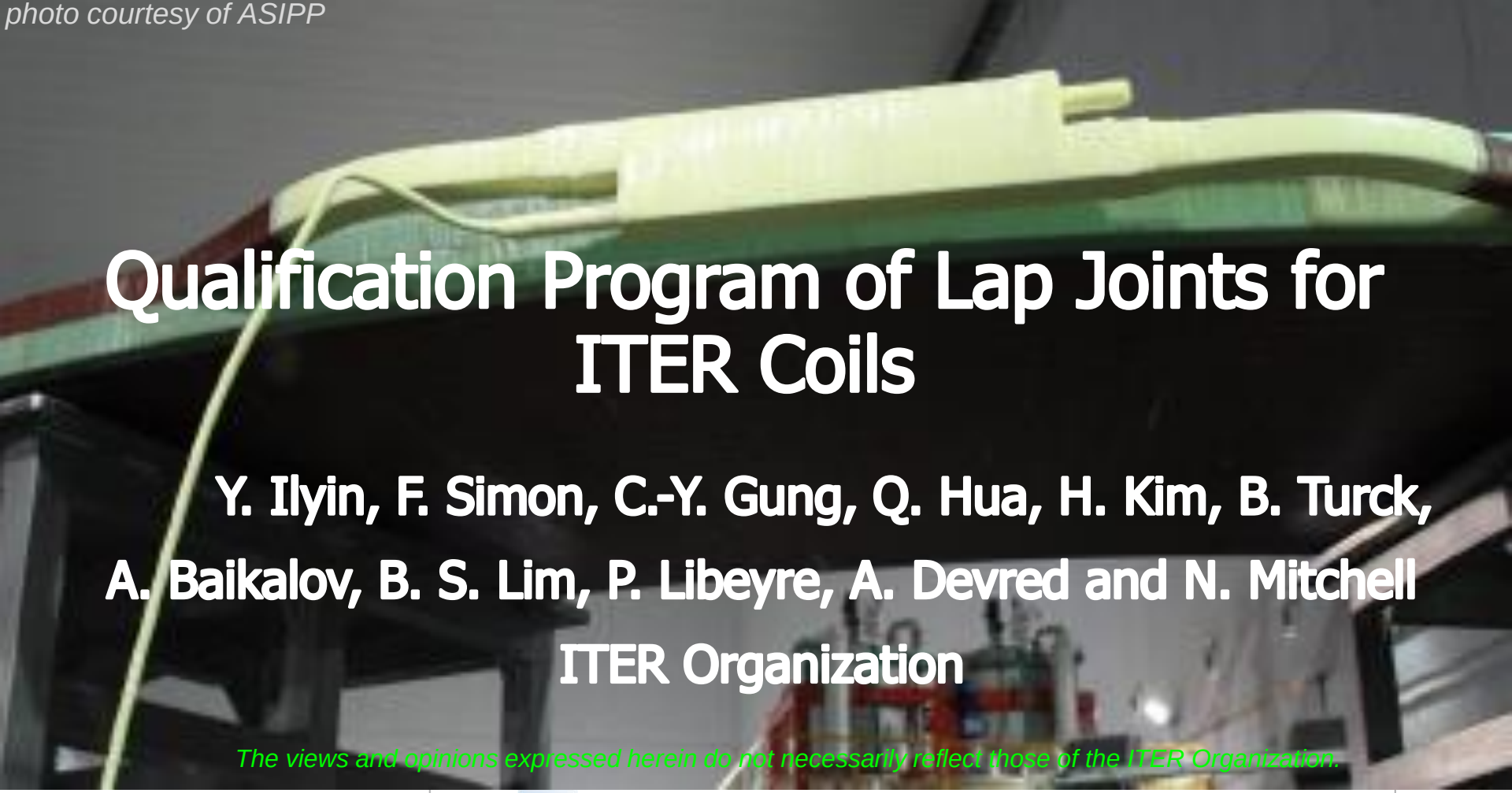

Qualification Program of Lap Joints for ITER Coils

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ITER Organization

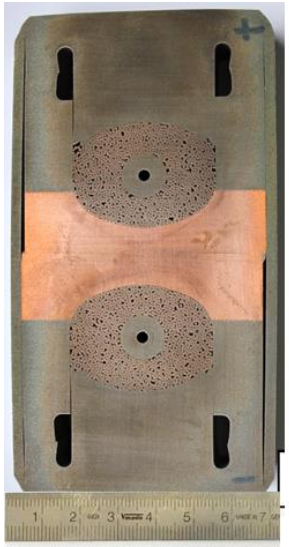
The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

Contents

- Design
- Materials, Interfaces, Welds
- Mechanical tests
- Electrical tests
- Pressure drop test
- Conclusions

Twin-Box Joint

PF



CC

TF

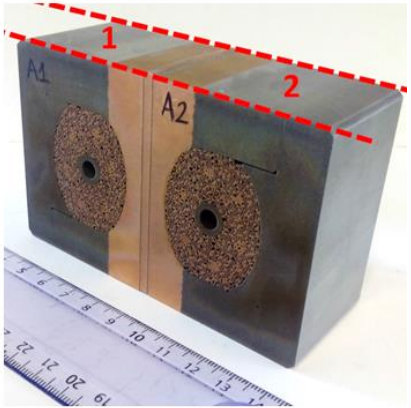


photo courtesy of CERN

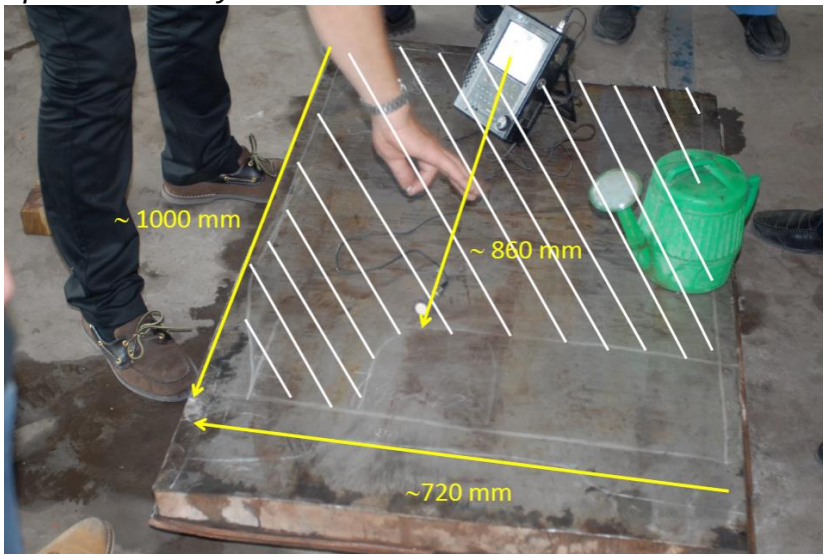
- In every coil/feeder of ITER
- Compaction to 18-22% voids
- Copper 12200/10200, ASTM B152
- RRR 6 (PF), 150 - 500 (other)
- ITER grade SS 316L/ 316LN
- Cu and SS explosively bonded
- Cable-Cu: soldered or pressed
- Box-Box: soldered or In wires

Approved Material Manufacturers

Coil	COPPER	316L/LN Stainless steel	Cladding
PF1 (RF)	MKM, GmbH, Germany	Forgiatura Morandini Srl, Italy	Energometall, Russia
PF2-5 (EU)	KME Germany AG & Co KG	Fomas Group, Italy	High Energy Metals, USA
Feeder, CC, PF6 (CN)	Aurubis, Finland	Guizhou Aerospace Xinli Forging&Casting, China	Nanjing LeiHui New Material China
TF EU	Aurubis, Finland	316L, Outokumpu Stainless AB, Sweden	High Energy Metals, USA
TF JA	Mitsubishi Shindoh, Japan	316LN, Daido Steel Co. Ltd., Japan	Asahi Kasei Corp., Japan
CS (US)	CSN Carl Schreiber, Germany	VDM Metals GmbH, Germany	Nobelclad, France

Material Acceptance

photo courtesy of ASIPP



UT of Feeder plate: the hatched part is acceptable with 1.6 mm FBH as reference.

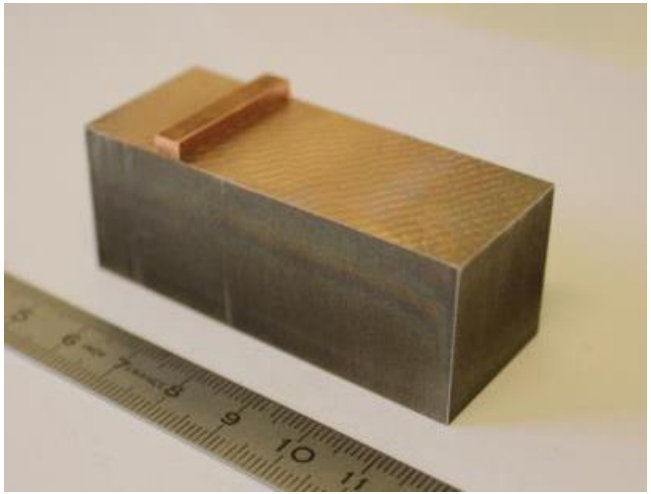


photo courtesy of CERN

Samples for tensile and shear test of the interface. Acceptance: interface stronger than copper.

Quality of Interfaces

Cable – Cu sole

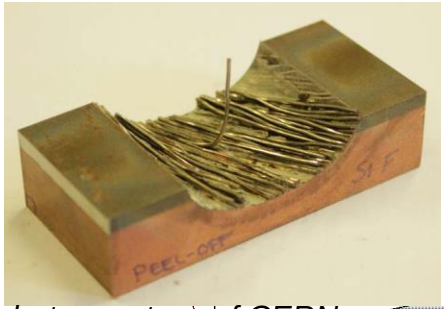
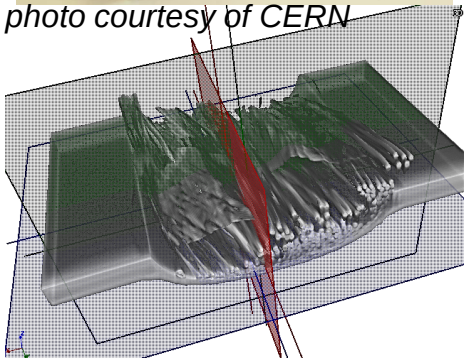


photo courtesy of CERN



Peel-off test on soldered strands (top) failing in cohesion. CT image (bottom) to visualize solder quality.

Box-Box

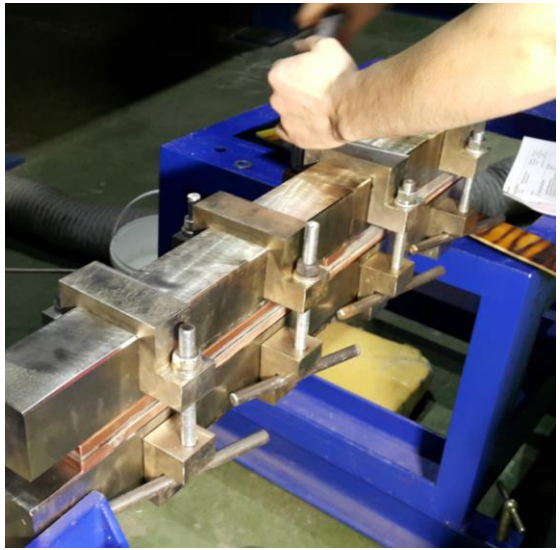
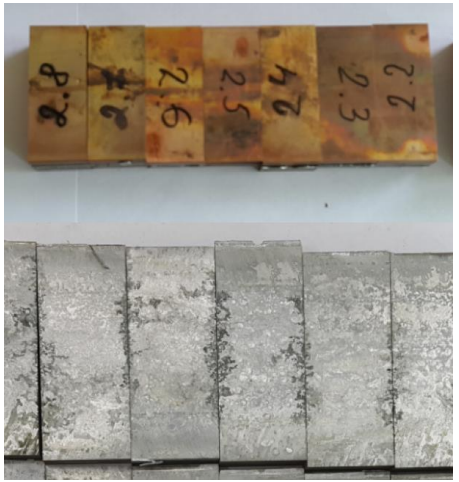


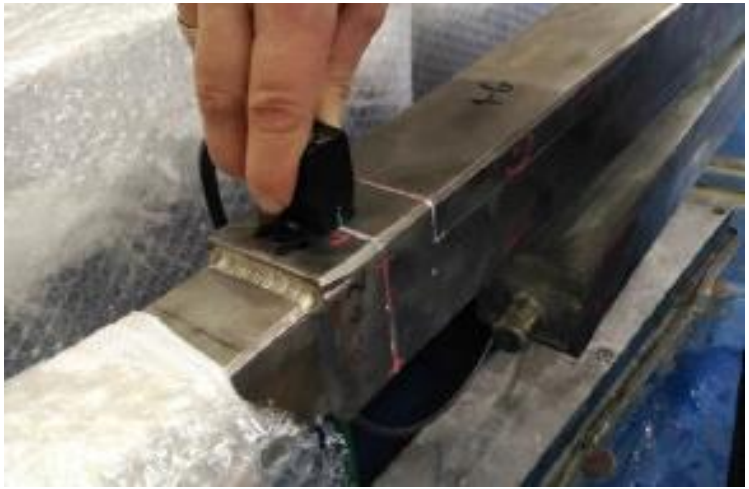
photo courtesy of SNSZ/ Efremov Institute



Qualification of box-box soldering process. The samples cut and tested in shear. Acceptance: >5 Mpa and below 20% void (by RT).

Welds

photo courtesy of Efremov Institute



Quality level B per ISO5817.
Weld process qualified to ISO15614-1.
VT, LT, PT of all welds. UT of all full-pen welds down to 1mm diam. defect.

Butt weld of jacket to joint box of the Feeder design in the fatigue test machine of KIT.

photo courtesy of KIT

When UT is not practical: fatigue test of 4 weld samples at 77K to 220,000 cycles (7x machine life time) at nominal load. During production: periodic welding of PPS.

Full Size Joint Test in Fatigue

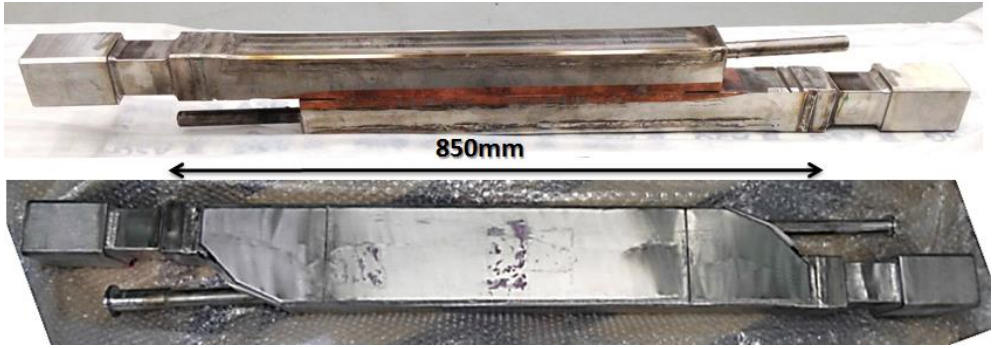
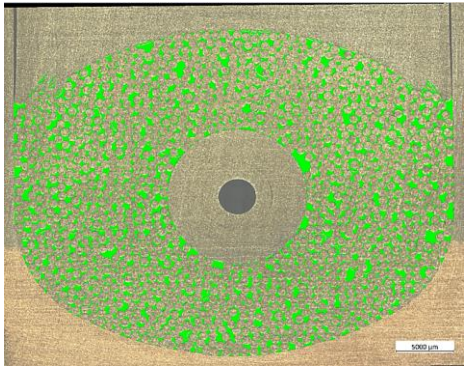


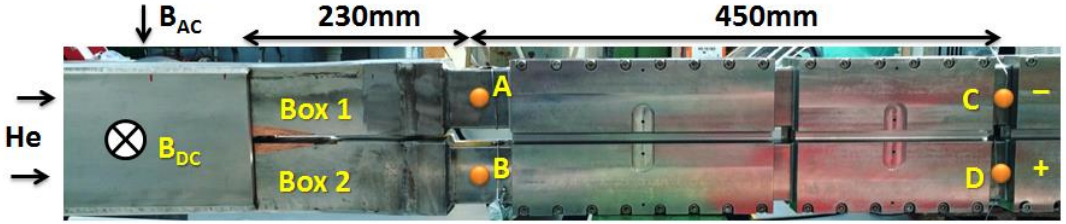
photo courtesy of ASG Superconductors

photo courtesy of CERN

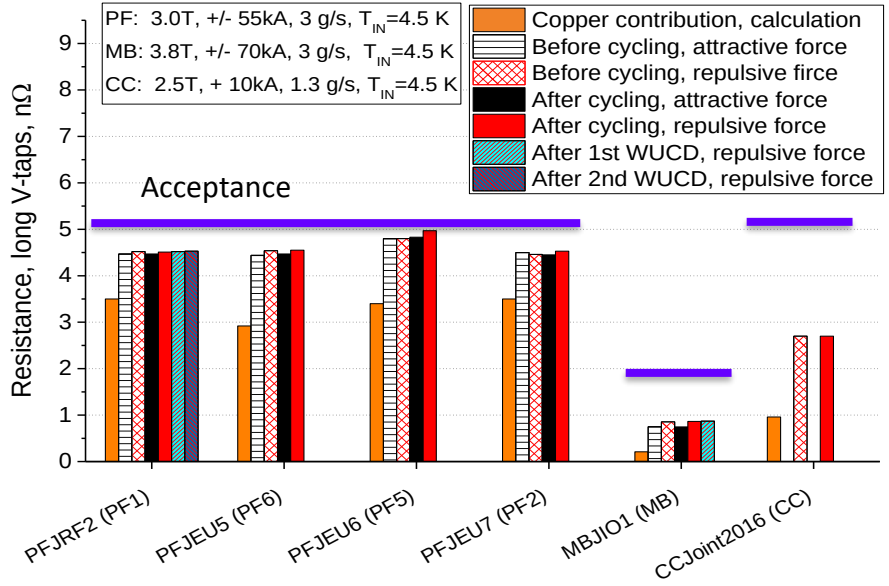


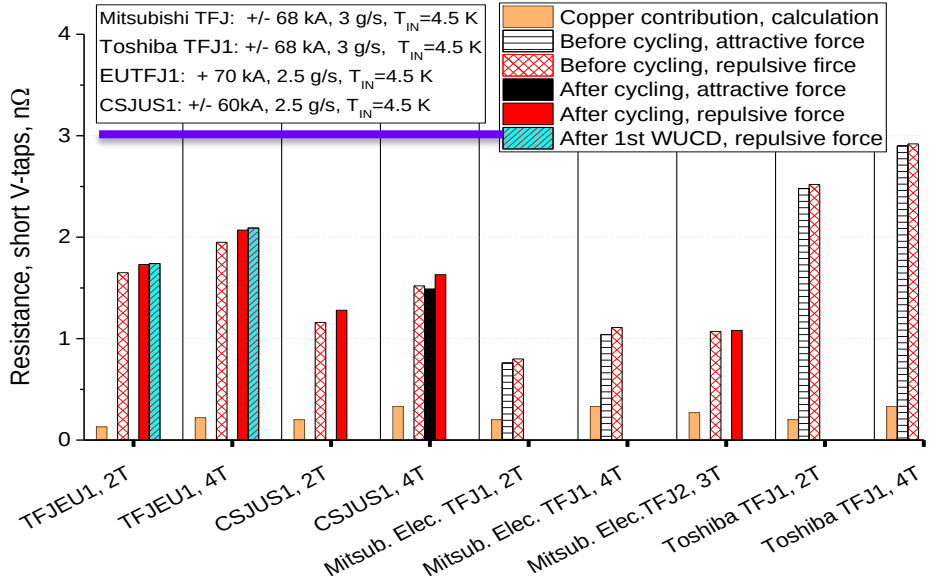
PF joints cycled at 77K from $7x10^{-5}$-$14x10^{-4}$ linear strain on the conductor jacket (F_{peak} = 500 kN) for 30.000 cycles.
LT and destructive test afterwards to check the welds' cross-sections and void fraction.

Electrical Resistance

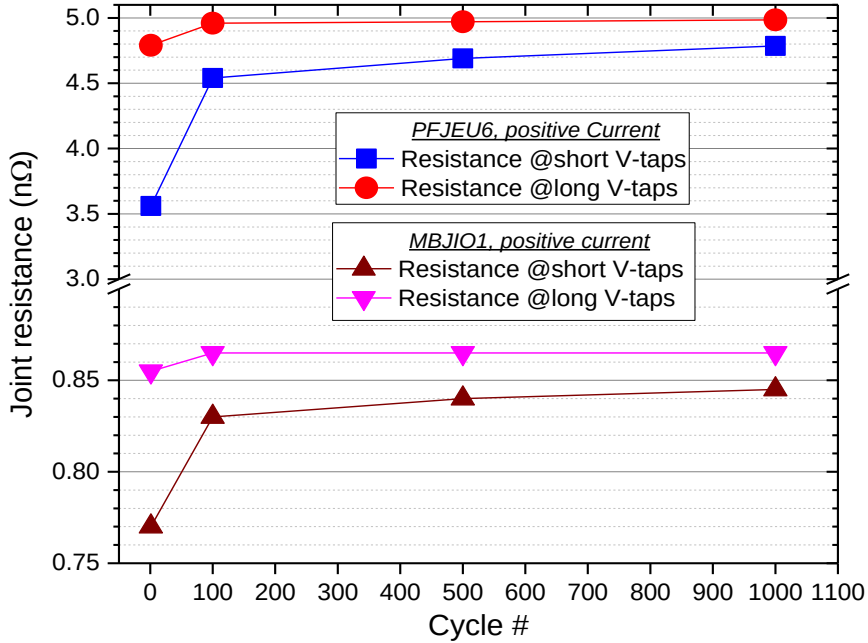


Full size joint samples tested in SULTAN and NIFS.
(AB=short Vtaps CD= long Vtaps.)





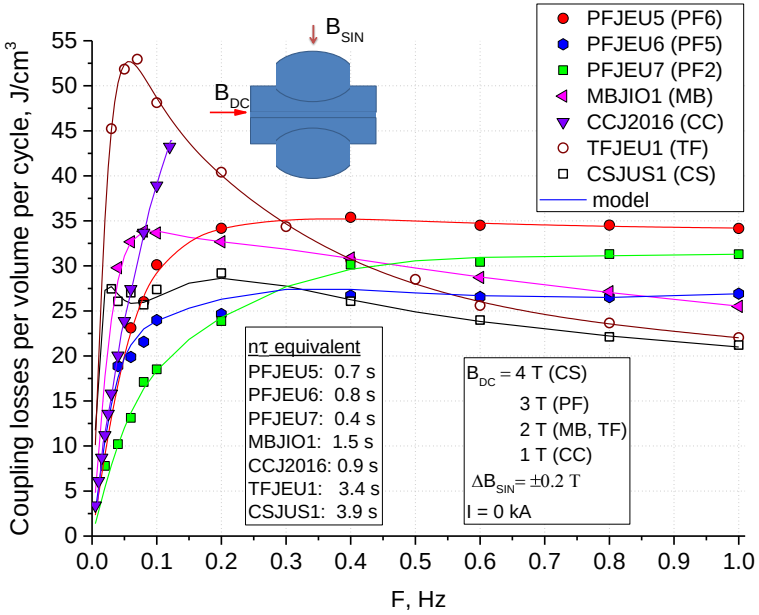
Electrical Resistance (II)

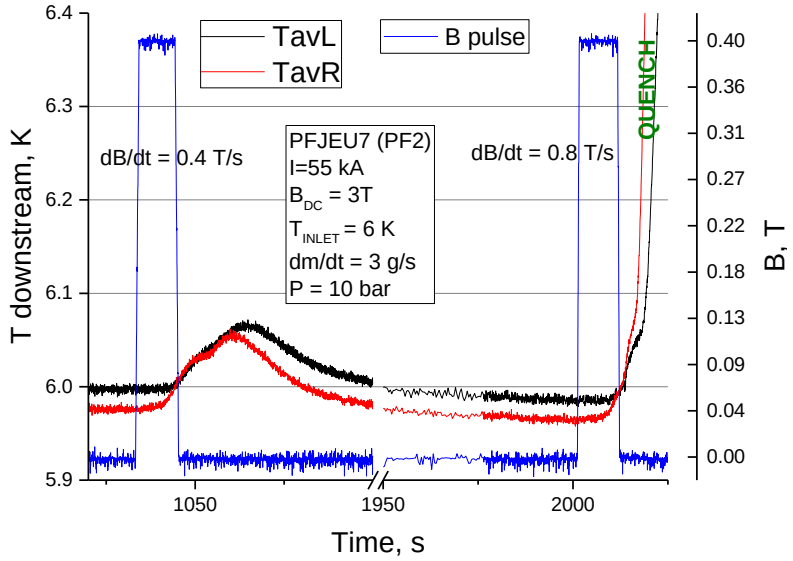


In NbTi joints weak dependence on cyclic load: saturation of resistance after 100 cycles.

Cyclic load for PF joints: 1000 cycles, 5T, 0/+33kA, for MB: 1000 cycles, 7T, -38/+38 kA,

AC loss, Stability

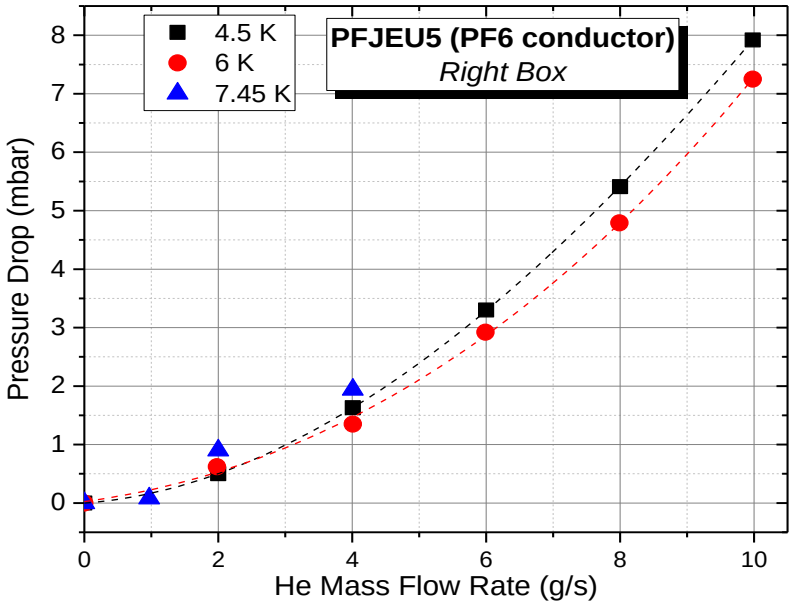




No acceptance criteria. Measured for modeling. Somewhat higher nτ than expected in PF joints. Significant contribution from cables.

NbTi joints are stable at plasma initiation: 0.4 T/s , 3T and 55kA.(field transvers to box-box interface plane)

Pressure Drop



8 mbar is 3% of the total pressure drop on the (smallest) PF1 Coil.

Conclusion

- Prior to start fabrication of the lap joints on the windings/leads, a broad program of qualification of the materials and manufacturing steps was set-up to the coil suppliers.

- The electrical performance is qualified by testing the full size joints in nominal operating conditions and above. All samples have passed the acceptance criteria.

- The mechanical robustness is qualified by testing the full size joints or the samples of the critical welds in fatigue at 77 K. No failure of the welds or soldered interface was detected in any of the samples.

- The core qualifiifcation program has been successfully completed by all coil suppliers with few remaining items to be finalized in 2017.

Acknowledgement

The work presented is the joint effort of ITER Domestic Agencies and many companies and research centers around the world.

The authors are in debt to A. Bonito-Oliva, K. Smith, P. Valente, C. Sborchia, G. Romano (*F4E*), R. Penco, P. Pesenti, G. Vercelli, F. Ortona (*ASG Superconductors*), N. Bugada, F. Chastel, (*CNIM*), P. Bruzzone, B. Stepanov, K. Sedlak (*SPC*), S. Sgobba, S. Langeslag, I. A. Santillana (*CERN*), K. P. Weiss (*KIT*), A. Nijhuis (*University of Twente*), A. Ustinov (*RFDA*), I. Rodin, E. Marushin, A. Mednikov (*D.V. Efremov Institute*), E. Niu (*CNDA*), G. Shen, B. Hu, J. Wei, L. Wang, K. Lu, C. Liu, X. Wen (*ASIPP*), N. Martovetsky (*USIPO*), A. Vostner, K. Hamada, S. Koczorowski (*ITER IO*).