ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE | SWISS PLASMA CENTER

EUROfusion Consortium

FIP/3-5

High Temperature Superconductors for Fusion at the Swiss Plasma Center

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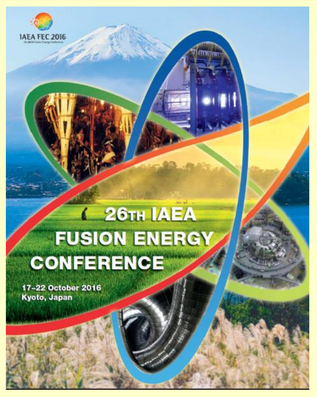


Fusion and HTS

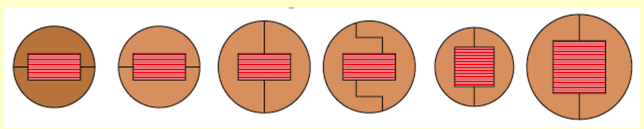
Looking at the several proposals of the last 18 years to use HTS in fusion magnets, the question arises if the future fusion devices either must or may use HTS. Today, the ARC compact, high field demonstrator is likely the only fusion device proposal, which must be made with HTS conductors (Bpeak ≈ 23 T). In other conceptual studies the use of HTS is an option, which is preferred by the designers for specific reasons, e.g. the possibility of operation temperature in the range of 20-30 K with drastically reduced nuclear shield or the assembly of helical coils by short segmented sections of winding, with thousands of joints.

EUROfusion, SPC and HTS

Although the baseline of EUROfusion DEMO uses Nb_3Sn and NbTi magnet technology, a fraction of the R&D effort at SPC explores the use of HTS conductors for the highest grades of the layer wound TF and CS coils.

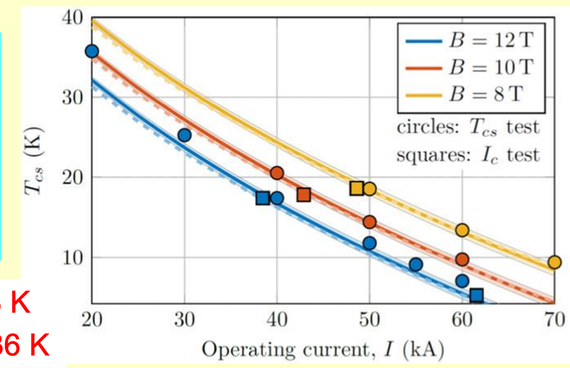
The soldered, twisted stacks of REBCO tapes as modular component

A rectangular/square stack of tapes is packed between two half shells of copper, twisted and soldered to build a solid, round "strand" to be used in multi-strand, cored cables. Parametric investigations optimize the geometry with respects to the critical twist, bending radius and transverse compression. The advantages of the soldered, twisted stacks are the low inter-tape resistance, allowing easy current re-distribution, the large copper cross section for quench protection and the mechanical stability.



The 60 kA, 12 T prototype

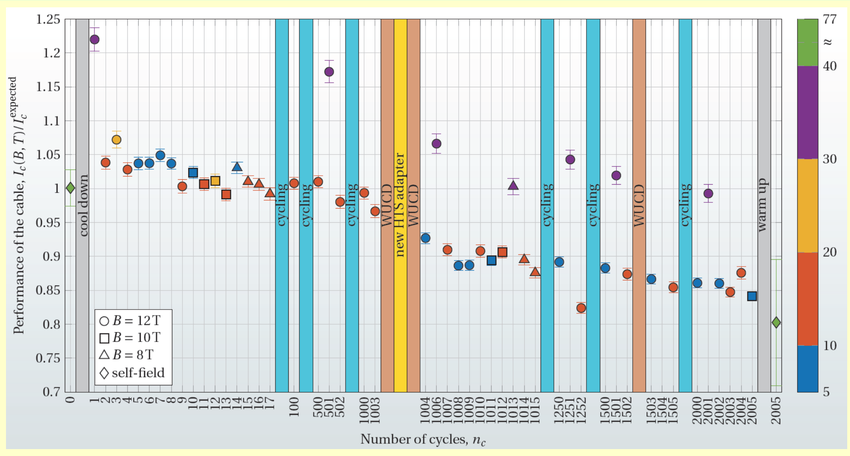
A 20 strands TF prototype conductor is built at SPC (two short lengths with Superpower and SuperOx tapes). A short length EDIPO sample was assembled and tested in 2015. The DC results match the prediction from the single tape performance.



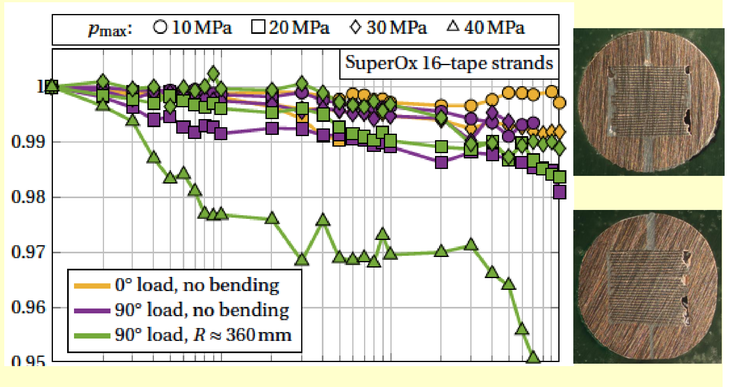
At 12 T background field, I_c = 60 kA @ 8 K

I_c = 20 kA @ 36 K

After 2000 electromagnetic load cycles, the DC performance degraded up to 20%.

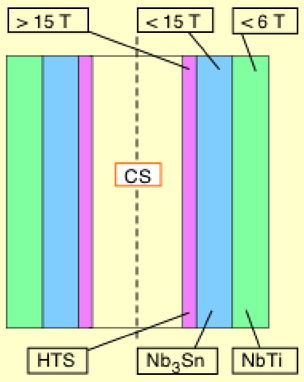


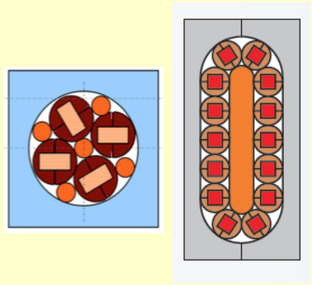
The cyclic load degradation has triggered parametric tests. However, the extent of degradation observed on the 60 kA prototype could not be reproduced on single strands under compressive load. Local defects of the stack soldering may be an initiation point for damage under transverse compressive load.



CS Conductor Prototypes

For the CS coil of DEMO, SPC proposes a peak field of 18 T in order to either maximize the flux (burn time) for the same radial build or minimize the radial build for the nominal flux. The CS is a graded layer winding made of HTS, Nb_3Sn and NbTi. Two layouts, both based on twisted, soldered stacks, are considered for a conductor of 53 kA – 18 T – 4.5 K.



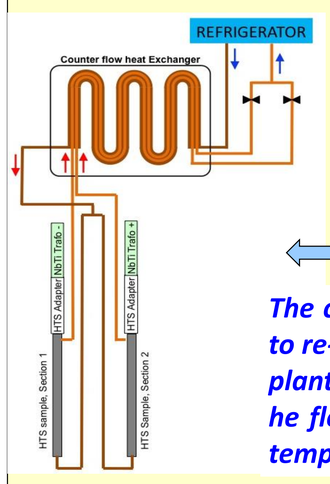


The two conductors have the same amount of superconductor, copper and operating current. They are being assembled at SPC and will be tested in 2017 to assess the DC performance stability and the AC loss.

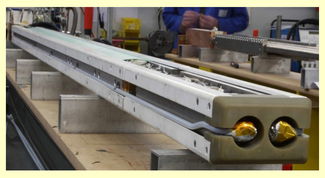
Test Facility at SPC for large HTS fusion conductors

The SULTAN test facility is the worldwide reference for qualification and acceptance of high current superconductors and joints for fusion (EAST, W7-X, JT60SA, ITER). It has been upgraded for test of HTS samples at variable temperature:

- *DC Background Field up to 11 T over 450 mm*
- *DC current for test conductor up to 100 kA*
- *Superimposed AC Field ±0.4 T, 0.01 – 6 Hz*
- *Superimposed Pulsed Field up to 3 T, 140 ms*
- *Supercritical helium up to 10 g/s, 4.5 - 50 K*
- *Test well for hairpin sample, 94x144x3500 mm*



A fully assembled SULTAN sample ⇨

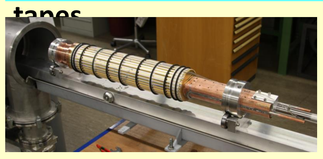


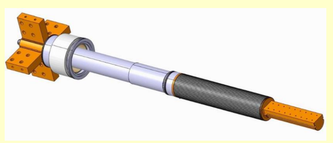
The counter-flow heat exchanger to re-cool the he flow to the cryo-plant < 10 K, and pre-heat the he flow to the desired operating temperature, up to 50 K

The HTS Adapter to connect the HTS sample to the 4.5 K operating NbTi transformer

HTS Current Leads

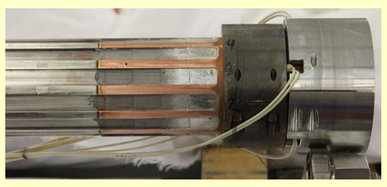
After two decades of HTS leads development with BSCCO tapes, SPC has recently built 20 kA leads with REBCO tapes.





HZB – 20 kA, 28 Stacks of BSCCO tapes, 54 K

EDIPO – 18 kA, 65 Stacks of BSCCO tapes, 80 K



NAFASSY – 20 kA , 77 K,
12 stacks REBCO tapes (12mm)

Conclusion

In the frame of the EUROfusion DEMO, SPC is active in the R&D of HTS high current conductors for fusion as technology demonstrators.

SPC maintains a unique test facility for characterization and qualification of full size, high current HTS conductors, open to international users.

An innovative proposal has been launched for a divertor coil to be installed in the TCV Tokamak in Lausanne, made of HTS, up to 2.5 T, LN2 cooled.

The commercial availability of long (>1 km), high performance HTS tapes and the high price compared to LTS are obstacles toward the use of HTS for reactor relevant projects, skyrocketing the overnight cost and the price of electricity for a fusion power plant.

Acknowledgement

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