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Summary of the Test Results of ITER Conductors in SULTAN

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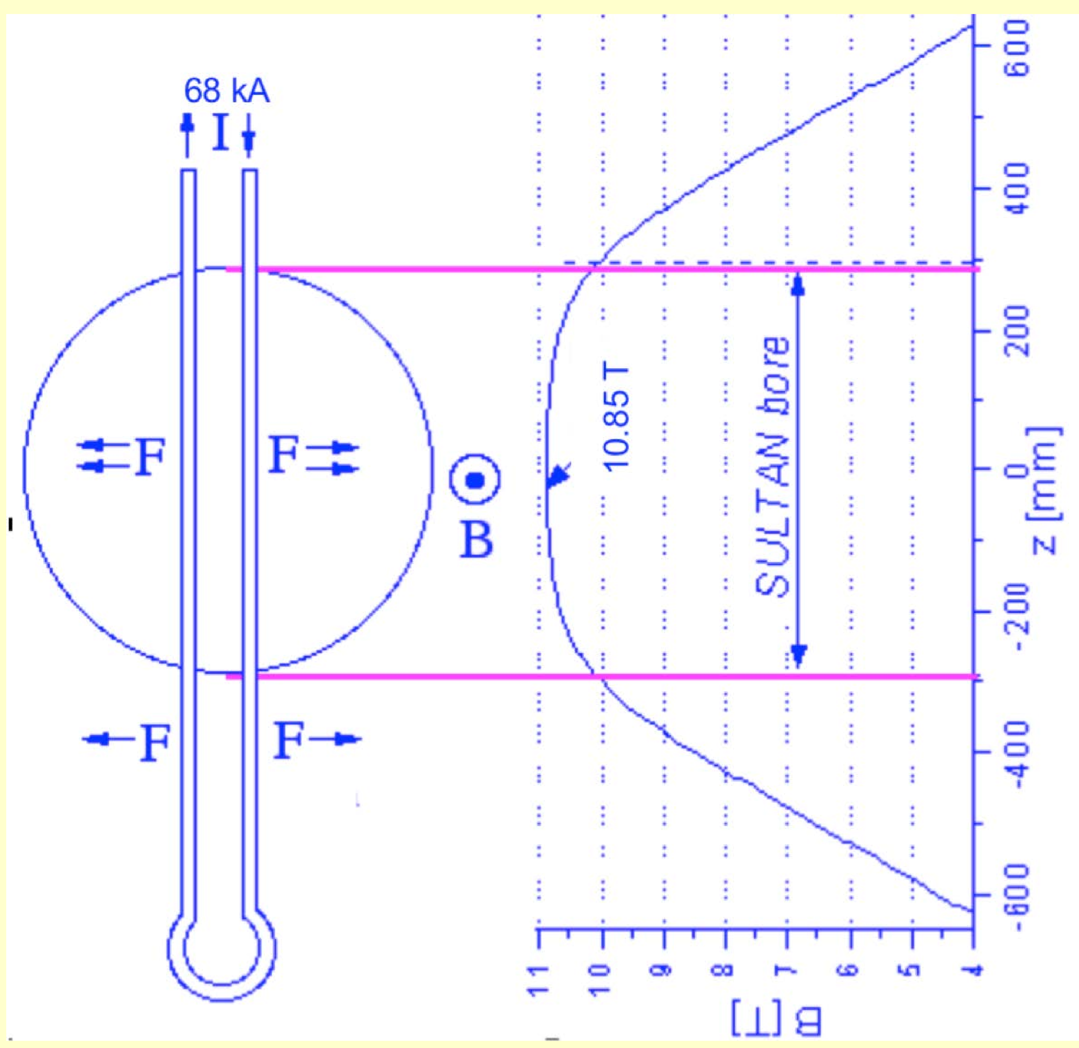
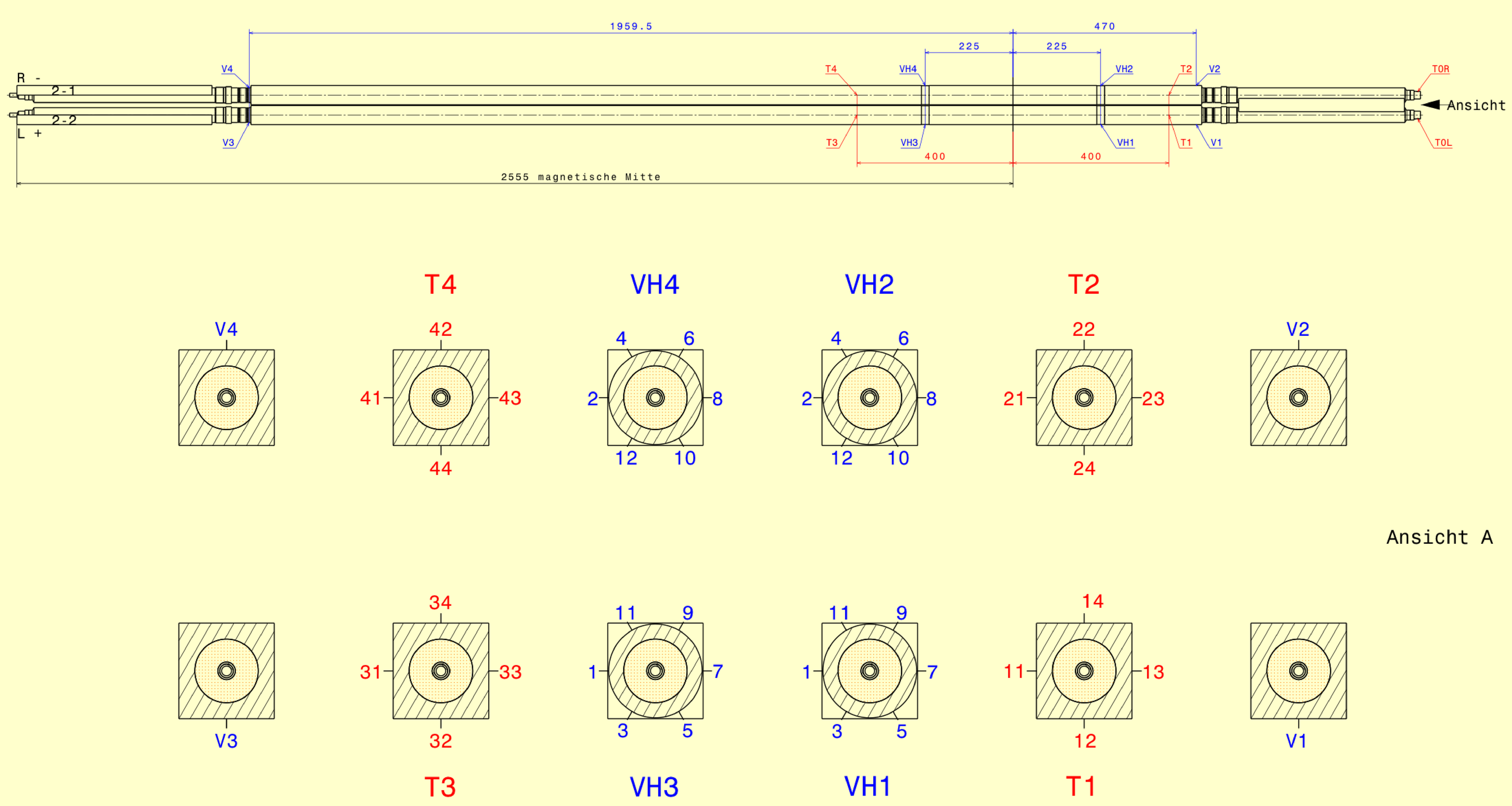
After completing the qualification tests, the tests of samples from the series manufacture are running in SULTAN. The acceptance criterion for current sharing temperature, T_{cs}, at the nominal operating field and current, is fulfilled for all the TF samples, with a broad scattering among the suppliers, from 5.8 K up to 6.6 K.
The assembly of the Nb_3Sn based CICC samples (for TF and CS coils) is carried out at CRPP. The NbTi CICC samples (for PF, CC and bus bars) are assembled at the suppliers, with a U-bend replacing the bottom joint. The poor performance of some Main Busbar (MB) conductor samples, caused by poor sample assembly, triggered the effort to assemble a MB sample at CRPP with solder filled terminations and a bottom joint. The superior test results of the MB-CRPP sample, closely matching the performance assessment carried out using 3-D field distribution and n-index behavior was a successful achievement of the last year of operation.
The winding companies must qualify the joint and termination manufacture by SULTAN samples. The first joint sample tested in SULTAN was a TF joint from EU, followed by a Correction Coil (CC) joint sample from China. All the ITER coils use the "twin box" design for joints, except the Central Solenoid. At the first test in SULTAN of a twin-box TF joint sample in 2013, an unexpected resistance increase was observed after an accidental dump of the SULTAN field. The resistance requirement for the TF joint was still fulfilled after the dump. The initial performance of the joint sample for Correction Coil conductor was not satisfactory.

The short sample conductor test in SULTAN

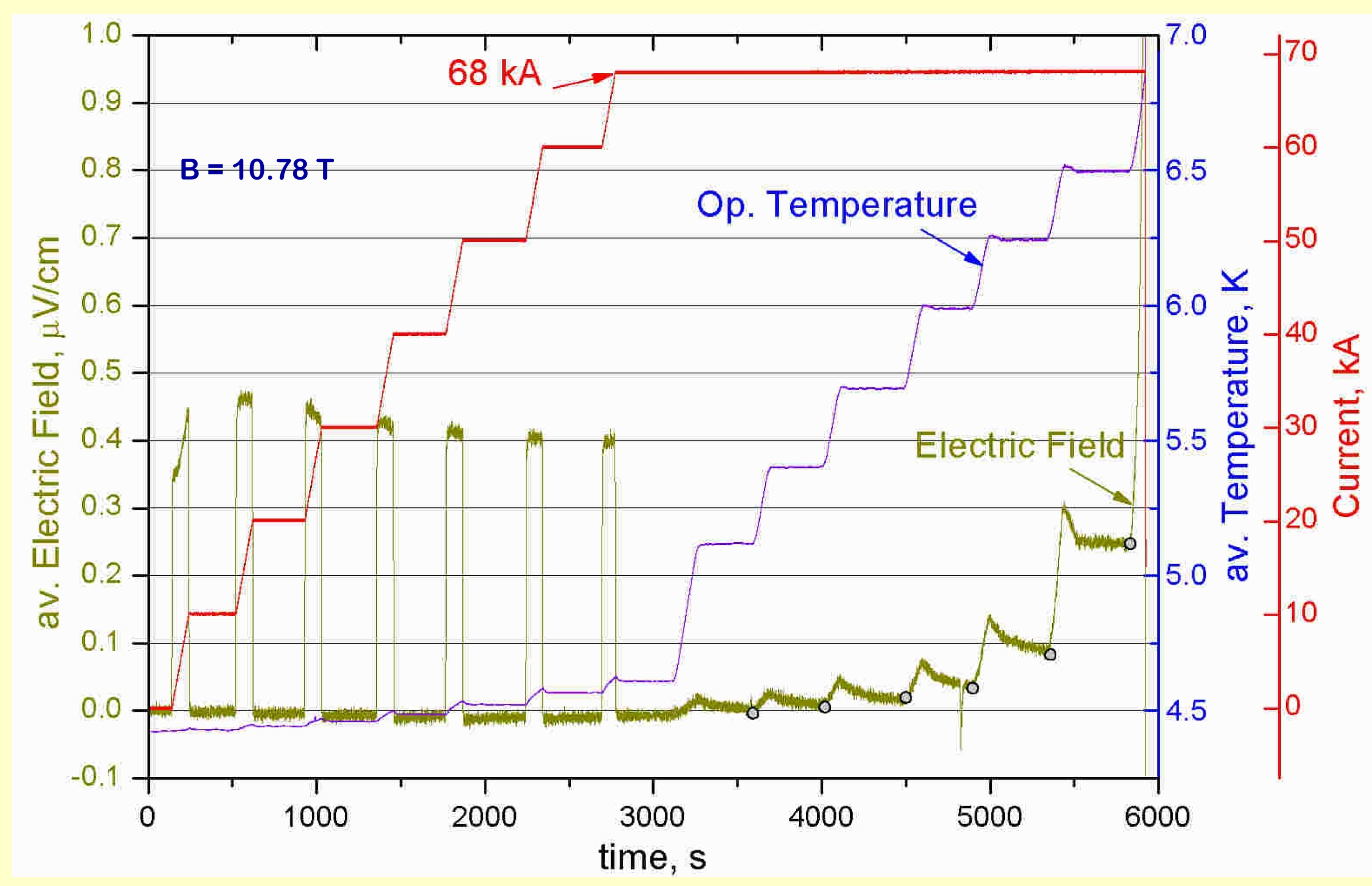


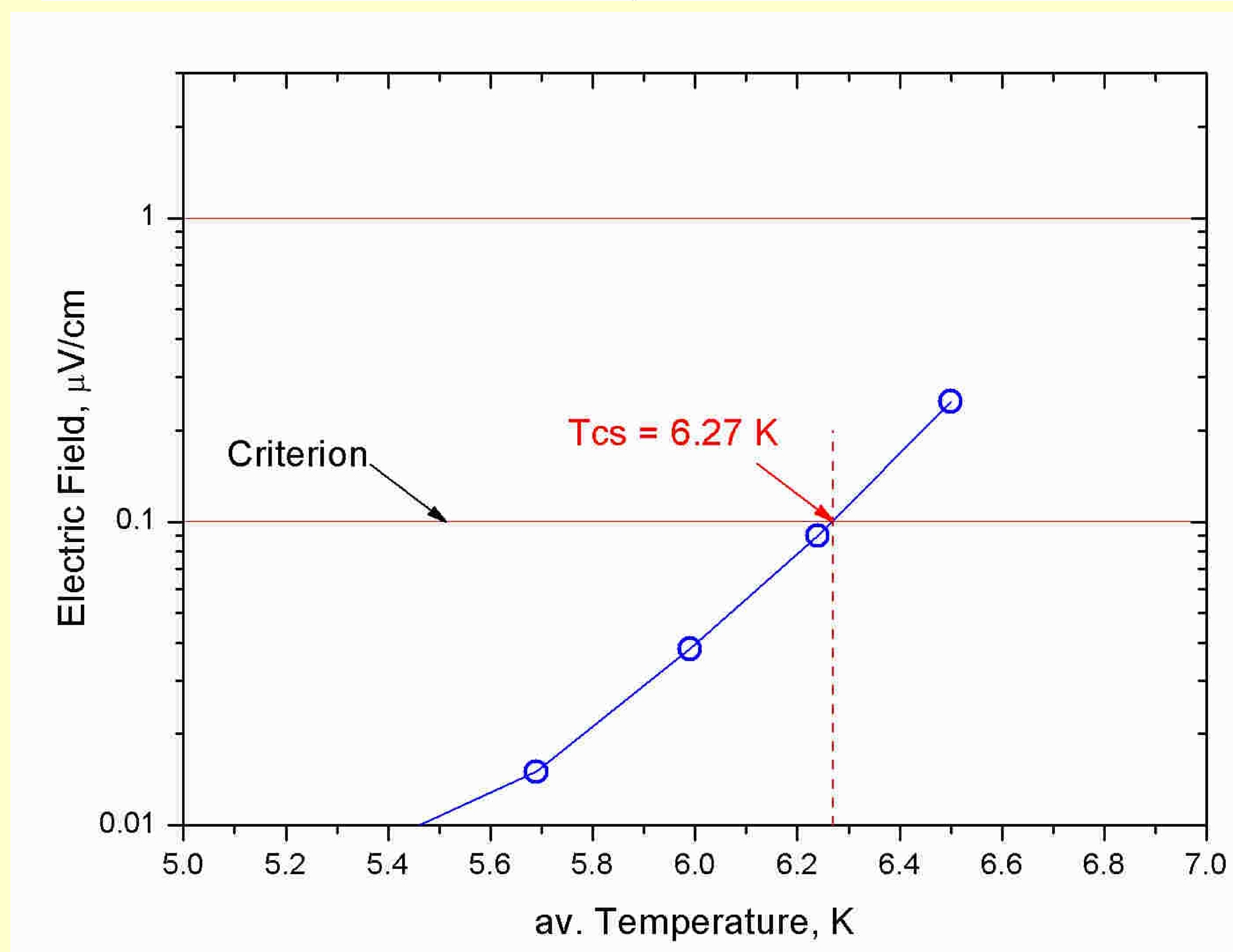
The layout of the short length conductor samples is dictated by the test facility, with two straight, 3.6 m long conductor sections in a hairpin configuration, inserted in the gap of the split solenoid, with up to 11 T DC background field. In the 450 mm long high field zone, the conductor experiences the relevant transverse load. Cyclic load is achieved by sweeping up and down the operating current in constant background field – one TF load cycle lasts about 40 s. One thermal cycle requires to warm-up and cool-down the whole sample assembly and lasts about four days.



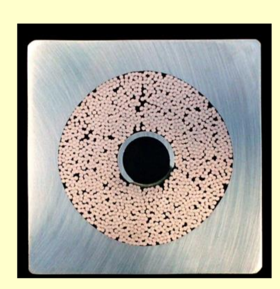
The T_{cs} test

The key test is the current sharing temperature, T_{cs}. At constant operating background field and operating current, the operating temperature is raised in small steps until voltage develops at the high field region. From the reversible voltage-temperature (VT) transition, the measured T_{cs} at 10 µV/m is compared with the requirement of the design, e.g. 5.7 K for TF conductor.





For TF conductors the T_{cs} test is carried out at 68 kA operating current and 10.78 T background field.

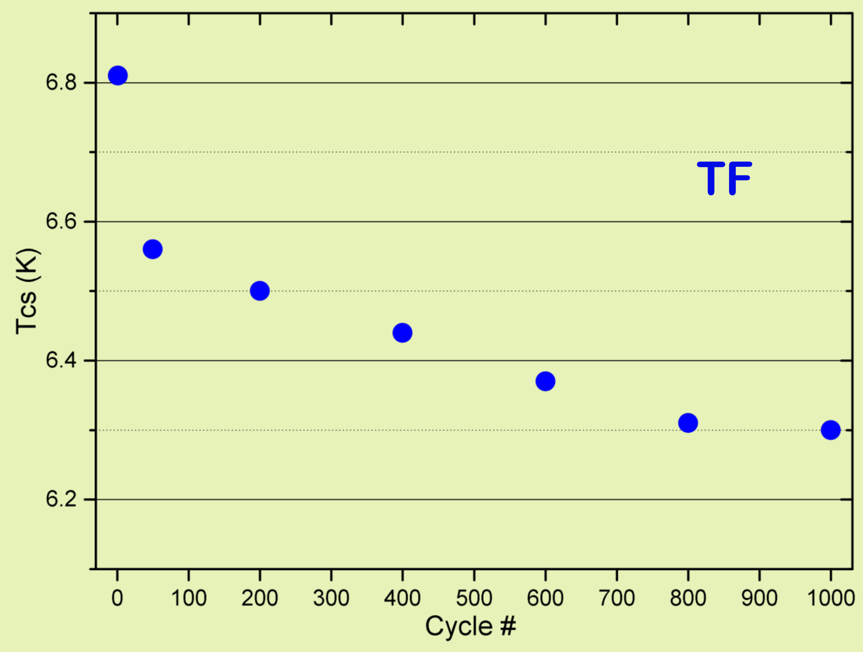


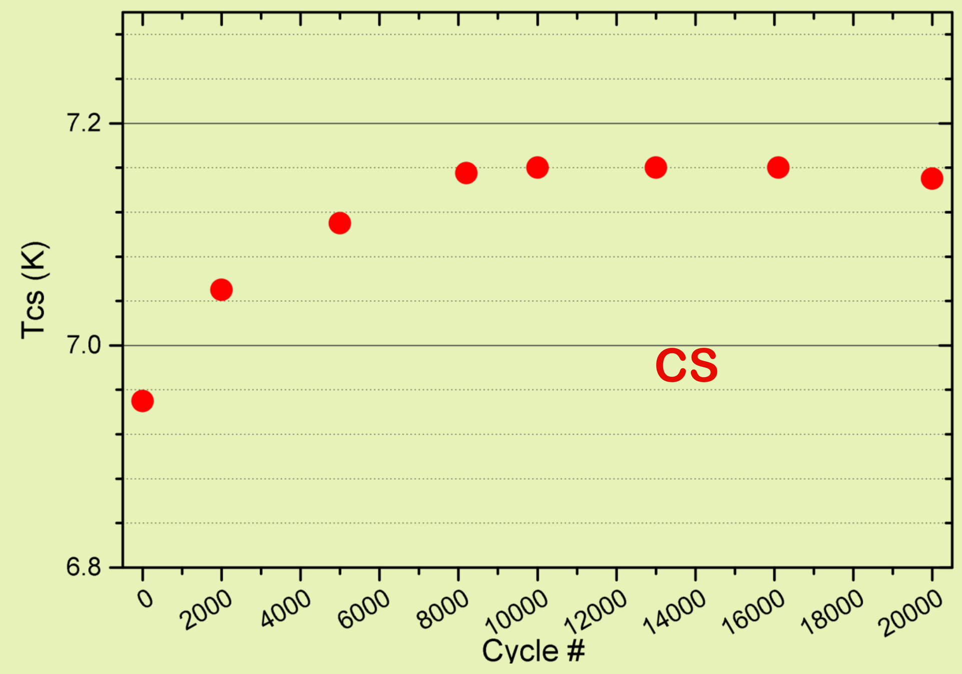
Two features affect the performance evolution for Nb_3Sn based CICC:
☺ the thermal strain relaxation due to the settling in the strand bundle in operation.
☹ the filament breakage due to local bending of the strands upon transverse load.

In the TF conductors with "long" cable pitch sequence, the filament breakage dominates over the strain relaxation and the net performance change is a degradation of the T_{cs}.

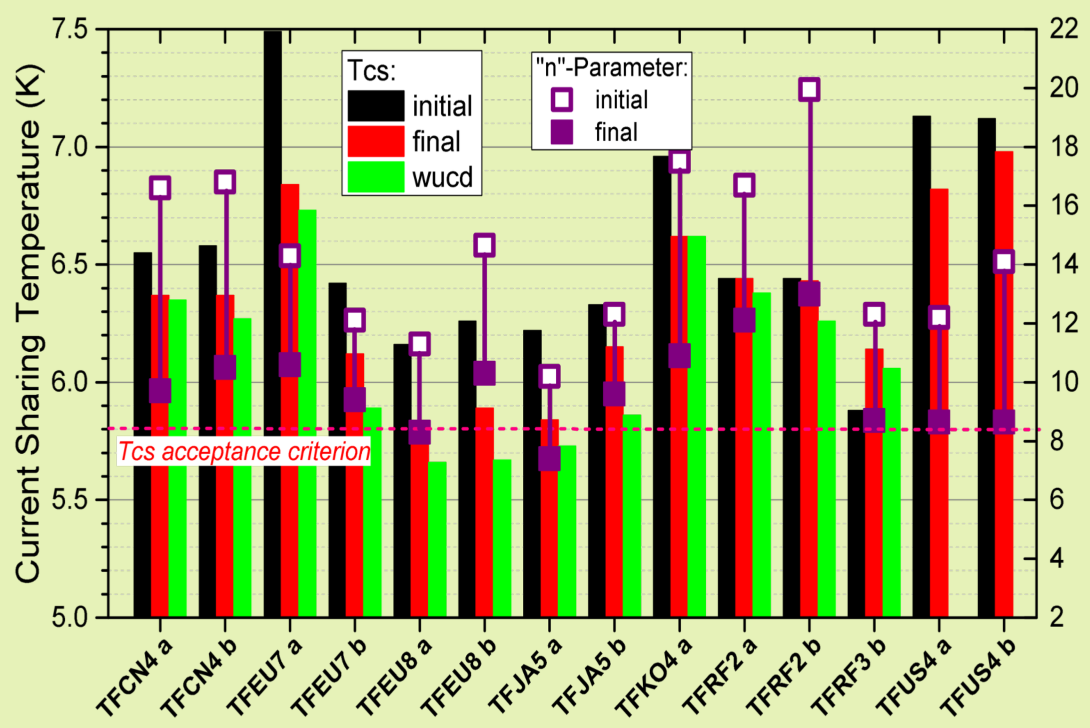
In the CS conductors, the rigid structure of the tightly twisted first triplet of strands, withstands the transverse loads without significant bending. The strain relaxation dominates over the filament breakage and the net performance change is an improvement of the T_{cs}

Results of the Nb_3Sn Conductor Samples

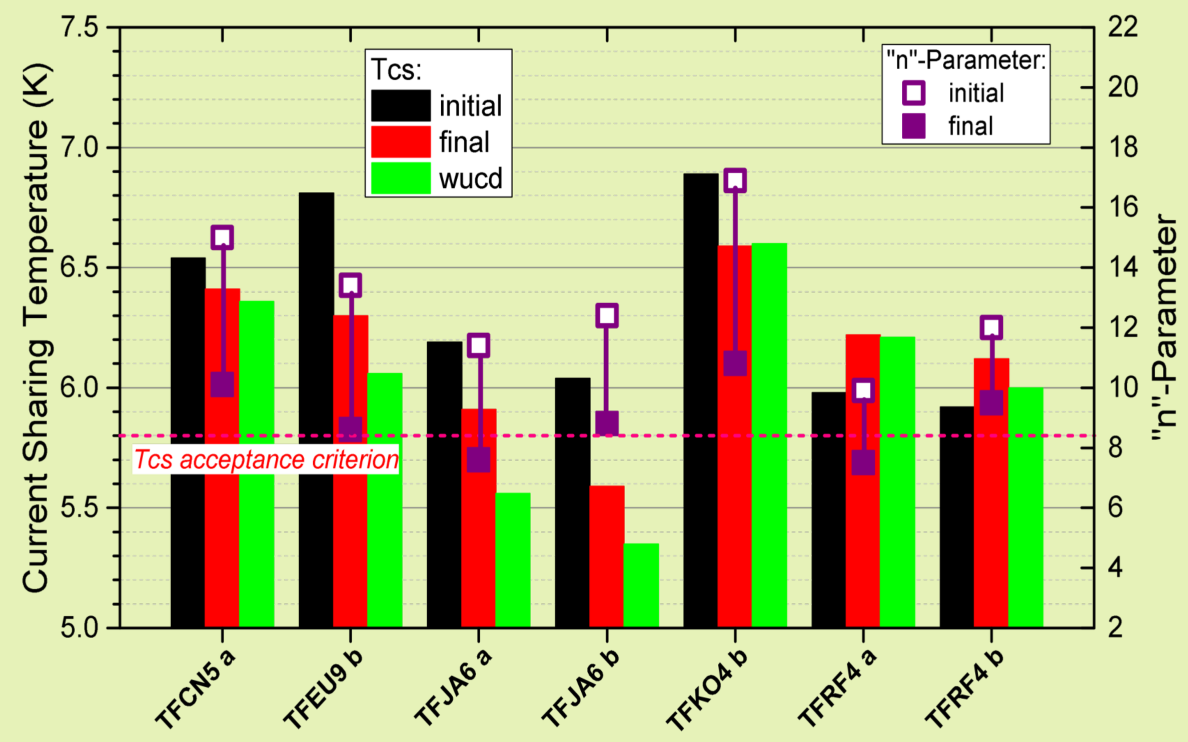




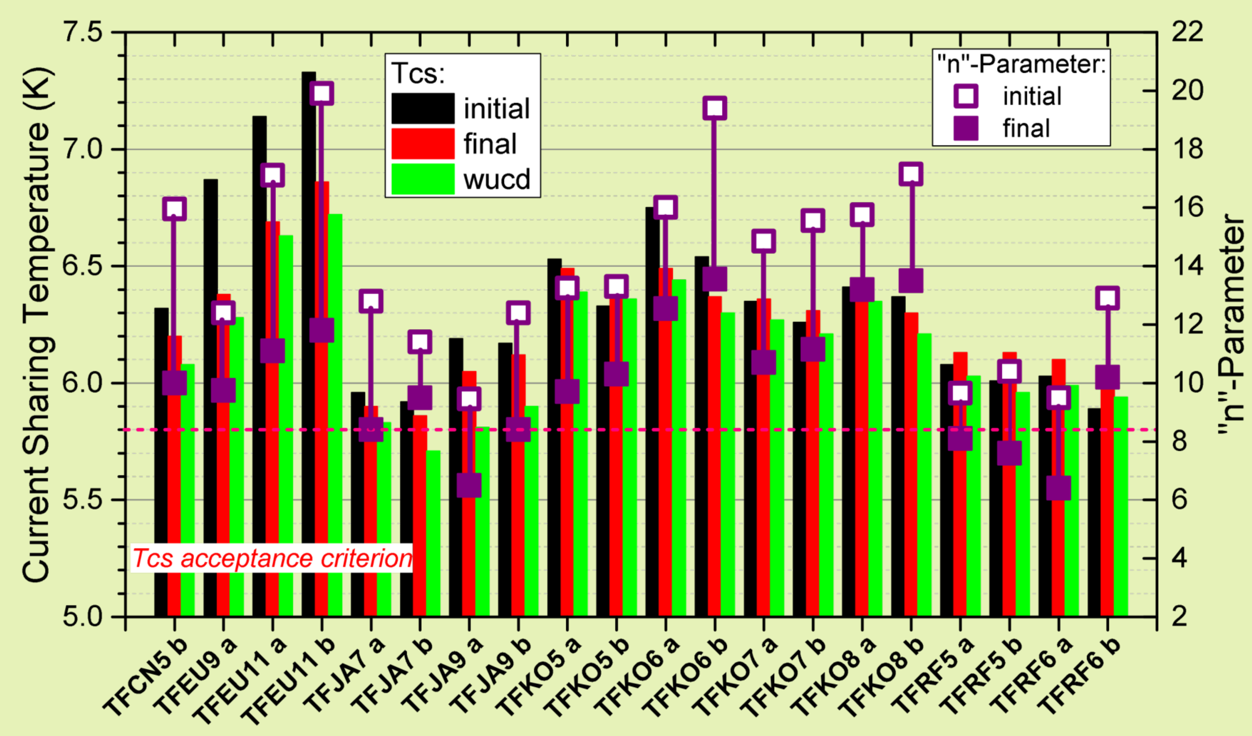
Results of TF Conductors Samples (68 kA / 10.78 T)



Supplier Qualification Test

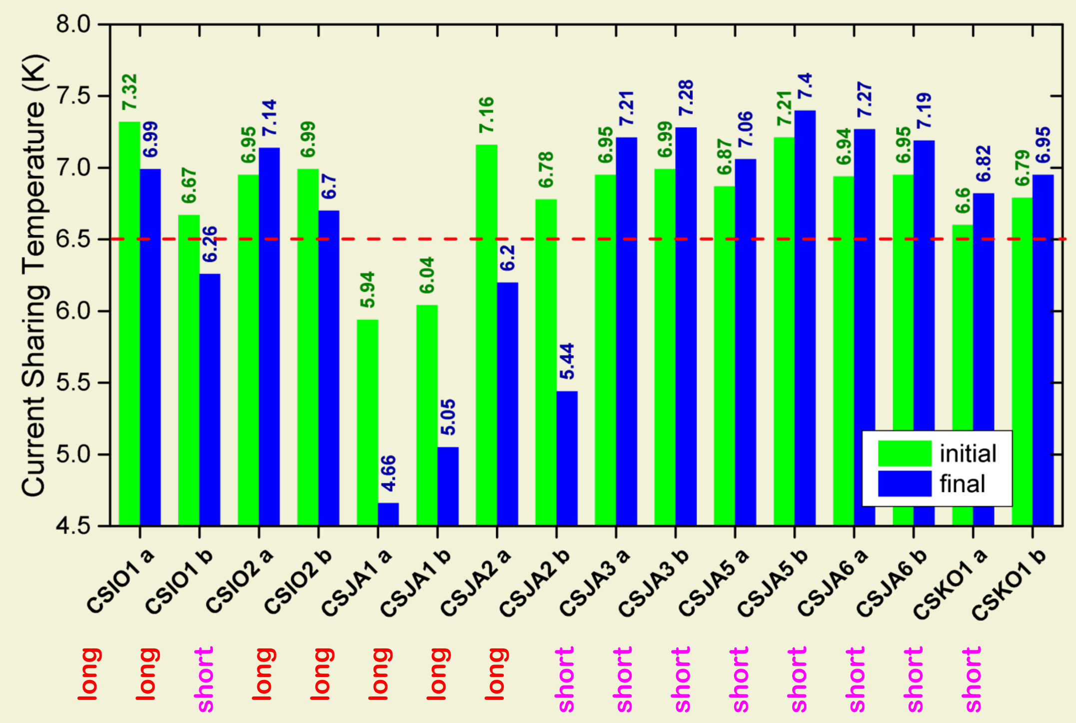


Process Qualification Tests



Series Production

The test is carried out immediately after cool-down, "initial", after 1000 load cycles, "final", and after a thermal cycle of warm-up/cool-down, "wucd". The ITER spec of 5.8 K is meant after 1000 load cycles, without the wucd. The n-index of the transition decreases upon cyclic loading, i.e. the transition broadens, as an evidence of strand breakages.



CS Conductors (45.1 kA / 10.85 T)

The initial developmental conductors had a "long pitch sequence" and suffered large degradation. With the "very short pitch" in the triplet, the performance was high and stable.
Three Japanese suppliers and one Korean supplier have been qualified

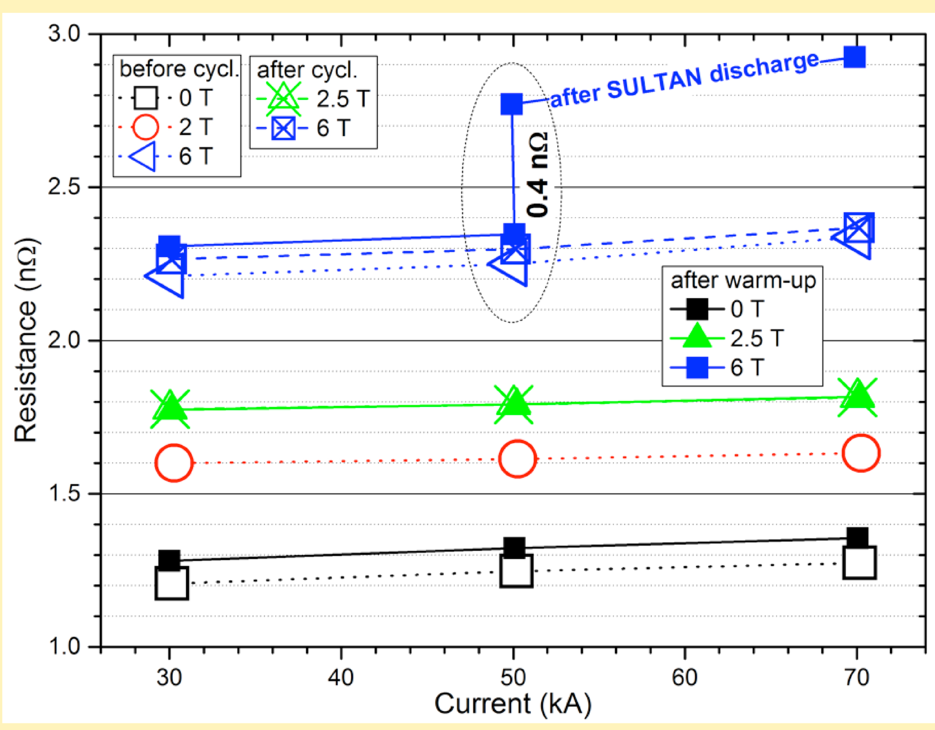
Progress and Schedule

In the last four years, over 70% of the planned conductor samples have been tested. The joint samples are prepared by the coil manufacturers as Qualification Samples. An extension of the contract for tests in SULTAN is being negotiated to accommodate the test of more CS samples (long duration and additional supplier qualification), of few delayed TF and PF samples and over a dozen of joint samples. The very last (joint) sample is expected to be tested about mid 2017.

DA	TF	CS	PF1/6	PF2/3/4	PF5	MainBus	CC	CCBus	Joints
CN	4			3	3	4	5	3	1 CC
EU	5	2	2						1 TF
JA	5	5							
KO	6	1							
RF	4								
% of planned samples	75%	30%	66%	75%	75%	80%	100%	100%	10%

Joint Sample

A TF joint from EU fulfills the spec R ≤ 3 nΩ at 2 T and 68 kA. The strong dependence of R on the operating current and background field suggests that the pressure contacts between strand bundle and copper plate are strongly inhomogeneous.
A field transient on the joint, caused by a fast discharge of the SULTAN field, produced a resistance increase ≈20%, due to the electromagnetic loads pushing the strand bundle away from the copper plate and thus weakening the contacts.



Conclusion

- **The testing rate in SULTAN matches the needs of the ITER coil construction. The operation of the test facility run without failures in the last four years.**
- **The conductor tests have been crucial to solve the issue of performance degradation in the CS conductor.**
- **The conductor degradation for the TF conductors, balanced by overdesign, is acceptable for the limited lifetime of the ITER TF coils. All the TF conductor samples passed the test so far.**
- **Starting from 2015, the SULTAN and EDIPO test facilities at CRPP will start also testing of R&D conductors for DEMO.**

NbTi Conductor Samples

Opposite to the Nb3Sn conductors, the performance of the NbTi conductors is stable and well predictable. All the PF, CC and CB samples fulfill the ITER spec.

For the MB (Main Busbar) samples, operating at high current and low background field, an unexpected poor performance was observed. At a closer look, the take-off happened at the U-bend, where the local self-field exceeds the nominal operating field. Applying the standard "bottom joint" instead of the "U-bend", the performance of the MB samples was recovered.

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