High Temperature Superconductors for Fusion at the Swiss Plasma Center

Pierluigi Bruzzone, Rainer Wesche, Davide Uglietti, Nikolay Bykovsky

EPFL- Swiss Plasma Center, Villigen-PSI, Switzerland

Outline

The HTS Current Leads

High Current Conductors for EUROfusion DEMO

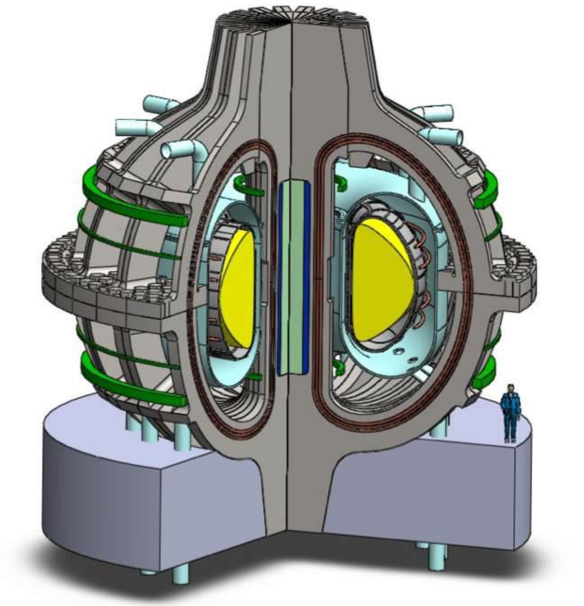
The Test Facility for large HTS Conductors

The future

Fusion and HTS

Does Fusion **must** use HTS?

Depends on the machine layout… From the point of view of operating field, only few designs, e.g. the ARC design (MIT, ≈23 T peak field) *must* use HTS.

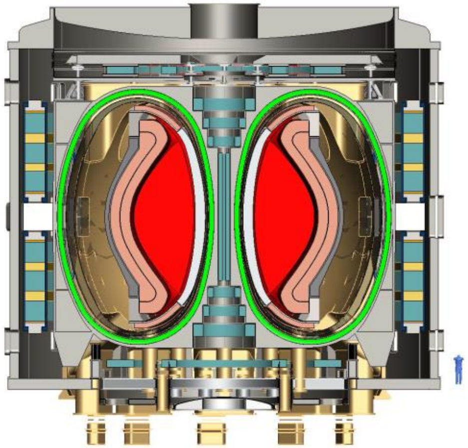


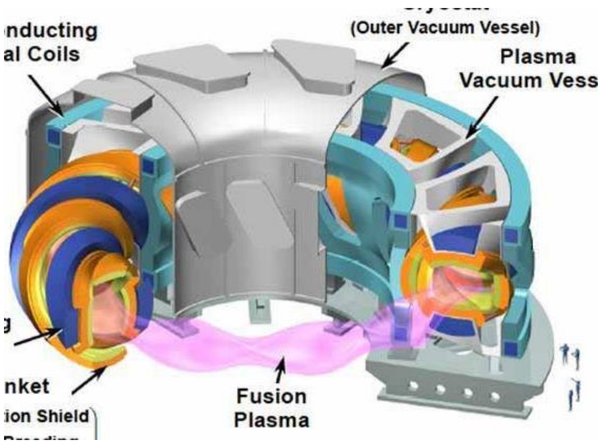
Does Fusion **may** use HTS?

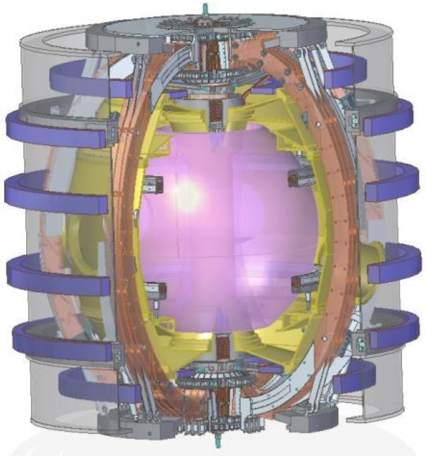
At operating field < 16 T, HTS may always be used. However, the potential advantages of HTS (higher operating temperature/margin) are balanced by prohibitive cost and (today) by production length limitations.

Fusion Projects and Coated Conductors

Disregarding the **must/may** question, few fusion projects world-wide consider the use of HTS at conceptual design level for magnets.





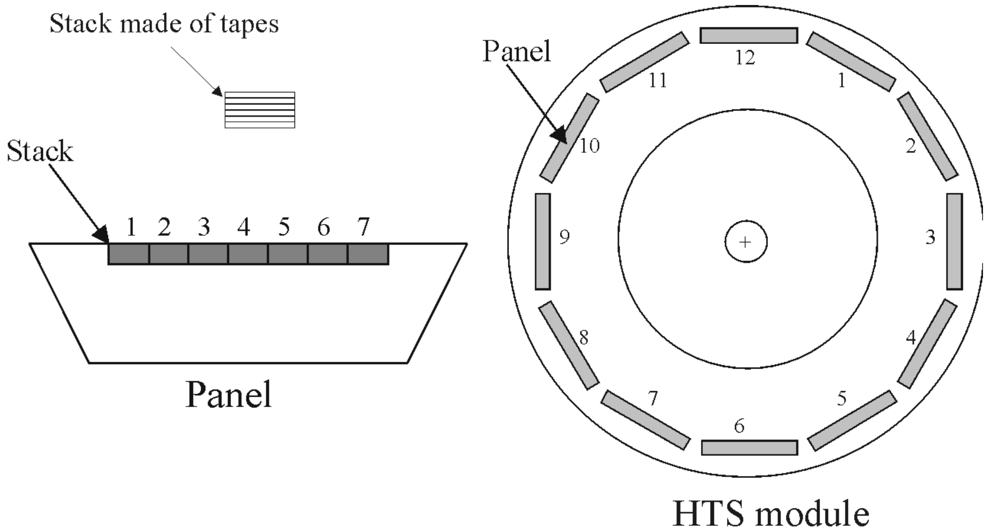


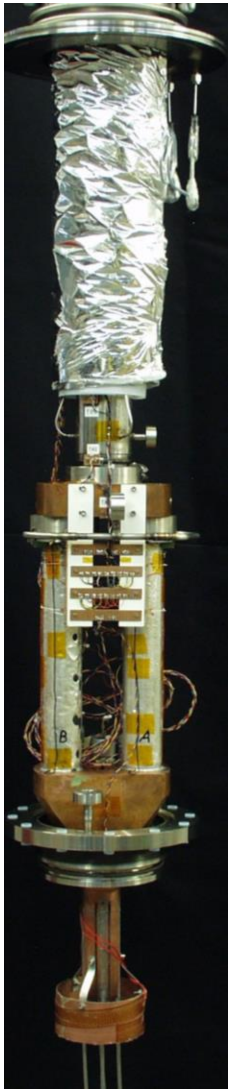
BTW, ALL projects have HTS **current leads**.

HTS Current Leads for Fusion at SPC

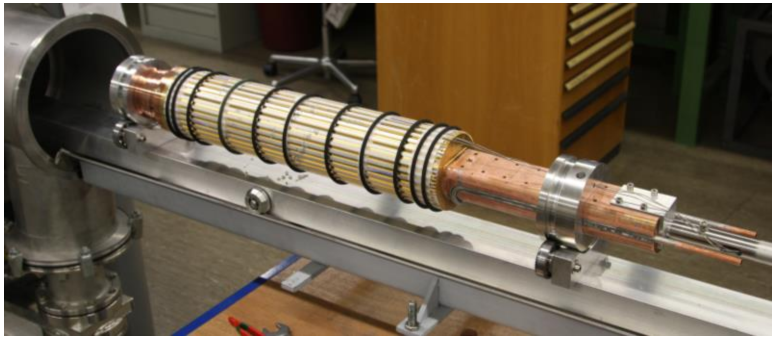
The early development – Bulk HTS 10 kA current leads

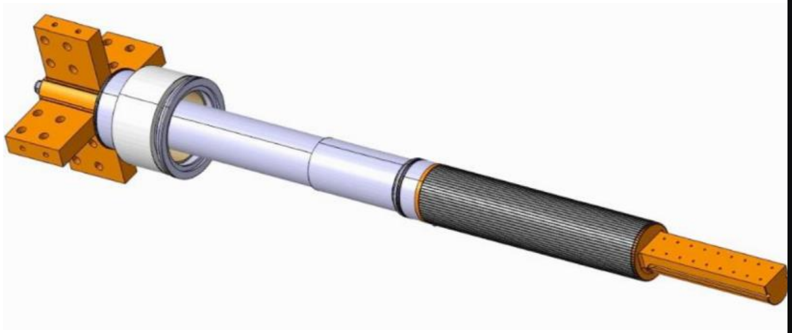
70 kA HTS Demonstrator for ITER, with KIT





Recent HTS Current Leads at SPC

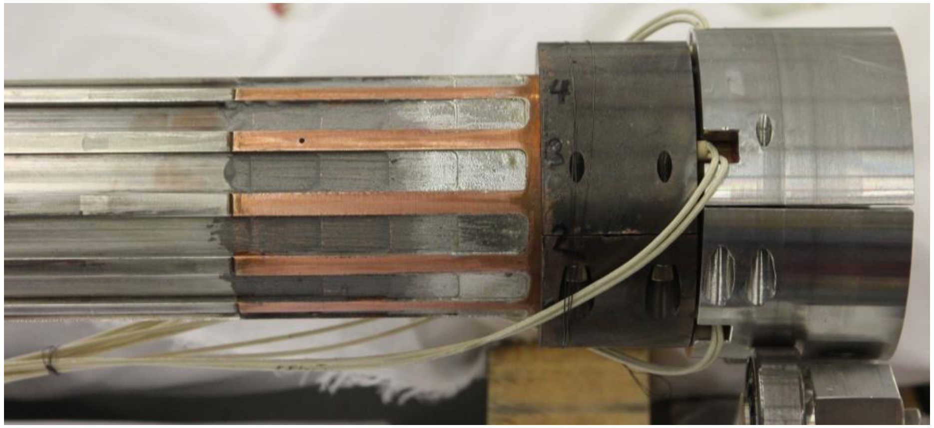




EDIPO – 18 kA 65 Stacks of BSCCO tapes 80 K

HZB – 20 kA 28 Stacks of BSCCO tapes 54 K

HTS Current Leads made by REBCO tapes at SPC



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

EUROfusion DEMO and R&D on HTS at the SPC

The PROCESS system code gives the DEMO baseline reference:

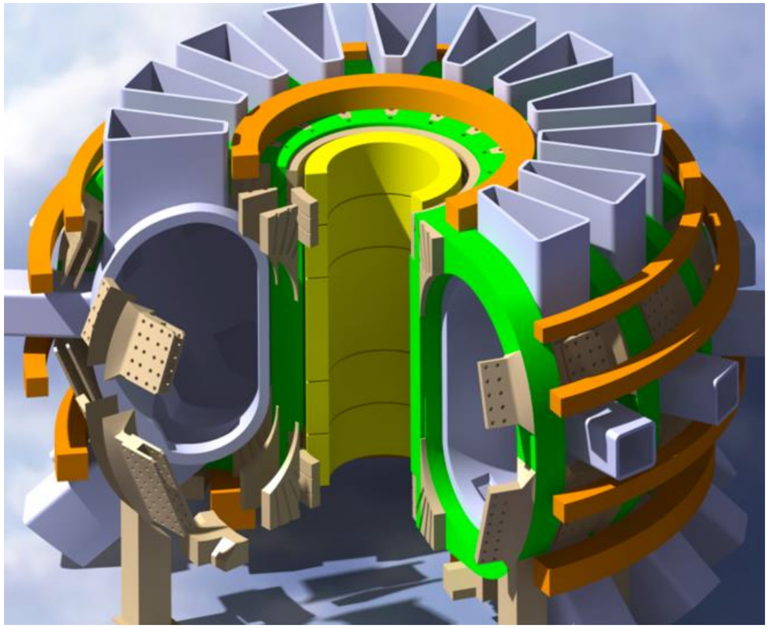
P_e = 500 MW

Major Radius ≈ **9 m**

Field on Torus ≈ 7 T

Peak Field on TF coils = **12.3 T**

Magnet Technology = **LTS**



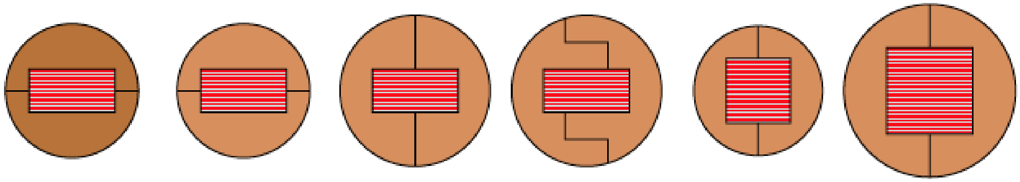
A fraction of the R&D effort at SPC explores the use of HTS for DEMO.

The HTS conductor development started in 2013 based on the operating field and current requirement for TF, 60 kA – 12 T. The superconductor technology is REBCO tapes.

The soldered twisted stacks of REBCO tapes at SPC

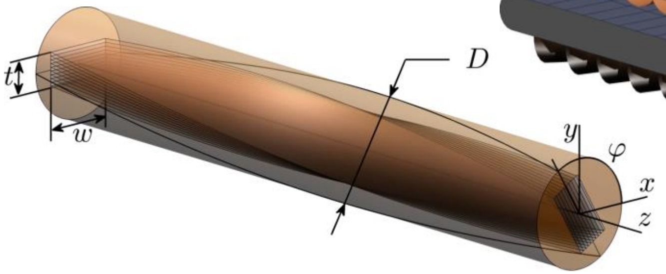
A rectangular/square stack of tapes is packed between two half shells of copper, twisted and soldered to build a solid, round “strand” to be used in a multi-strand, cored flat cable.

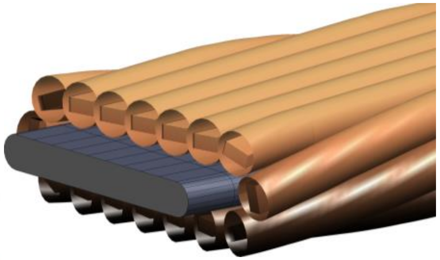
Strand geometry optimization

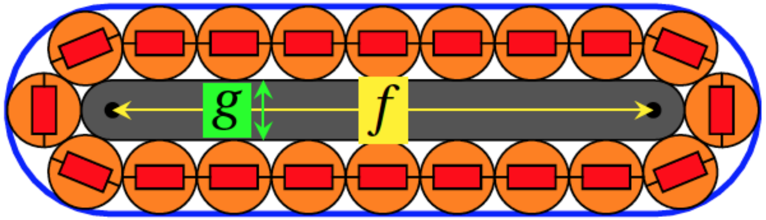


Bending, twist and transverse compression tests, for CC and BSCCO tapes.

From the bending test results, a 20 strands cable prototype is designed and modeled with optimization of the core size and twist pitch, to keep the strain within the reversible limits.

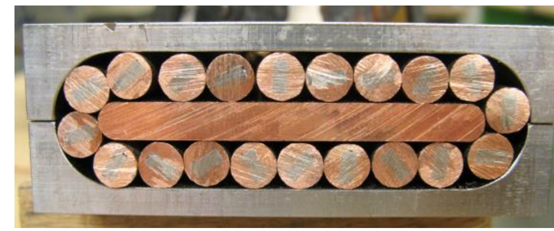




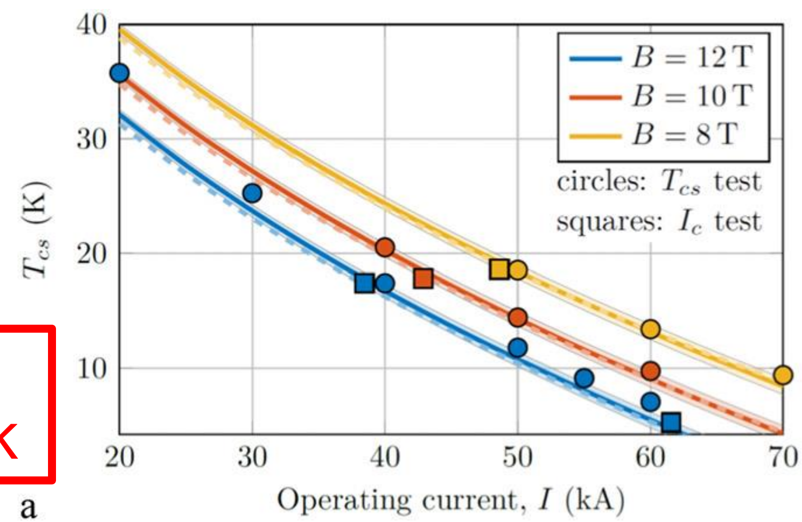


The 60 kA prototype conductor at SPC

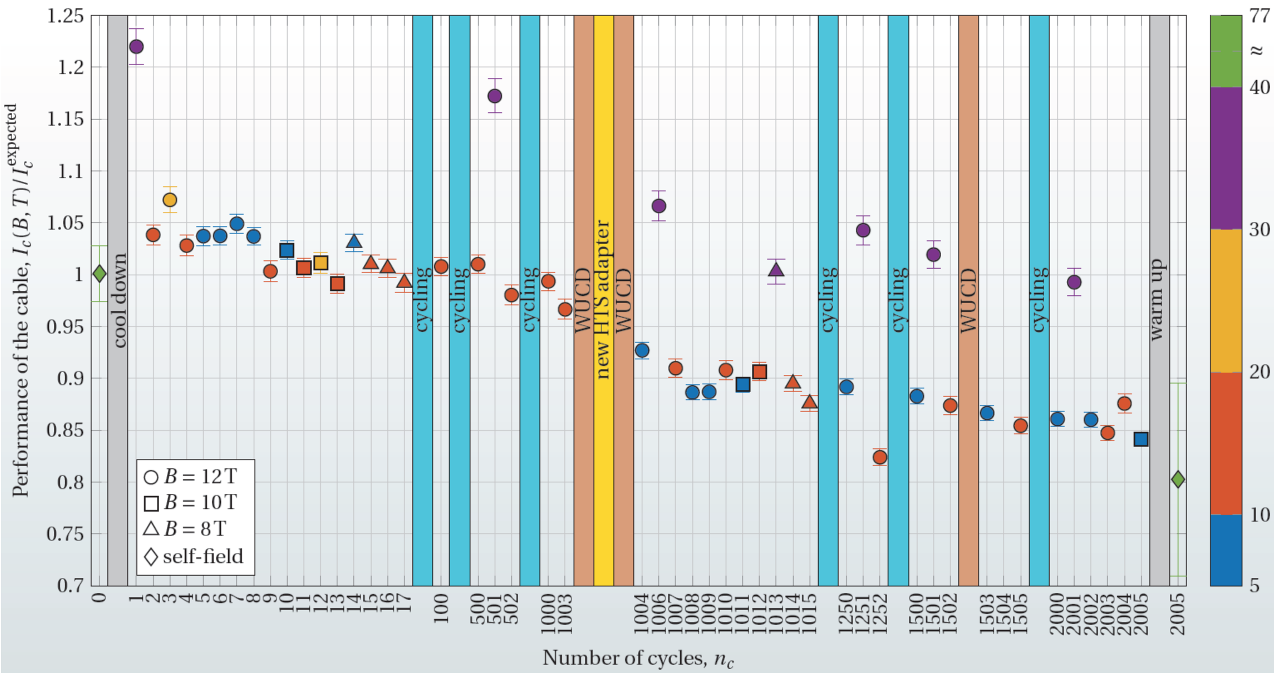
A 20 strand cable prototype is built at SPC (two short lengths with Superpower and SuperOx tapes).

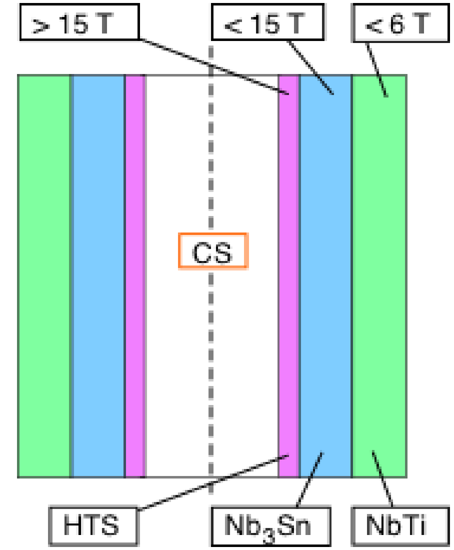


A short length EDIPO sample was assembled and tested in 2015

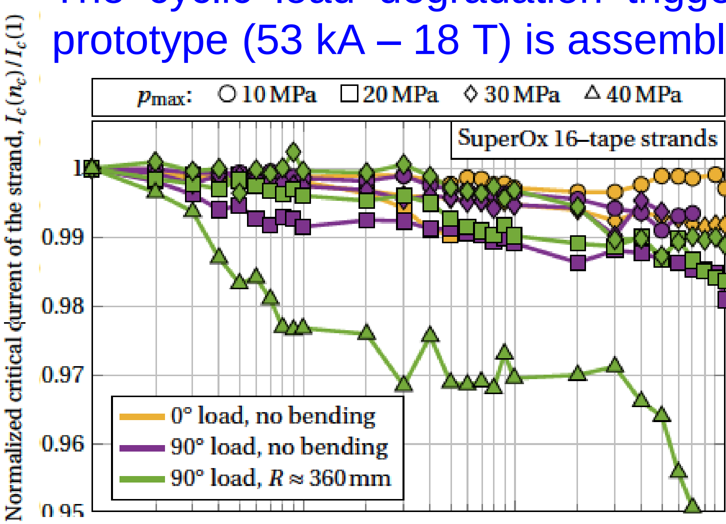


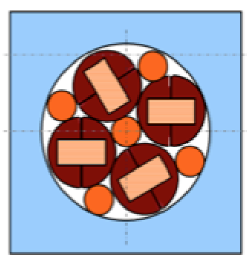
At 12 T background field, I_c = 60 kA @ 8 K
I_c = 20 kA @ 36 K

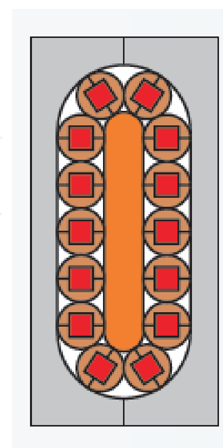


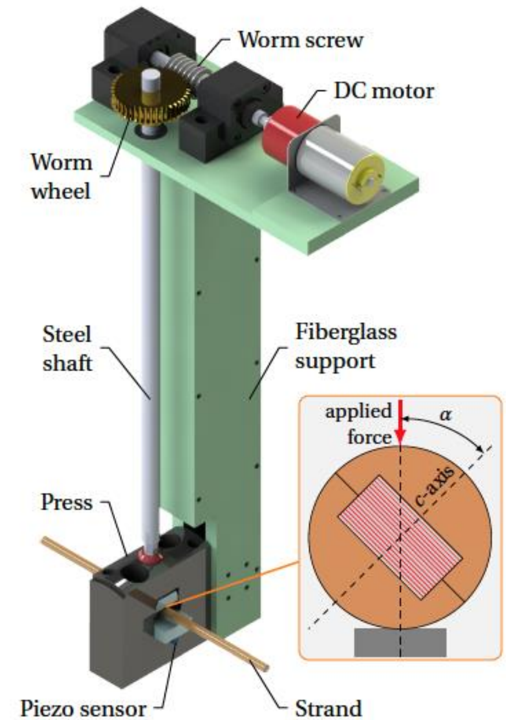


The cyclic load degradation triggered parametric tests. A CS prototype (53 kA – 18 T) is assembled with two layout variations.









Test Facilities at SPC - SULTAN

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)

DC Background Field up to 11 T over 450 mm

DC current for test conductor up to 100 kA

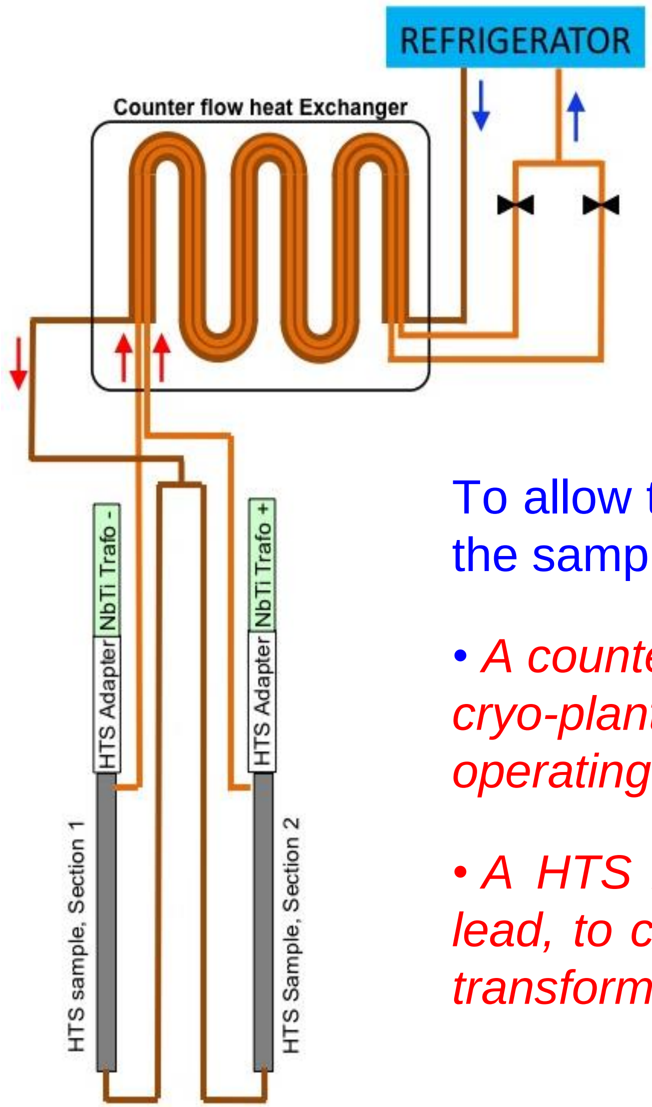
Superimposed AC Field ±0.4 T, 0.01 – 6 Hz

Superimposed Pulsed Field up to 3 T, 140 ms

Supercritical helium up to 10 g/s, 4.5 - 8 K

Test well for hairpin sample, 94x144x3500 mm

Upgrade of the Sample Environment, forced flow

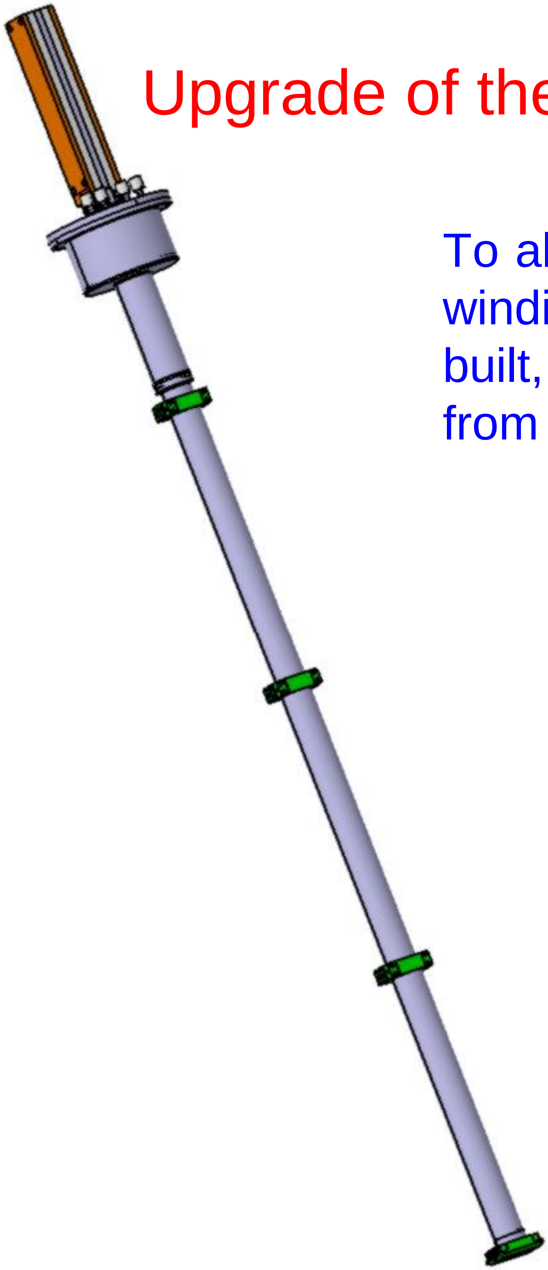


To allow testing of HTS in variable temperature, up to 50 K, the sample environment has been upgraded with:

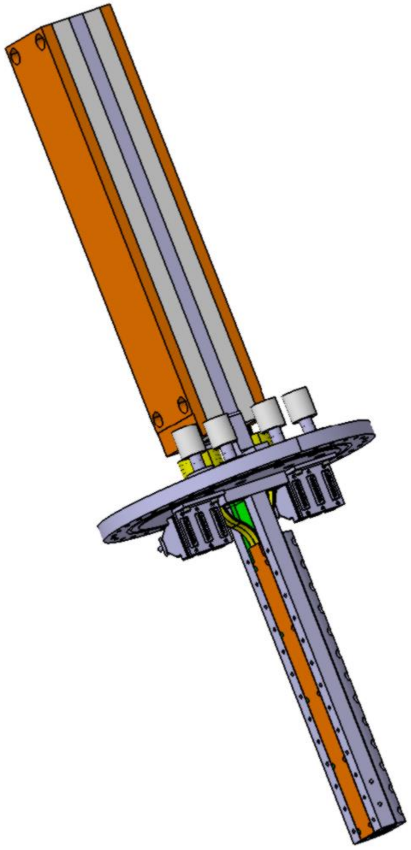
- *A counter-flow heat exchanger to re-cool the he flow to the cryo-plant < 10 K, and pre-heat the he flow to the desired operating temperature, up to 50 K*

- *A HTS Adapter, similar to the HTS module of a current lead, to cut the heat flow toward the NbTi superconducting transformer (operating at 4.5 K)*

Upgrade of the Sample Environment, He cryostat



To allow testing in SULTAN of HTS conductors and small windings in static helium atmosphere, an insert cryostat is built, where the temperature of helium can be controlled from 4.2 K (helium bath) to 50 K.



It includes also a HTS adapter, for operating currents up to 30 kA

Summary - The Present

Beside the HTS current leads, with continuous update of know-how and technology, SPC develops HTS conductor designs and prototypes in the scope of the EUROfusion DEMO conceptual studies:

*A **TF** HTS conductor in the innermost layer has the advantage of tolerating higher nuclear heat load and moderately high temperature (6-7 K) for heat removal.*

*A **CS** HTS conductor in the innermost layers has the advantage of allowing higher peak field (>15 T) and hence optimize the size and flux of the CS*

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 Future

In the medium term, there is room for small size “technology demonstrators” and “proof-of-principle” devices made by HTS. High field, >30T, small bore HTS hybrid solenoids are state of the art. Large bore 20 T solenoids are challenging. Non-solenoidal shapes are much more challenging. The main challenge is NOT the superconductor, but the mechanics.

Beside the development and qualification of high current cables, the quench management in HTS large coils, is a key technology issue to be addressed. For operation at 25-30 K, the heat removal capability by very low density gas is another issue.

The commercial availability of long (>1 km), high performance HTS tapes and the prohibitive 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.