EPFL

SWISS PLASMA CENTER

Rectangular HTS conductors for fusion magnets

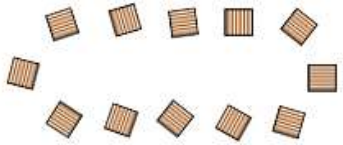
Background, motivation and design status

Background and motivation

HTS conductor R&D (2013-19) was focused on cables made with twisted-stack strands, because it was assumed that twisting is needed to reduce losses and current imbalance. These assumptions were never justified by a rigorous physical analysis.

In 2019 it has been shown that **twisting a stack has modest impact on losses and inductance mismatch among tapes**. https://doi.org/10.1016/j.cryogenics.2020.103118
The conductor space design is now much wider:

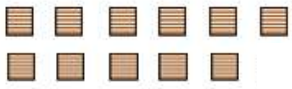
fig. 8 https://doi.org/10.1016/j.cryogenics.2020.103118



Twisted stack flat cable

2 twist pitches

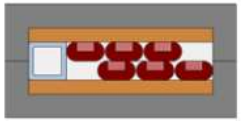
$L_{t\ stack}$~300 mm
$L_{t\ cable}$~1–3 m



Non-twisted stack Roebel

1 trans. length

$L_{t\ stack}$=$L_{t\ cable}$~200 mm



$L_{t\ stack}$= ∞
$L_{t\ cable}$~1–3 m

Monolithic, non-twisted stack

-

L_t = ∞

All three have similar AC losses

Highest AC losses. Not for CS?

Abandoned by SPC because too weak and negligible advantage on AC loss

See Nikolay presentation

Next two slides

Monolithic, non-twisted stack

NIFS, 2008

https://doi.org/10.1109/TASC.2008.922522
https://doi.org/10.1016/j.cryogenics.2016.06.011

EUROfusion DEMO

- Operation at 12 T, 20 K. Only HTS.
- <10 m long (segmented coils): current redistributes at joints (ind. imbalance); coupling currents closes at joints
- DC magnet (seldom, slowly charged): large losses (~5 MJ/m^3) are tolerable

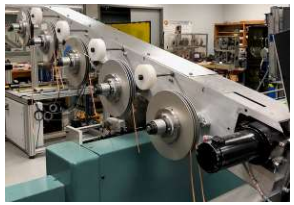
- Operation at 18 T, 5 K. HTS+LTS
- Km long: about inductance imbalance and losses see https://doi.org/10.1016/j.cryogenics.2020.103118
- AC magnet (continuously, fast ramped): does satisfy losses requirement?

A conductor for DC magnets (<0.005 T/s) may not work in AC magnets (up to 1 T/s).
Could ITER TF conductor be used in the CS?

Over 10 non-twisted, non transposed concepts since 1968. Two recent examples:

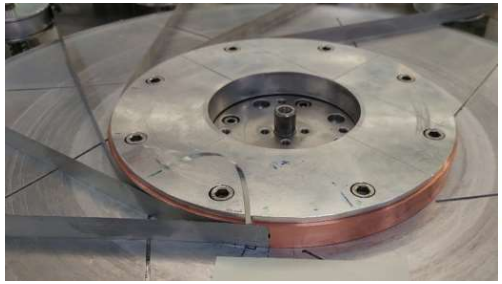
T. Painter, NHFML

O1B.2-1 Thomas Painter, First test results of the integrated coil form technology, TOFE 2020

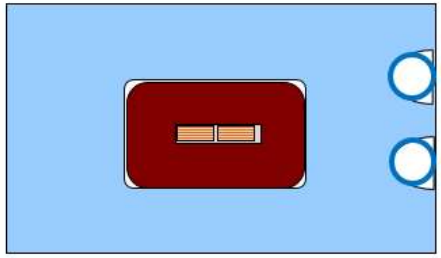


tokamak energy
a faster way to fusion

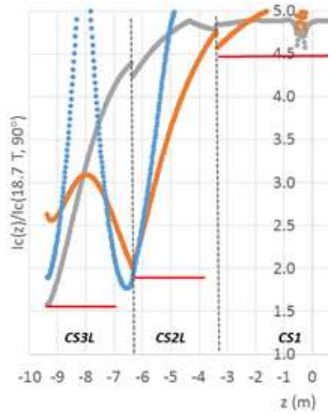
Model coil in construction now, not in 2024…



Status of the design of monolithic, non-twisted stack for hybrid CS at SPC



Proposed in early 2019
for the quench experiment



What has been done?

- Selected the stack cross section (number of tapes) in all CS modules: parallelism between tapes and CS axis has a modest effect on I_c in 4 out of 5 modules. Cost reduction is negligible.
- Designed the copper elements (quench protection) to simplify manufacturing.
- Designed steel jacket for the CS conductor (grading and simplification) and SULTAN test conductor
- Studied influence of stack aspect ratio on losses and strain. Peak strain after winding on 1.5 m radius: <0.1%; thermo-hydrualic analysis is needed for the aspect ratio selection.
- Measured transverse critical stress (⊥ tapes): >80 MPa (about 15–50 MPa in round twisted stacks)

What is missing?

- Measure transverse critical pressure in the direction parallel to the tapes (very high operating value)
- Select test configurations for full load operations in SULTAN (not necessary full size conductor).
- Submit paper about design to a journal.

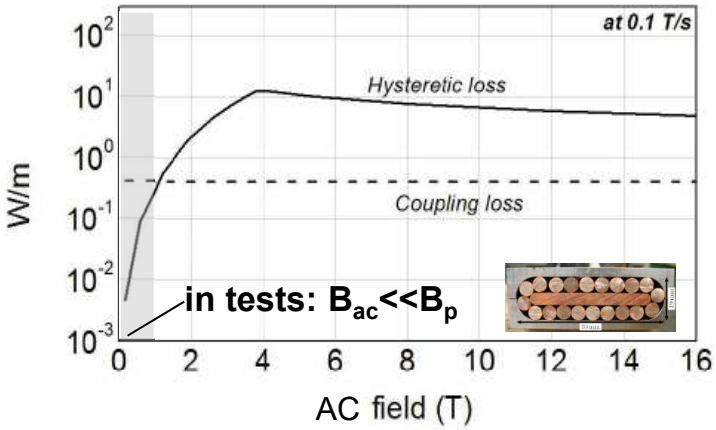
CS magnet: AC loss

AC loss is not important. It is the only thing (with fatigue of course) that matter.

Commonwealth Fusion is developing a low-loss VIPER cable for the SPARC CS.

Cables made with tapes have much larger losses than multifilamentary cables (<1 T/s). The main contribution is hysteretic loss (eff. fil. ∅ ~1000 μm instead of 10–30 μm).

Could the CS be wound with 200 μm filaments Nb_3Sn strands?



Small scale version of the hybrid CS (similar field, J_c, geometry): 25 T cryogen-free solenoid at Tohoku University. **Losses (W/m³) in HTS insert are 10–100x higher than in the LTS outsert.** https://doi.org/10.1109/TASC.2014.2366552 https://doi.org/10.1016/j.cryogenics.2016.05.010

No need to wait for tests. Thermo-hydraulic analysis could start any time.

- Peak temperature in the winding: 6 K, 15 K, 30 K, …? (Ic reduces by 50% from 5 K to 20 K)
- Can the monolithic, non-twisted stack be used in CS?
- Optimal stack aspect ratio?