# Summary of the Test Results of ITER Conductors in SULTAN


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Poster FIP/1-4Ra
Friday afternoon

# Research, Development and Production of ITER Toroidal Field Conductors and Poloidal Field Cables in Russia


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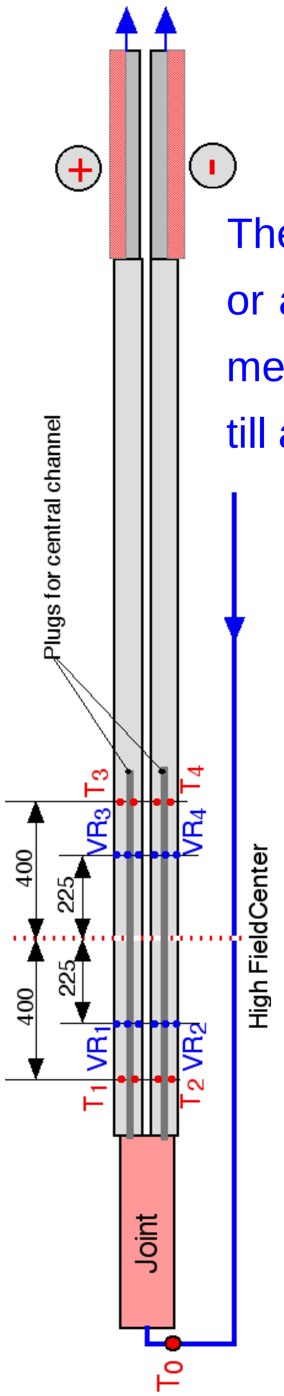
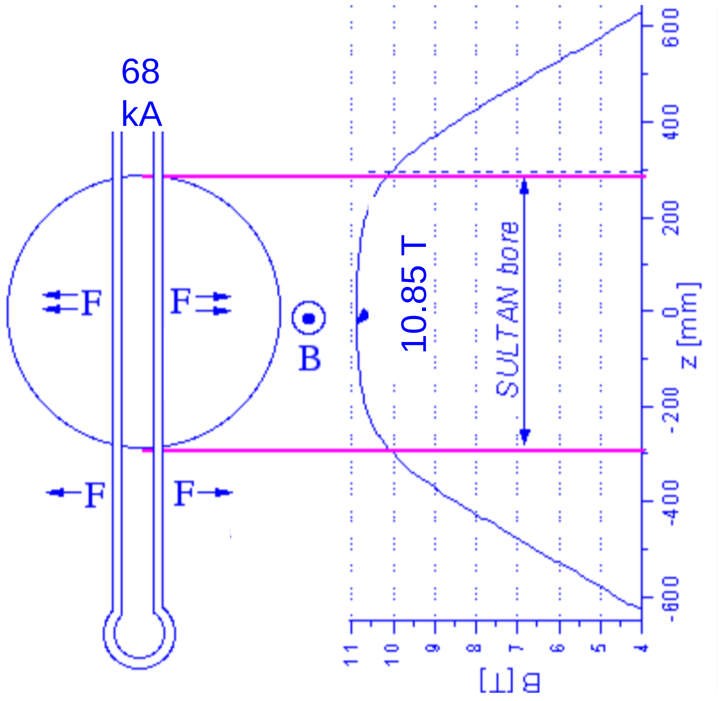
Poster FIP/1-4Rb
Wednesday afternoon

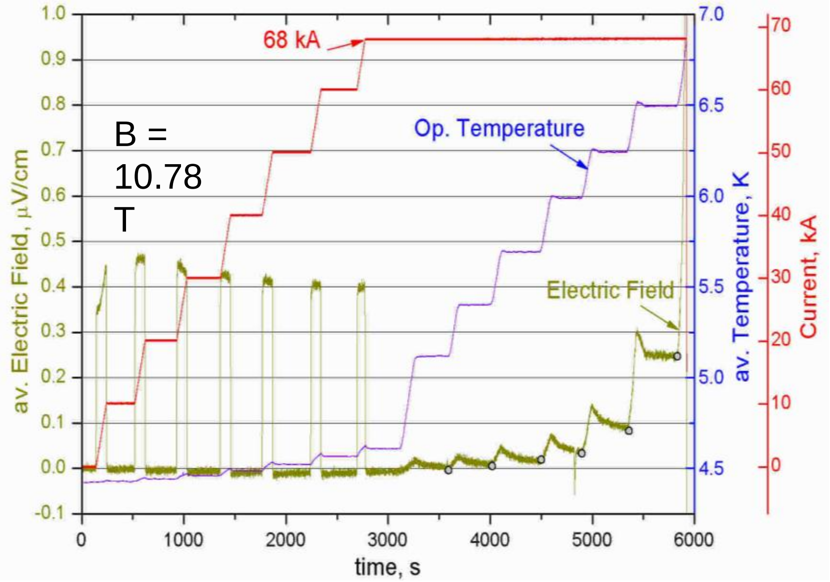
*The views and opinions expressed herein do not necessarily reflect those of the ITER Organization*

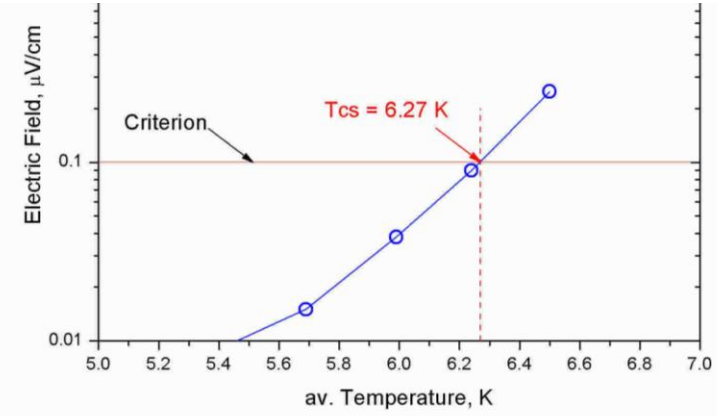
# The ITER Conductor Samples

The hairpin sample consists either of two sections joined at the bottom (TF and CS) or a single U-bent section (PF, CC, Busbar). The current sharing temperature, $T_{cs}$, is measured at constant field and current, by slowly raising the operating temperature, till a voltage builds up at the high field zone.



# Samples tested in last four years

| 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%* |

Depending on the stage of the Procurement Arrangement, the conductor samples are identified as Developmental, Supplier Qualification, Process Qualification, Production

The joint samples are prepared by the coil manufacturers as Qualification Samples.

The very last (joint) sample is expected to be tested about mid 2017

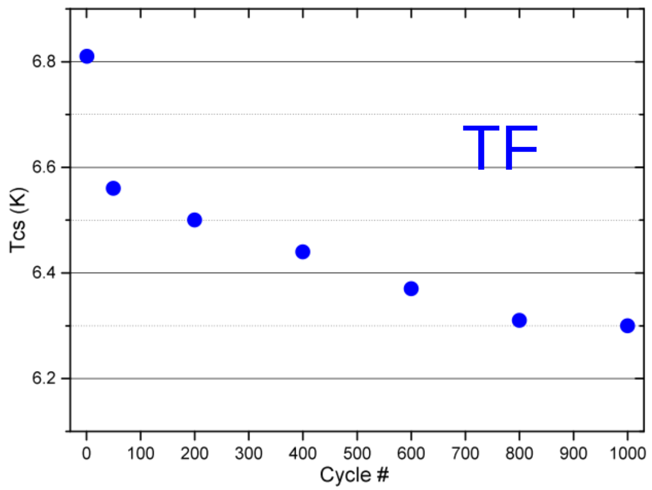
# Results of the $Nb_3Sn$ Conductors

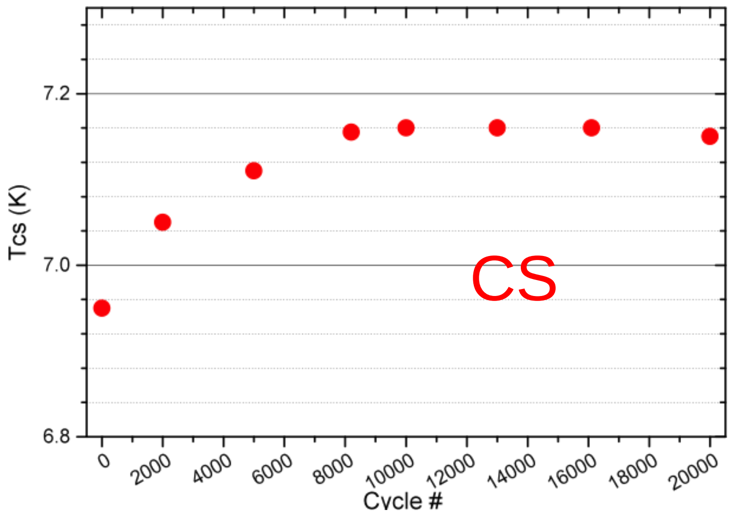
Two features affect the performance evolution for $Nb_3Sn$ based CICC:

☺ 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 $T_{cs}$.



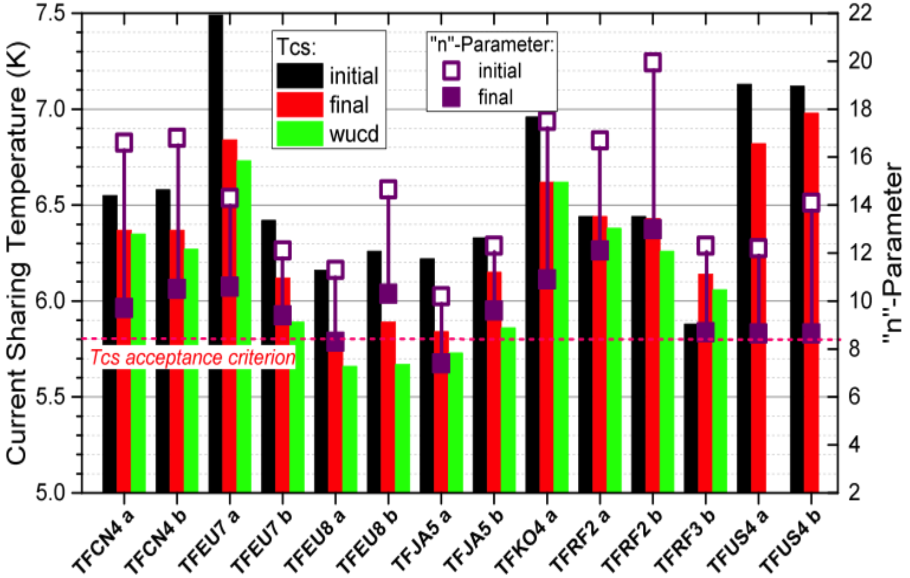

In the CS conductors, the rigid structure of the tightly twisted first triplet of strands, withstands the transverse loads without significant bending. The strain relaxation dominates over the filament breakage and the net performance change is an improvement of the $T_{cs}$.

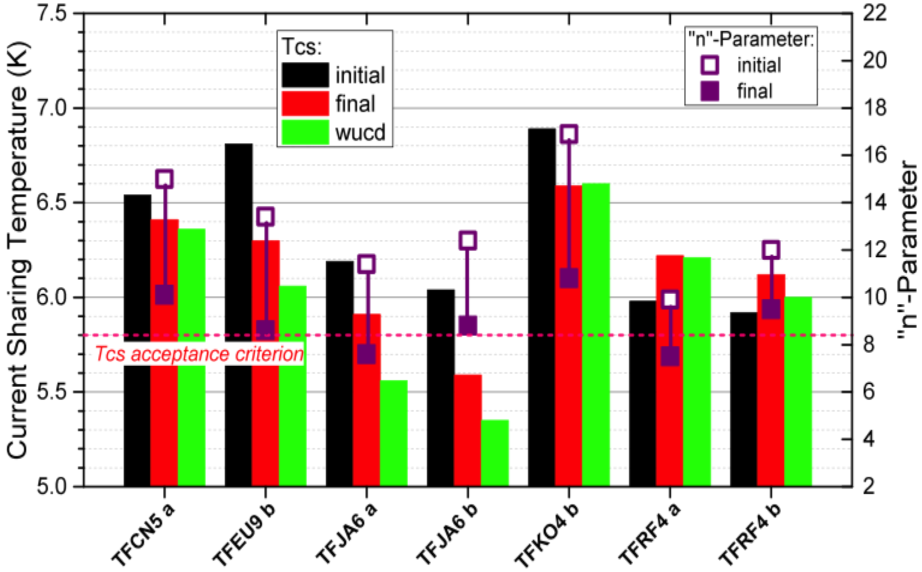
# Performance Degradation of TF Conductor

Supplier Qualification

Process Qualification

$T_{cs}$ test at 68 kA, 10.79 T background field



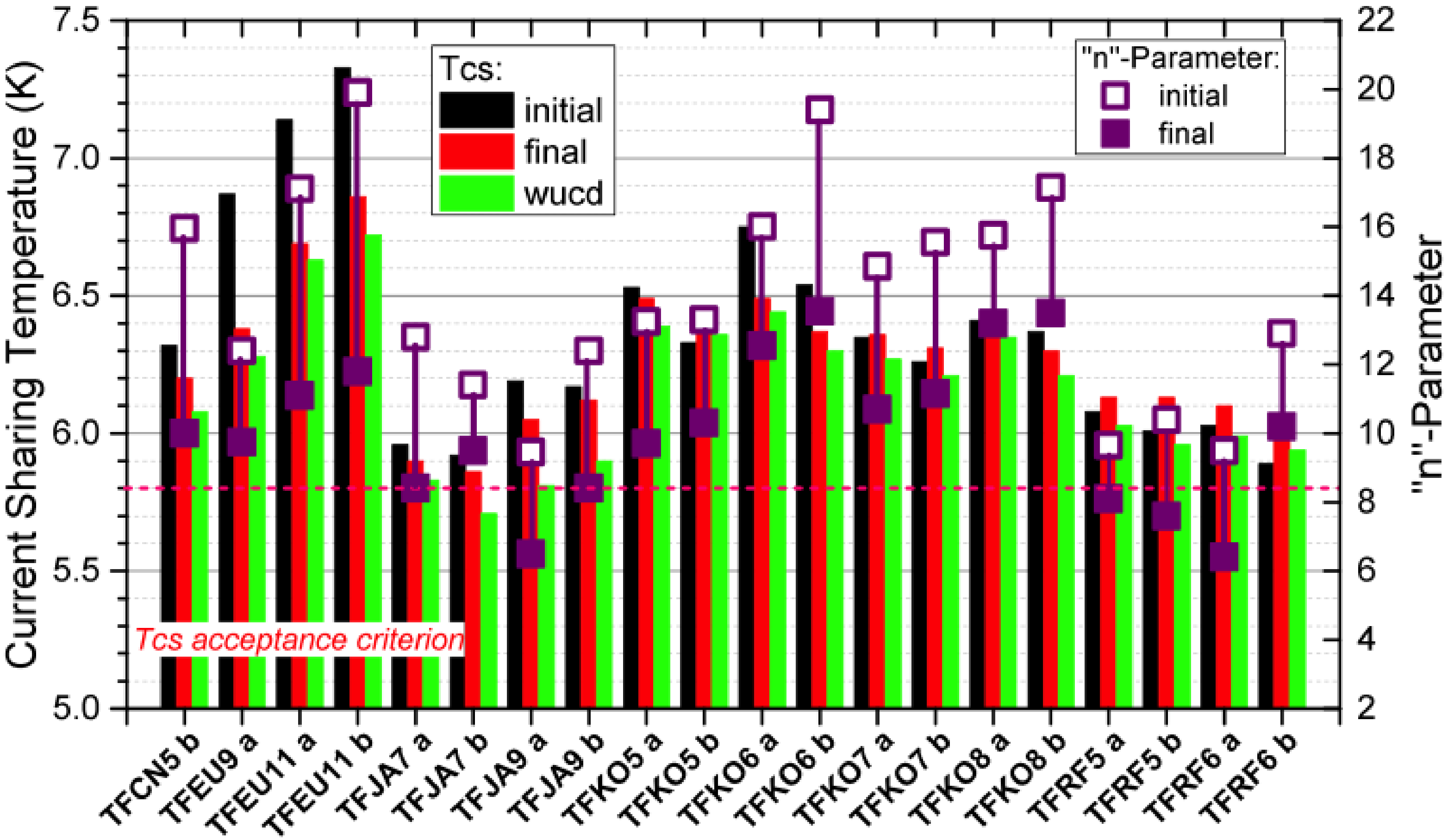




The test is carried out immediately after cool-down, “**initial**”, after 1000 load cycles, “**final**”, and after a thermal cycle of warm-up/cool-down, “**wucd**”. The ITER spec of 5.8 K is meant after 1000 load cycles, without the wucd.

The **n-index** of the transition decreases upon cyclic loading, i.e. the transition broadens, as an evidence of strand breakages

# Performance Degradation of TF Conductor

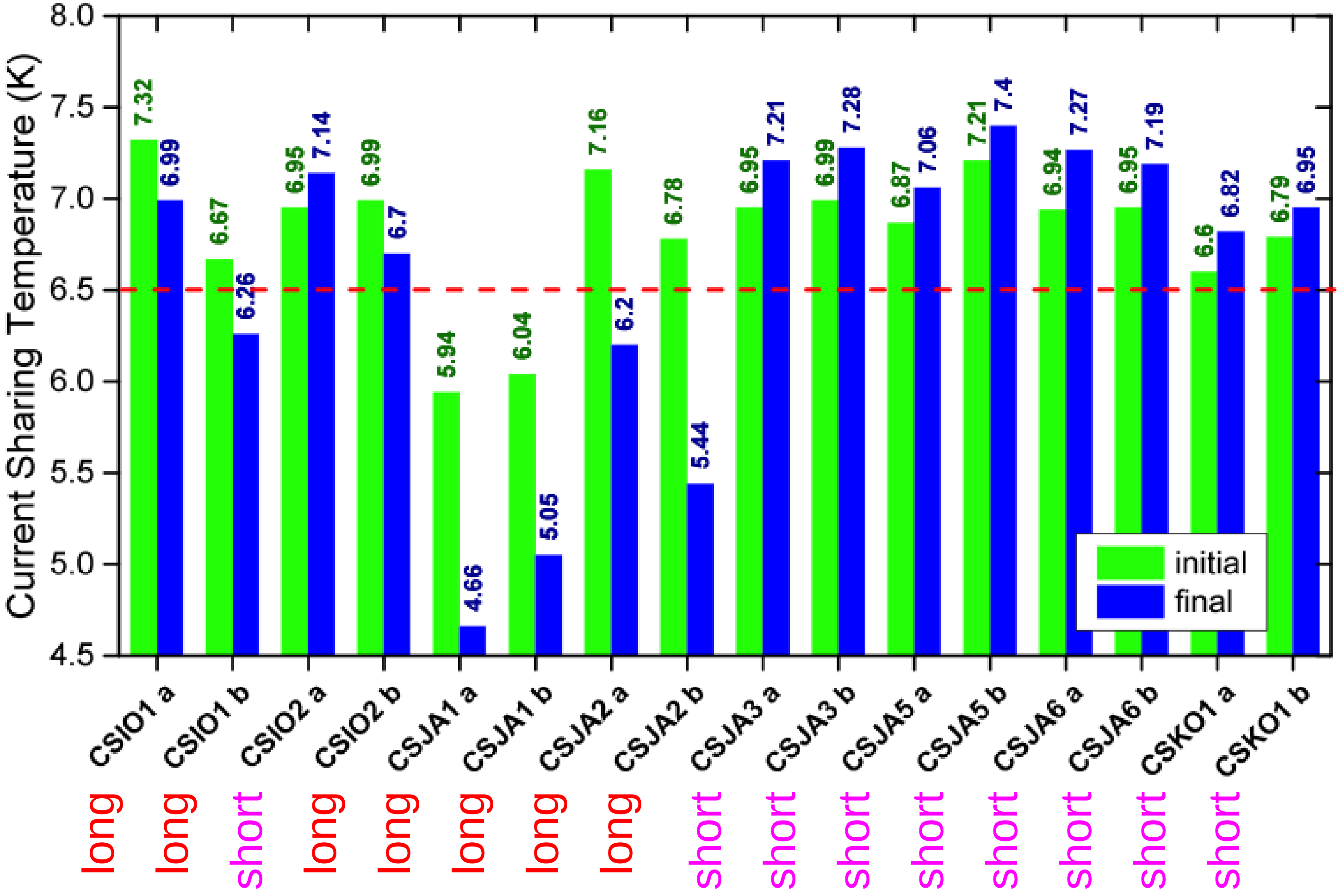
## Series Production




In the RF conductors the $T_{cs}$ performance is stable. A possible reason is the frictional property of the Cr plating of the Russian vendor, which may promote the sliding at the strand crossovers and mitigate the local strand bending.

# Performance of the CS Samples

$T_{cs}$ test at 45.1 kA, 10.85 T background field, **≥10 000 load cycles**

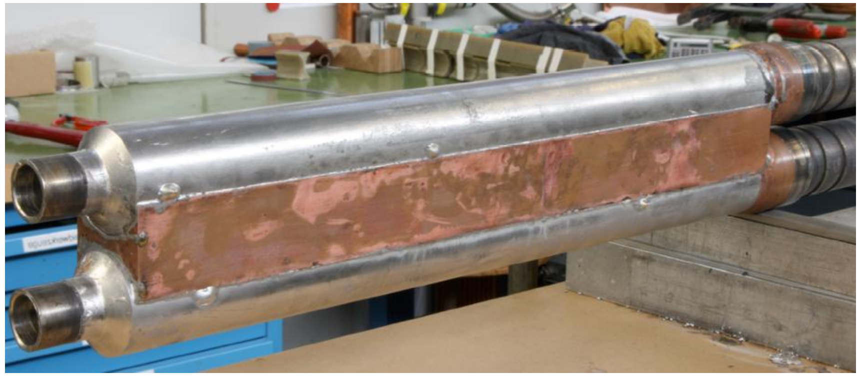



The initial developmental conductors had a "long pitch sequence" and suffered large degradation. With the "very short pitch" in the triplet, the performance was high and stable.

# Performance of the NbTi Conductor Samples

Opposite to the $Nb_3Sn$ 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.

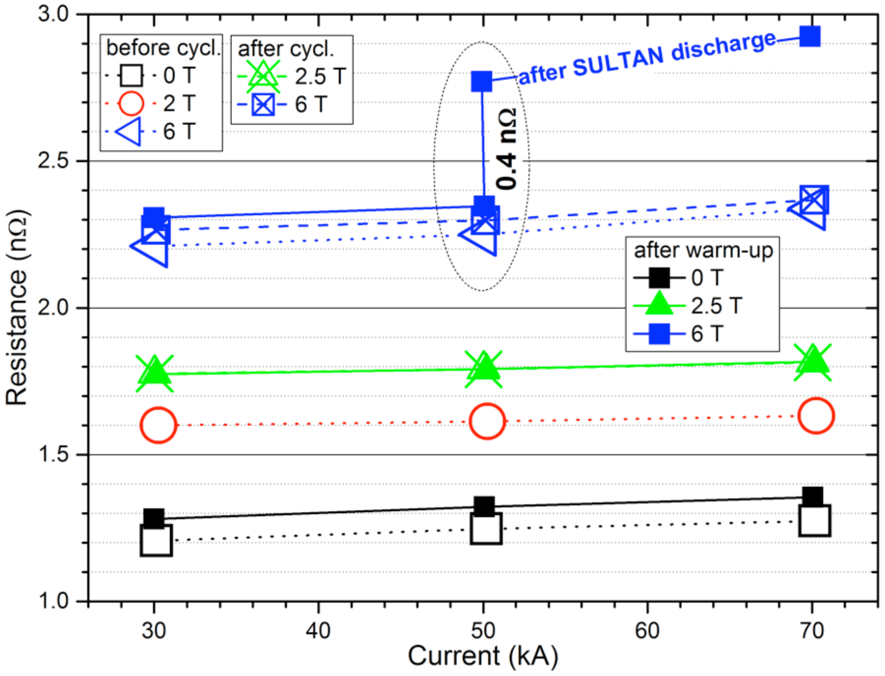


Applying the standard “bottom joint” instead of the “U-bend”, the performance of the MB samples was recovered.

# Joint Samples

A TF joint from the European industry fulfills the spec R ≤ 3 nΩ at 2 T and 68 kA. However, 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, with early saturation of the few low resistance contacts. A field transient on the joint, caused by a fast discharge of the SULTAN field, produced an unexpected resistance increase ≈20%, due to the electromagnetic loads pushing the strand bundle away from the copper plate and thus weakening the contacts.

A sample of the CC joint, prepared in China, was tested in summer 2014. The very high resistance, exceeding the spec by an order of magnitude, suggests pollution of the contact between strand bundle and copper plate.



# Summary

The testing rate in SULTAN matches the needs of the 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

Most of the planned tests of conductor samples are completed. An extension of the lease contract for the SULTAN test facility is being negotiated, including the qualification tests for the joints prepared by the coil manufacturers.

Starting from 2015, the SULTAN and EDIPO test facilities at CRPP will start also testing of R&D conductors for DEMO.

# Russian Scientific R&D Cable Institute (VNIIKP) in ITER

VNIIKP has a long story of participation in ITER since 1993, with several short samples for Sultan and conductors for the TF and PF insert coils.

Many multi-strand cables and cables in conduit have been developed.

The production line for ITER is upgraded to match the ITER PA demands:

- *New electro-plating facilities for Ni and Cr strand coating*
- *New stranding machines in the new workshop*
- *New jacketing line has been built at anew site*
- *New QA stations in accordance with the strict demands of ITER QA program*

# Strand Coating at VNIIKP

NbTi and $Nb_3Sn$ strands are produced by Chepetsk Mechanical Plant (Glasov) and delivered to VNIIKP

The coating facilities have been upgraded:

*A second cleaning line has been installed to increase productivity*

*Improvement of  Ni and Cr technology*

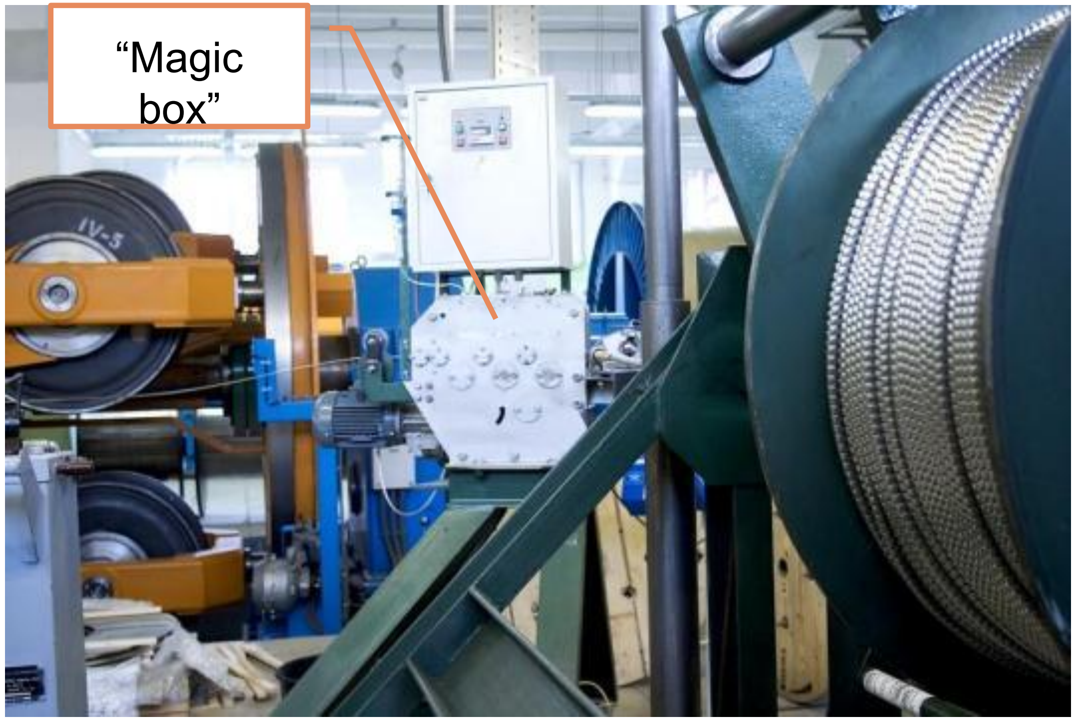
*Soft technology and ecologically cleanness*

Evaporator and distiller

# Production of the central spiral

Two highly efficient spiral making machines installed to produce up to 100-200 m of spirals per day from 6 to 14 mm in diameter (10mm TF and 12 mm PF)

We have delivered ~15 km spirals to other ITER teams



# Cabling Facility

Two high speed tubular machines (1-st and 2-d stages)

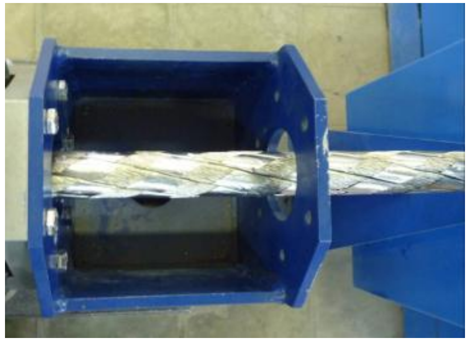
Two medium planetary machines (3-d and 4-th stages)

One large planetary machine (final 5-th stage) equipped by the set of special compacting calibers to increase density of a cable

Final twisting takes 3-5 days for a 800 m cable





# Cabling – PF cabling

RF produces all NbTi cables for PF1 and PF6 poloidal field coils, while EU performs jacketing of all cables for the coils mentioned.

In total VNIIKP has to produce 41 poloidal cables (5 dummies) with lengths 414 m and 734 m.

By October 2014 28 cables have been produced

19  cables has been delivered to ICAS in Chivasso, Italy for jacketing

# TF cabling and jacketing

The TF qualification and preproduction phases have been successfully passed.

By October 2014 24 TF cables have been delivered to the jacketing line.

A new jacketing line located in Protvino city on territory of IHEP consists of a gallery with ~900 m length and a workshop where the equipment for welding, testing, compaction and coiling is placed

# Jacketing - Equipment

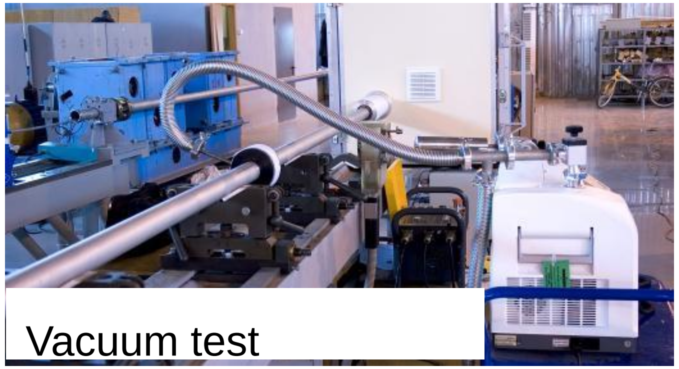
Welding is a very important procedure under very strict QA/QC check

The jacketing line is equipped by automatic welding machine, X-ray camera, vacuum test camera, TV for visual control of welds, vacuum control equipment, etc.

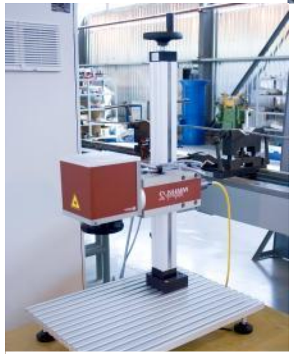
Welding head

Visual test set

X-Ray camera



Vacuum test



Laser marker

# Jacketing - Winder

The test facility is equipped by the winder to prepare 4m transporting solenoid.

Important issue is to keep misalignment between turns as little as possible. Right now we reached digits ± 3 mm misalignment in 4 m diameter 3.5 m high transport coil against ± 30 mm stated in PA.

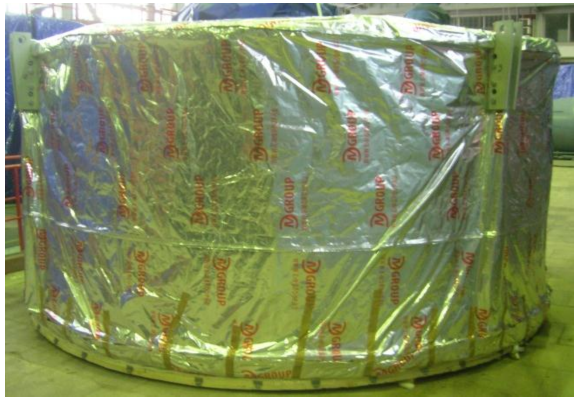
Winder

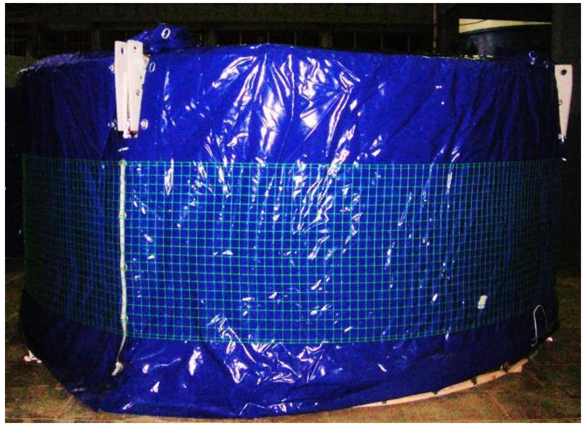
Bending device

Trial conductor on the winder

# Jacketing – Packaging

To transport from Russia to Italy the special package has been developed by stainless steel shells and plastic bags. Inner bag is vacuumed.





# Final vacuum leak test

The vacuum chamber used previously for testing of T-15 superconducting coils has been renovated in NRC “Kurchatov Institue”

The vacuum chamber has 4.8 m inner diameter and about 5 m total height.

It is equipped by large vacuum pumps and instrumented with high accuracy measuring devices for the measurements of pressure, temperature, He flow, He leak as well as a mass spectrometer to measure the gas composition in a chamber

View of the facility

The conductor inside the chamber

- All conductors prduced successfully passed global leak test that qualified this facility for use in accordance with PA

# TF Production and Delivery

In total 28  TF conductor lengths have to be delivered byVNIIKP.

By October 2014 23 conductor lengths have been produced

16 conductors have been delivered to ASG facility in La Spezia in Italy to wind the ITER TF coils.

View of the facility

# Conclusion

- The production line of VNIIKP including coating of strands, cabling, compacting, jacketing, packaging and global leak test successfully passed all qualifications procedures

- The production of PF cables is in full steam and 28 out of 41 cables have been produced, 19 of them have been delivered to EU.

- The production of TF conductors is in full steam as well and 23 of 28 conductor length are produced - 16 of them delivered to EU.

- The cable Institute is successfully completing its duty in production of PF cables and TF conductors as the in-kind contribution of Russia to ITER.