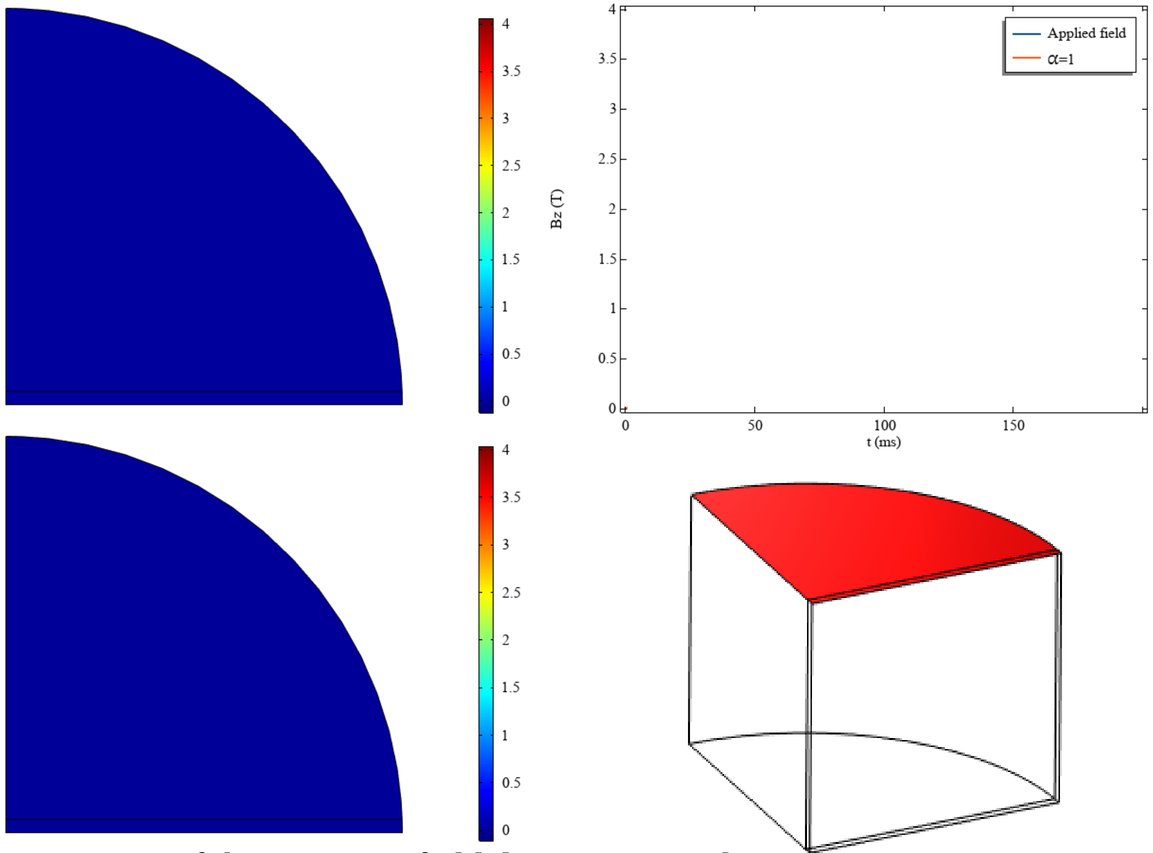
- Due to symmetries → ¼ of the geometry is simulated



Parameter	**Value**	**Description**
J_{c0}	300 A/mm^2	Self field critical current density at 77 K
B_0	0.5 T	Magnetic field dependance constant
β	1.2	Magnetic field dependance exponent
n_0	20	n exponent at 77 K and B = 0 T
n_1	6	n exponent at 77 K and B >> B_0
T_c	92 K	Critical temperature
T_0	77 K	Reference temperature
T_a	60 K	Initial temperature
B_a	[0.5 T : 9 T]	Applied flux density
τ	10 ms	Pulse time constant
α	[0.25 : 1]	Weld to bulk body critical current ratio
P_{cryo}	50 W	Cooling power of the cold head
d	6 g/cm^3	RE-Ba-Cu-O density
C	150 J/(kg.K)	Heat capacity
γ	5 W/(m.K)	Thermal conductivity

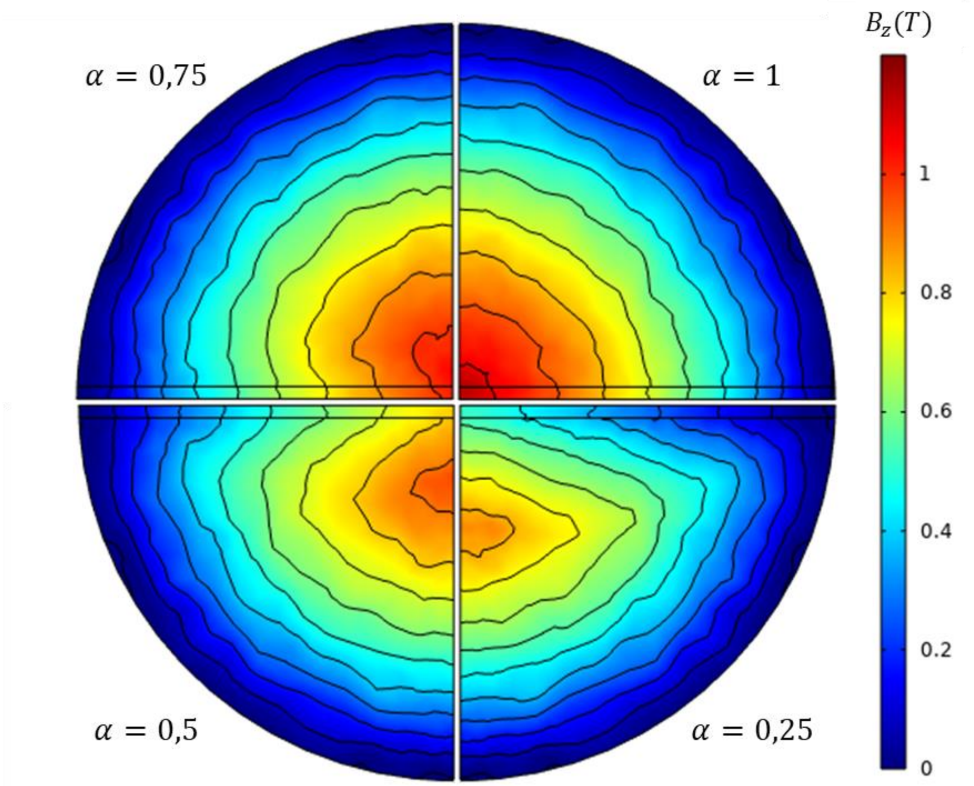
Results – Field maps

HTS 2020 Modelling



Penetration of the magnetic field during a 4 T pulse

Top: α = 1 Bottom : α = 0.5

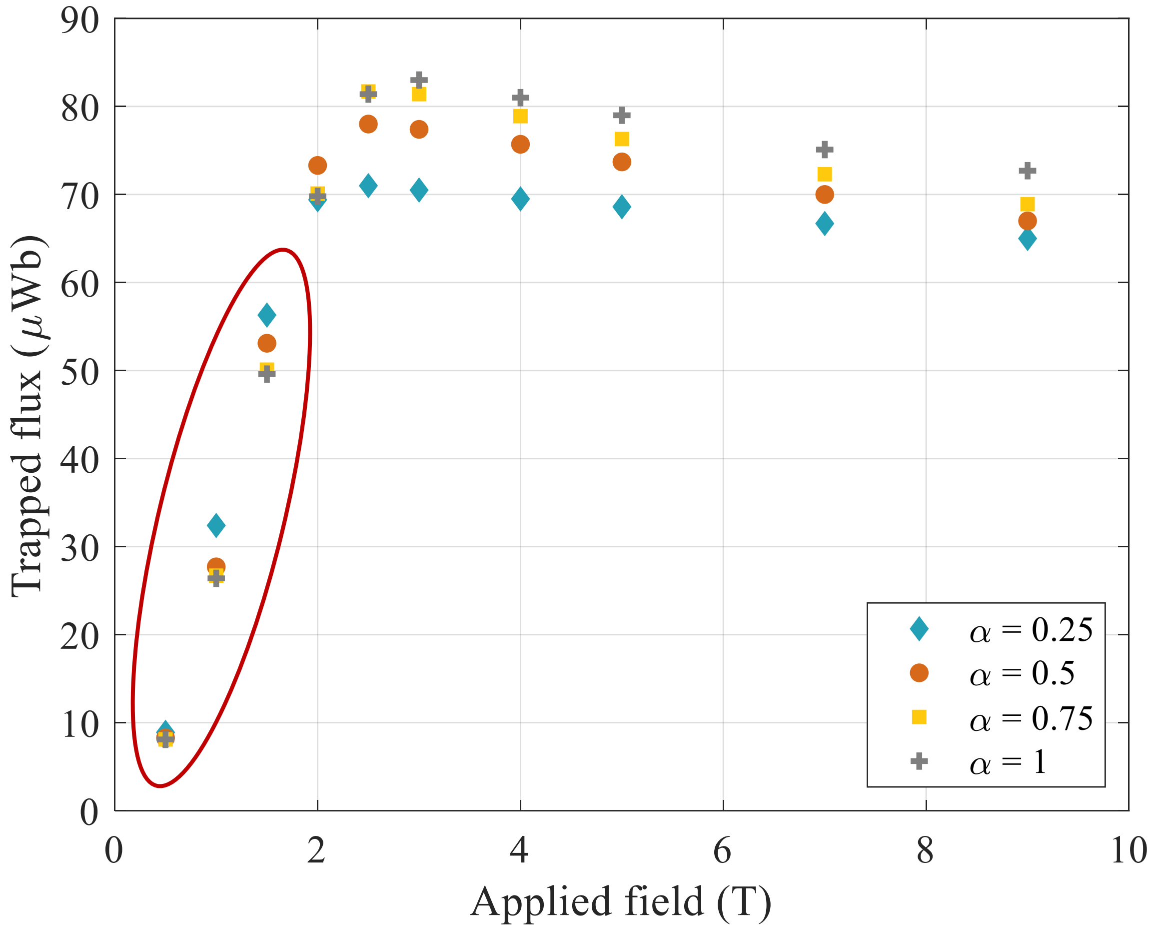


Trapped field map after 60 s

Results – Trapped flux

Trapped flux on the bulk surface:

- Above 2 T → weld reduces the trapped flux
- Below 2 T → weld increases the trapped flux (up to 13 %)



Conclusion

- A superconducting weld with a reduced critical current help the magnetic field to penetrate the bulk
  - ❖Increased trapped flux at low applied field
  - ❖Decreased trapped flux at high applied field
  - → Applications with small inductor coil (magnetisation from armature windings)

- The solder can be doped to improve its thermal properties at the expense of the magnetic properties

HTS 2020 Modelling

Thank you for your attention

Rémi Dorget, ☎ (+33) (0)6 82 52 22 86, 🖂 **e-mail**: remi.dorget@univ.lorraine.fr

UNIVERSITÉ DE LORRAINE | GREEN

芝浦工業大學 SHIBAURA INSTITUTE OF TECHNOLOGY

SAFRAN