HTS insert for a particle accelerator using a twisted stacked cable

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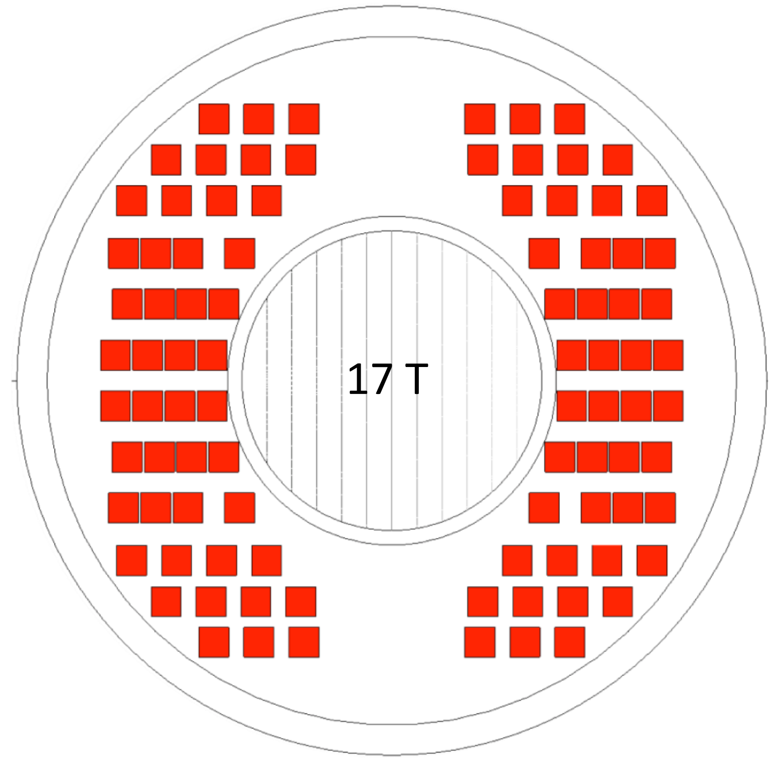
Outline of contents

- *HTS twisted stacked magnet design*
  - 2D magnet cross-section
  - 3D magnet ends
- *Current distribution analysis*
- *Future aspects*
- *Conclusions*

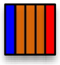
2D HTS twisted stacked design

46-turns HTS insert

Parameter	Value
Center field B_0	17 T
Current density J_{op}	650 MA/m²
Operating current I_{op}	10.4 kA
Conductor area	1472 mm²
Field quality B_3/ B_5	1.5/ 0.78 units
Inner/ external tube	2/ 4 mm

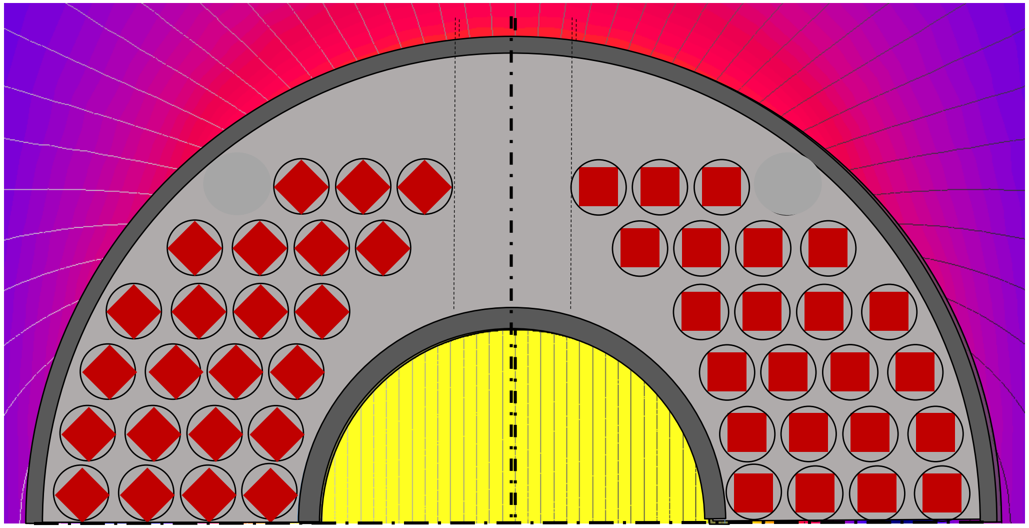


Main highlights of twisted stacked design

- ✓  4 x 4 mm block-coil consisting 20 ReBCO stacked tapes of 4 mm wide achieves required I_{op} = 10 kA with 46-turns HTS stacked cable.
- ✓ Three or four block-coils are assembled and aligned in horizontal to facilitate the mechanical architecture and winding.
- ✓ Good field quality as possible within range of J_{op} = 600 – 700 A/mm².

Winding topology

2D magnet ends cross-section at twist part



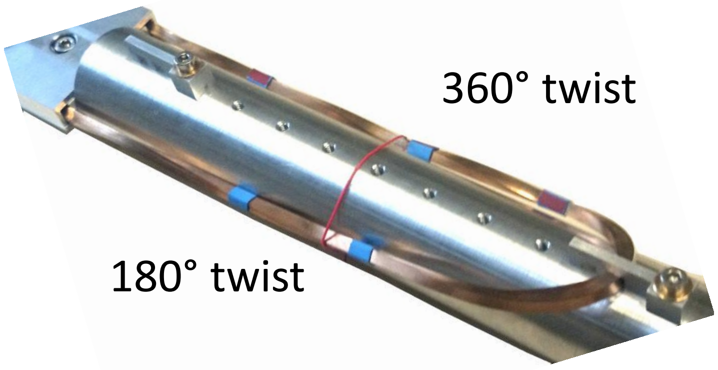
Racetrack coil (above beam tube)

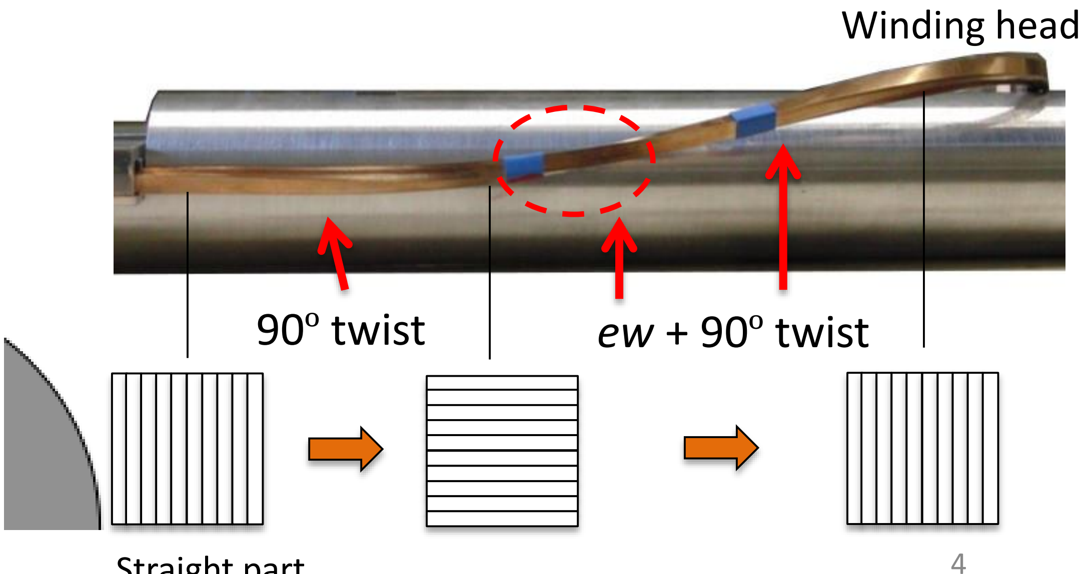
➡ 180° twist one side
0° on the other

Flared-ends coil (below beam tube)

➡ 180° twist one side
360° twist on the other

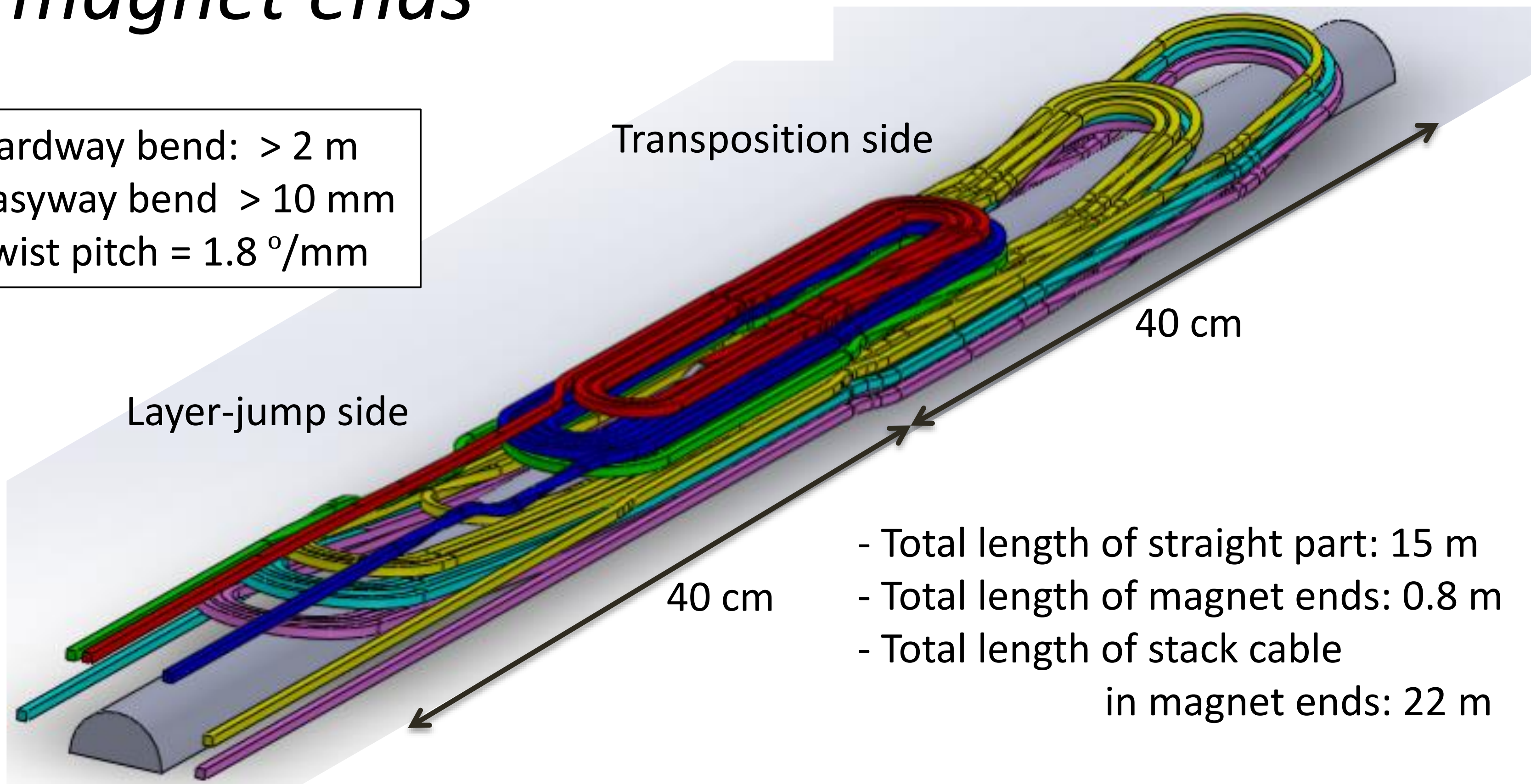
Flared-ends coil





3D magnet ends

Hardway bend: > 2 m
Easyway bend > 10 mm
Twist pitch = 1.8 °/mm



- Total length of straight part: 15 m
- Total length of magnet ends: 0.8 m
- Total length of stack cable in magnet ends: 22 m

Main highlights of 3D HTS coil-ends

✓ 46-turns HTS insert is consist of six double pancakes. Three coils at top and at bottom are the racetrack and flared-ends coils, respectively.

✓ Double pancake is connected with layer jump. Layer jump is done with twist + *ew* bending or with *hw* bending.

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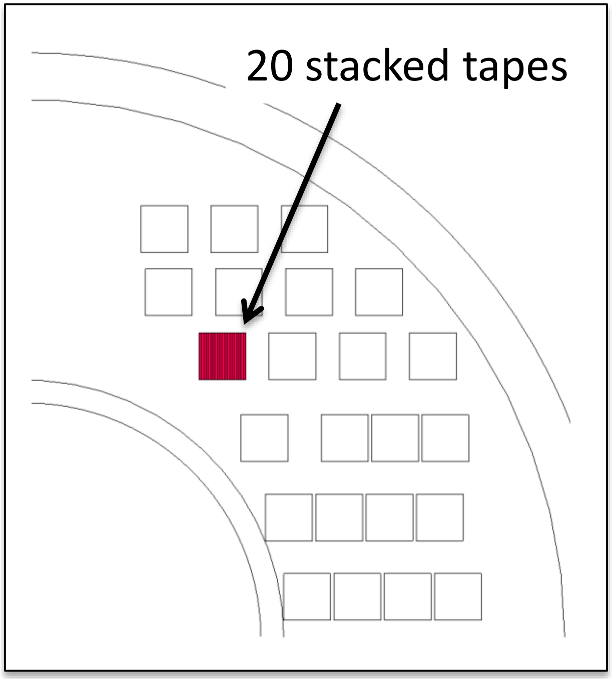
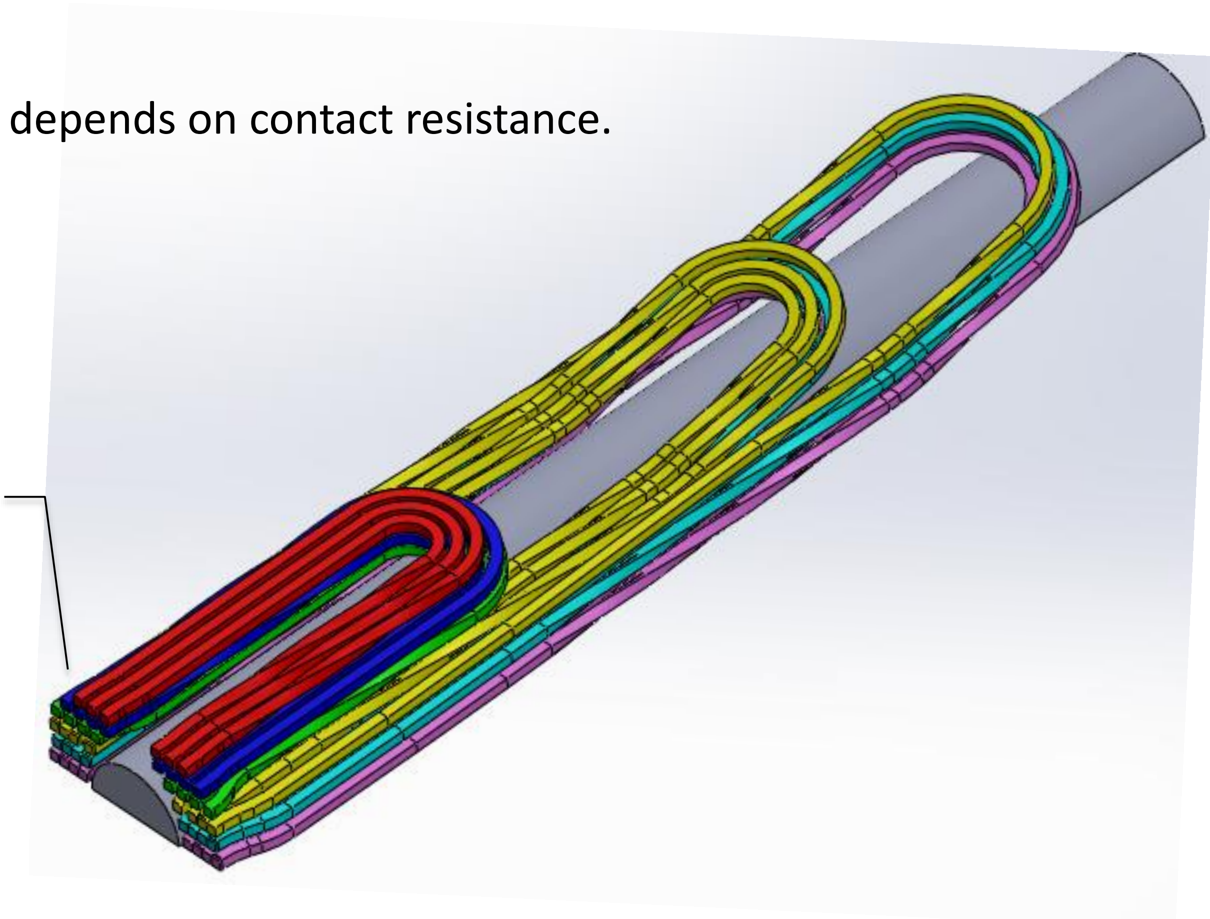
  Winding test

- *Conclusions*

Current distribution ～Introduction ～

1. Twisted stacked cable (TSC) has only one twist per turn out of 15m long insert.
2. Stacked tapes are insulated each other in order not to allow the current sharing.
3. Current distribution of TSC depends on contact resistance.



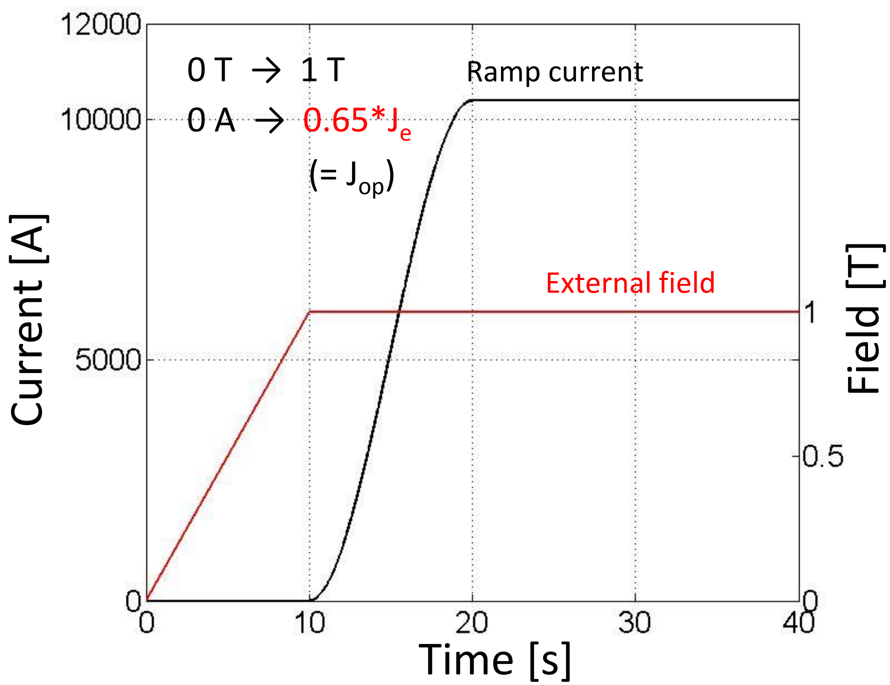


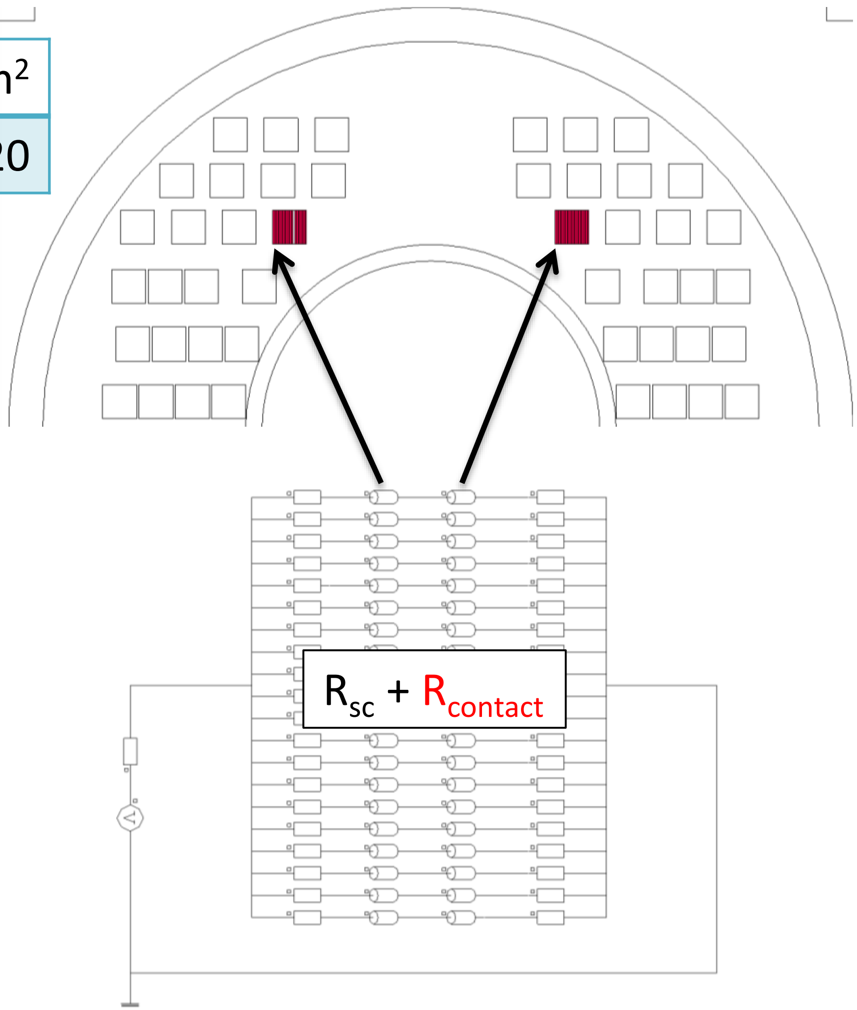
Current distribution ~Numerical setup ~

- Specification for HTS tape

Engineering current density J_e	1000 MA/m^2
n-value	20

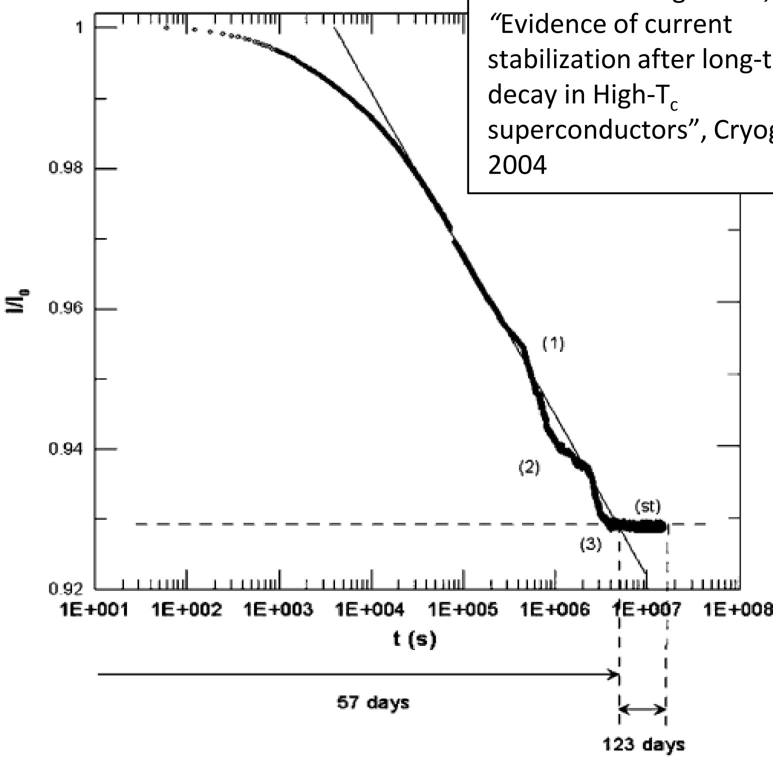
- Operating condition



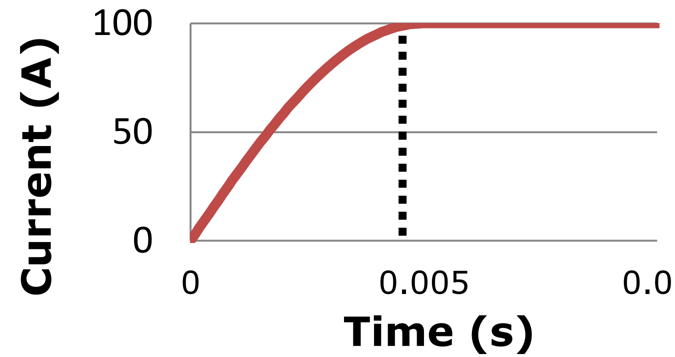


Current distribution ~Numerical setup ~

Using the right *E-J* characteristics for the material

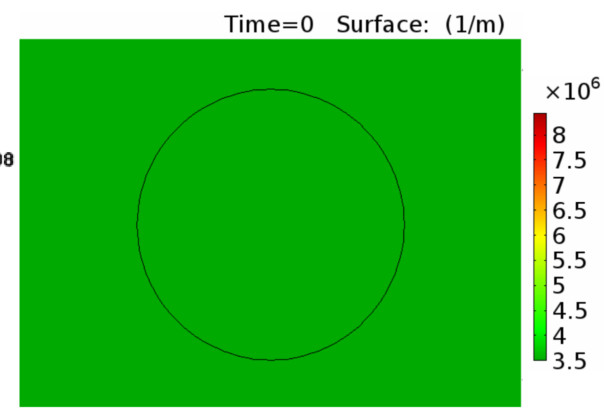


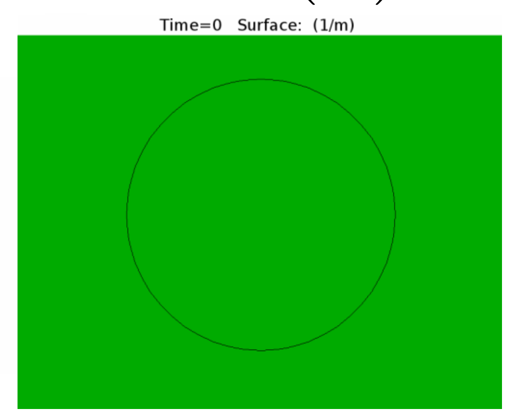
H. Gonzáles-Jorge *et al.*, "Evidence of current stabilization after long-time decay in High-T_c superconductors", Cryogenics, 2004



$$E = E_0 \left(\frac{J}{J_{c0}} - 1 \right)^{n_0}$$

$$E = E_c \left(\frac{J}{J_c} \right)^{n}$$





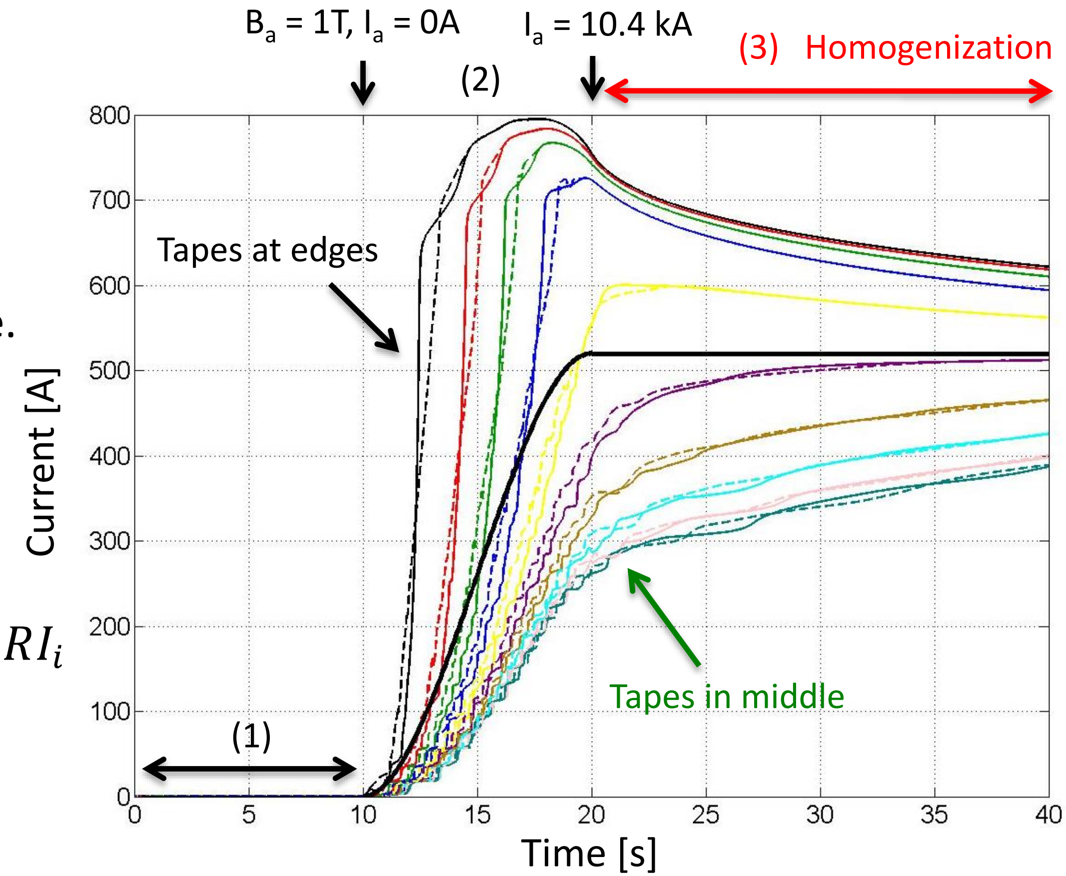
Current distribution ~1st step ~

- 15 m long magnet + Constant contact resistance R = 1000 nΩ

1) Current remains zero during the external field. (Twist transposition)
2) Tapes at edges have more current due to a shielding current in middle.
3) Current equilibrates depending on total resistance and inductance.

$$L_i \frac{dI_i}{dt} + \sum_{\mathrm{j=1}}^{\mathrm{N}} \mathrm{M_{ij}} \frac{\mathrm{dI_j}}{\mathrm{dt}} + E_c \left(\frac{I_i}{I_c}\right)^n \cdot l + RI_i$$

$$= \mathrm{V}$$

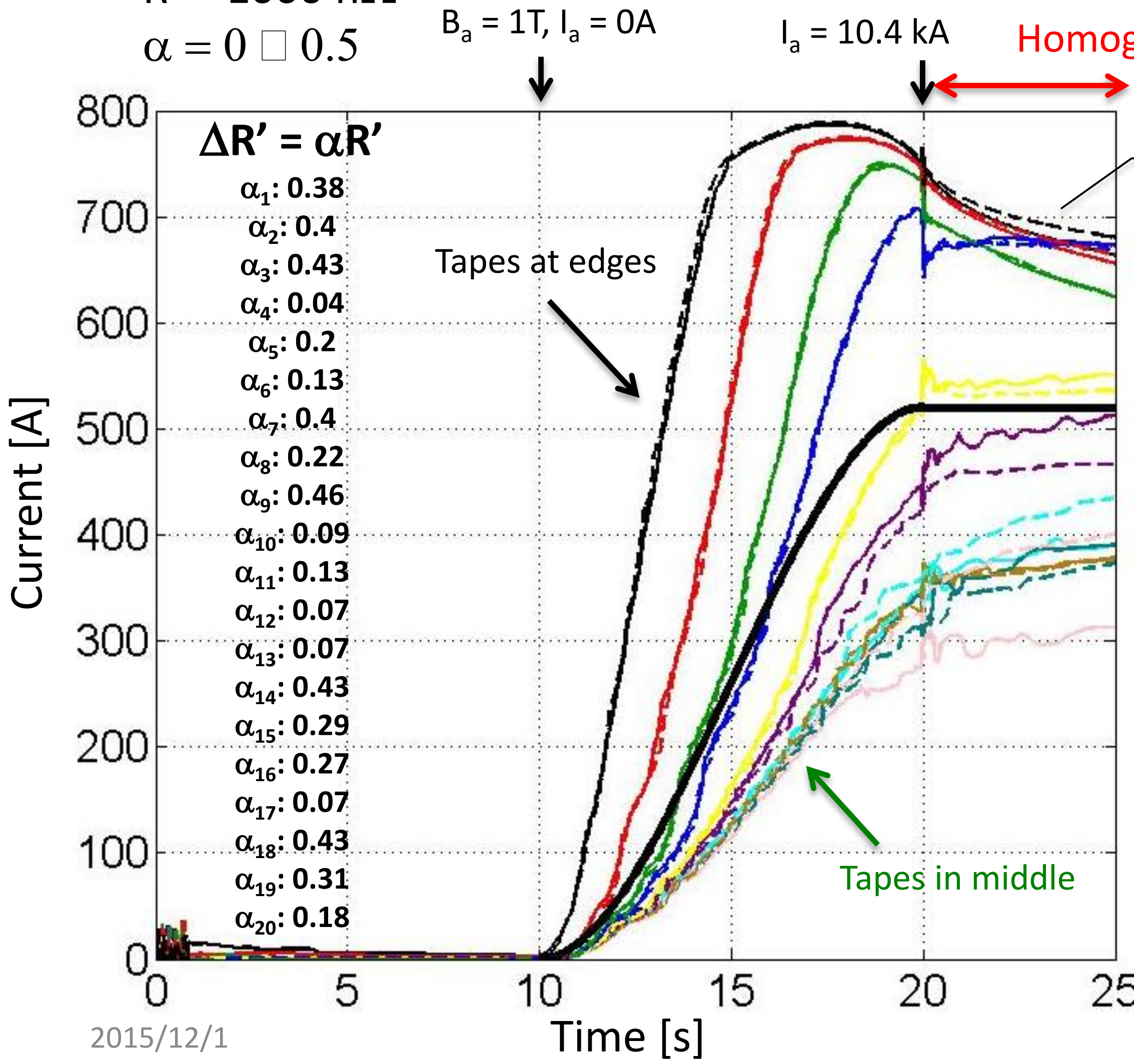


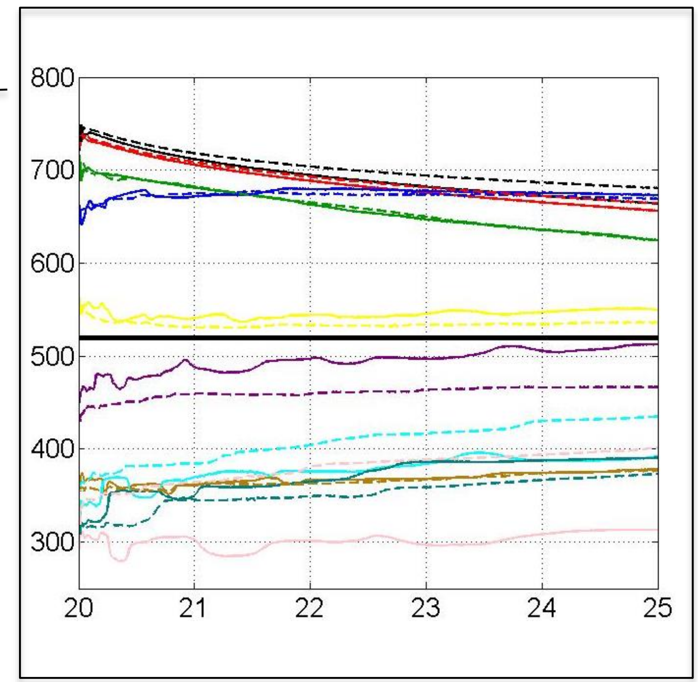
Current distribution ~2nd step ~

- 15 m long magnet + Random contact resistance R (= R' + ΔR')

  R' = 1000 nΩ

  α = 0 □ 0.5





$$L_i \frac{dI_i}{dt} + \sum_{j=1}^{N} M_{ij} \frac{dI_j}{dt} + E_c \left(\frac{I_i}{I_c}\right)^n \cdot l + RI_i$$

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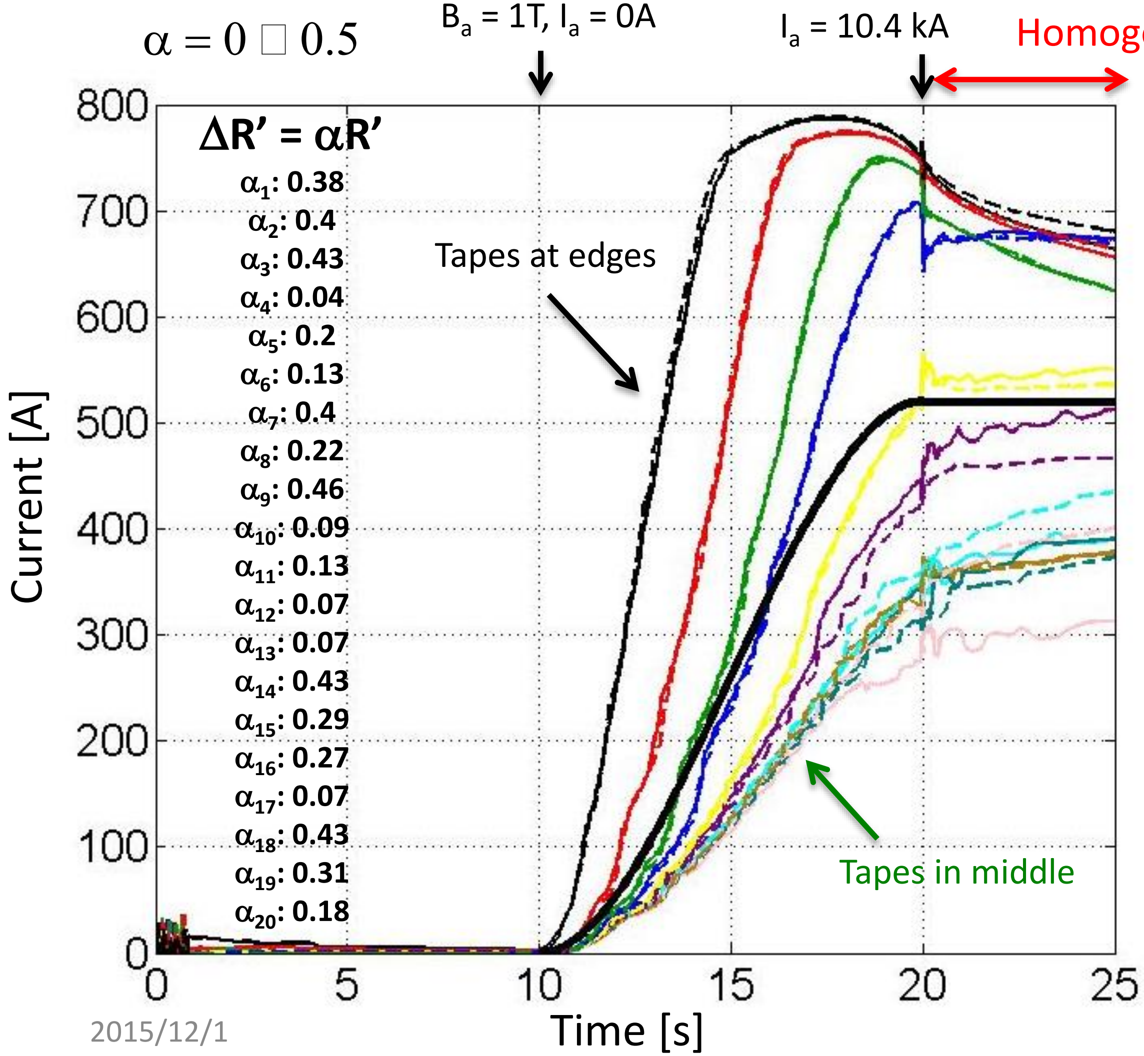

Next step

1) Long period analysis
2) Smaller R' with less variation α
3) Anisotropic dependency
4) Divide all block into 20 tapes

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Test for current distribution

<Objective>

To see the current distribution of twisted stacked cable with the ramp current. And to see the behavior after the end of the ramp current (Long period test).

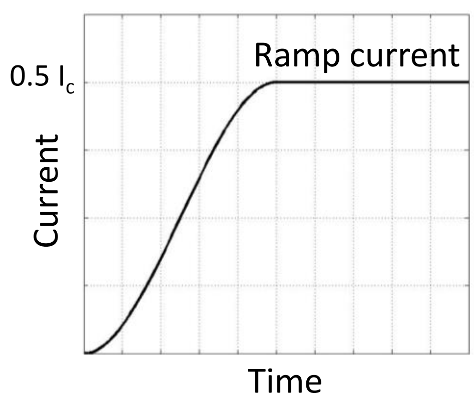
<Plan>

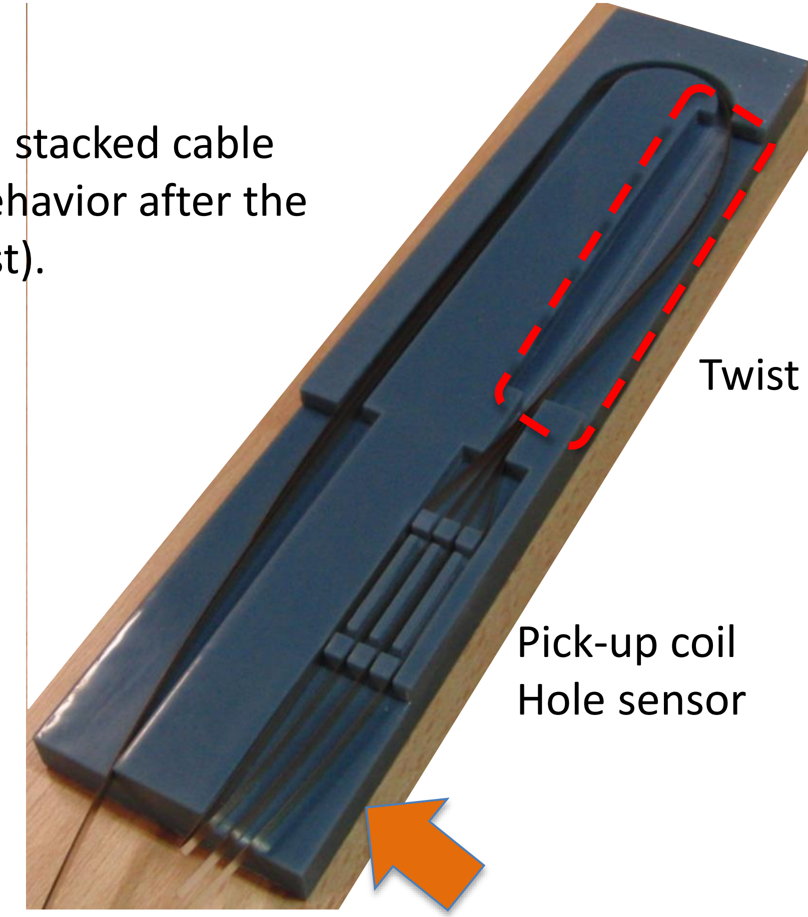
1) Test at 77 K in Grenoble

December/ 2015

2) Test under external field

January or February/ 2016
Fresca 10 T test station ?





Electrical joints (MIT)

Conclusion

- 46-turns HTS twisted stacked design achieved a field of 5 T with J_e = 650 MA/m^2 and a good field quality. Large J_e is needed as the background filed penetrate into c-axis at twist part. The relative magnet ends' positions of HTS insert and LTS outsert may maintain the large J_e.

- Twisted stacked cable needs to be insulated because there is only one twist per turn out of 15 m long HTS insert. Therefore, the current distribution is determined by the contact resistance. Further analysis is ongoing.

- Current distribution test of twisted stacked cable is planed to especially see after the end of the ramp current.