Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

27th International Conference on Magnet Technology (MT27)
Fukuoka, Japan / 2021

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DC characterization of a Low-Field Nb_3Sn prototype conductor for a DEMO TF coil

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Introduction and content

- ENEA conceptual design studies for the DEMO TF coils:

DEMO ENEA Low Field layer wound Wind&React Conductor (LF-WR4 CICC): designed with a small number of sc Nb_3Sn strands (#120) and a high number of stabilization copper wires (#690) → lowest field grade

- LF-WR4 DC characterization (Sultan facility at SPC)

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could not reach operating conditions (5.4T – 70.8kA) due to early quenches → <u>but achieved T_{cs} is stable with cycling</u>

Investigation/explanation of DC results:

- Measurements analysis
- tomographic analysis

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Susceptibility analysis of strain distribution

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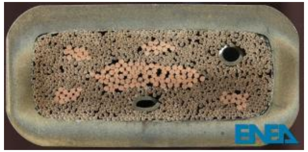
Low Field layer wound WR4

ENEA layer wound winding pack layout for the DEMO TF coils →advantage: optimized distribution of steel and superconductor in winding pack

CICC design: **rectangular,** with:

- **thick** steel jacket (const. thickness)
- **distributed** pressure relief channels
- Low Void Fraction (**25-28%**)
- **Long Twist Pitch** cable configuration

- HF-WR1 conductor (#1080 Nb_3Sn strands) prototype feasibility has already been demonstrated in 2015 and performances measured at SPC



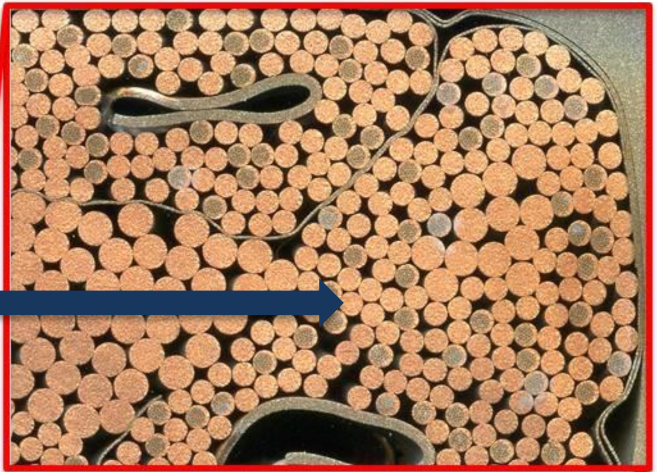
- LF-WR4 is the **lowest field grade**: #120 Nb_3Sn strands and #690 copper wires → prototype feasibility has been demonstrated and test performed at SPC in February 2021

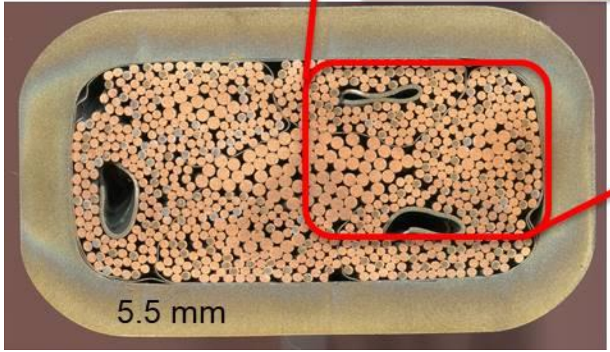
Low Field layer wound WR4

DEMO LF-WR4 is an extreme case: huge amount of Cu to limit T_{hs} → 15% sc

few Nb_3Sn strands in the cross section

J_{op}= 1500A/mm^2





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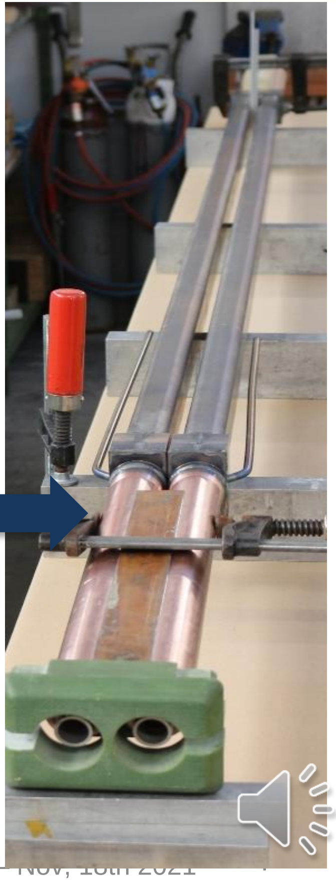
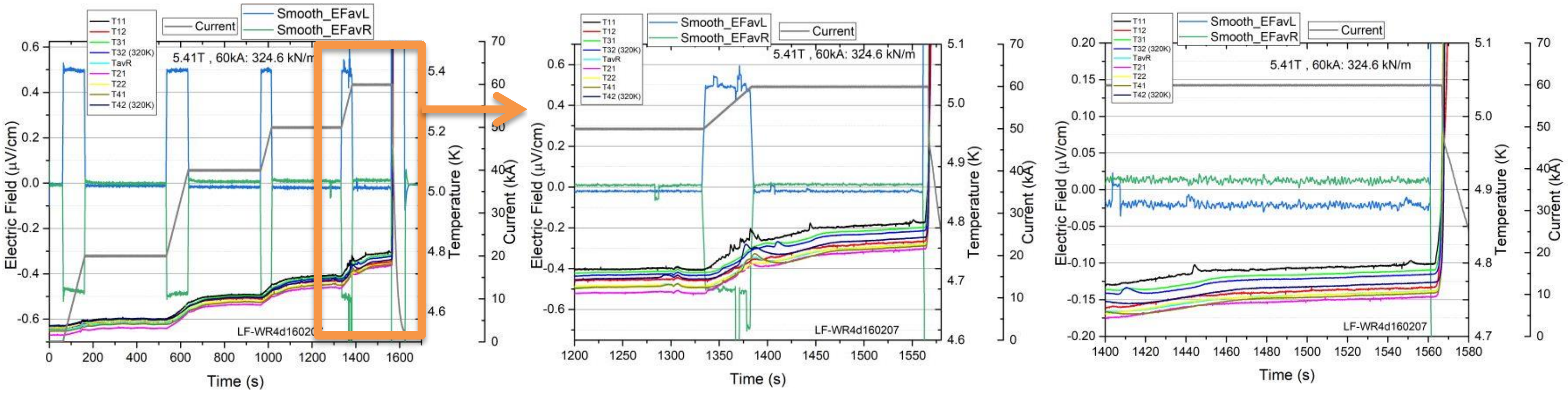
Sultan sample: assembly procedure at SPC→ *application of Cu sleeves at conductor termination, steel transition pieces, Copper termination, instrumentation, insulations, mechanical structure etc.*



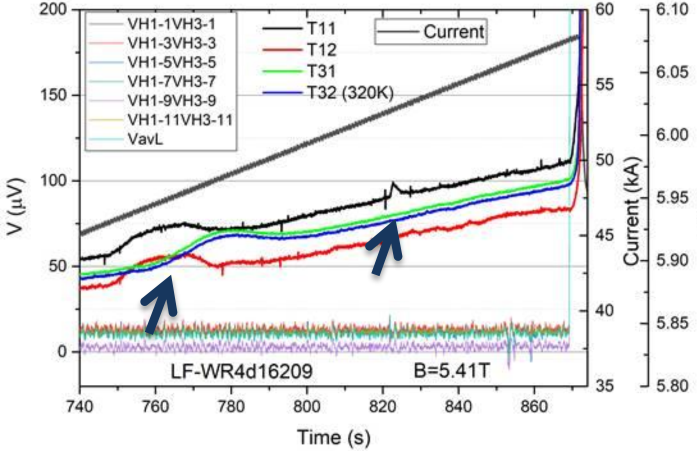
LF-WR4: investigation on DC transition

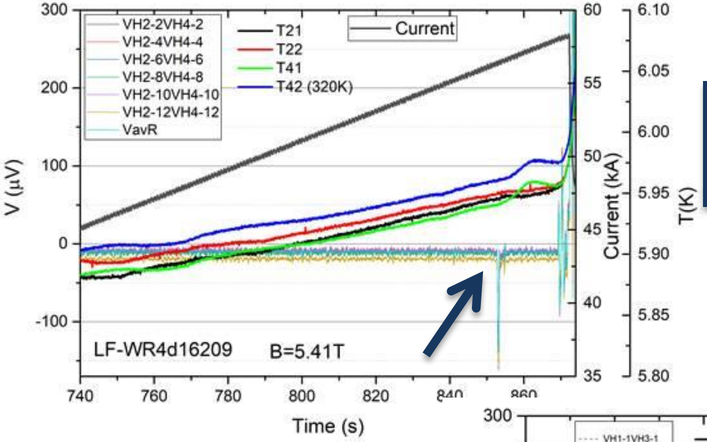
First DC measurements: **quench at 60kA flattop (5.41T x 60kA → 324.6kN/m)→** could not reach operative conditions (5.4T – 70.8kA)



- At flattop a current re-distribution is likely: from an «inductance-dominated» configuration to a «contact resistance-dominated» configuration
- redistribution could be not effective as there are few Nb_3Sn strands in the cable section

LF-WR4: investigation on DC transition





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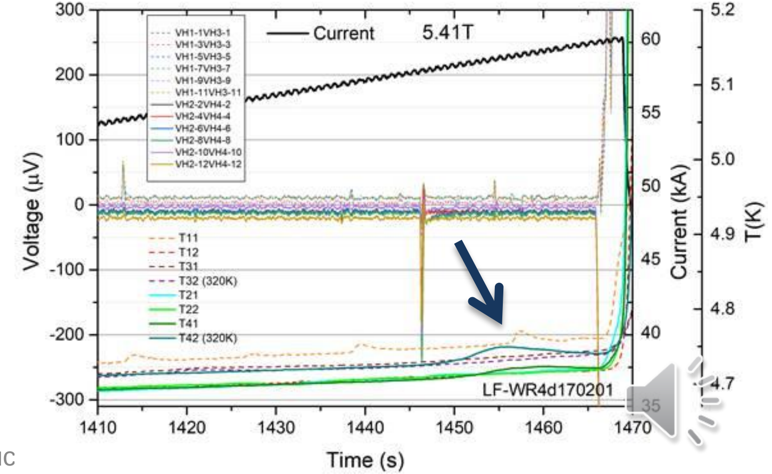
Quenches during current ramps

Voltage spikes during the ramps, accompanied by temperature oscillations

Possible explanations for early quenches:

- Strands movements due to E-M. load
- Uneffective current redistribution among the few sc strands in the cross section



LF-WR4: investigation on DC transition

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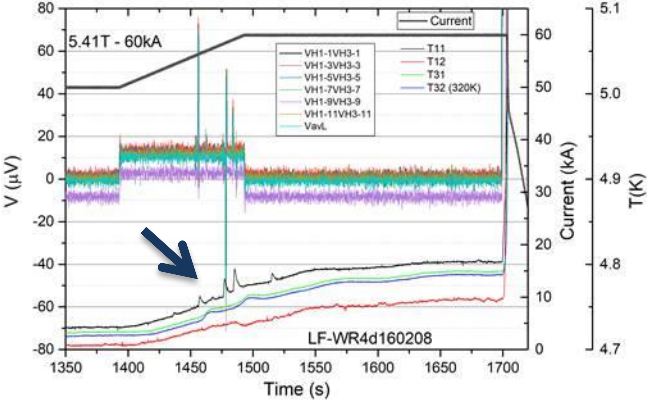
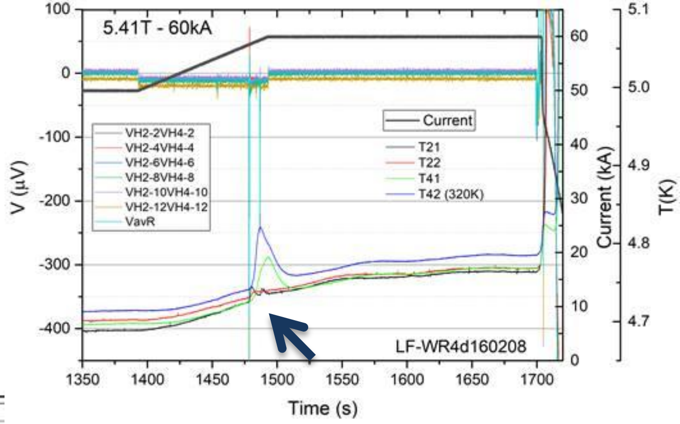
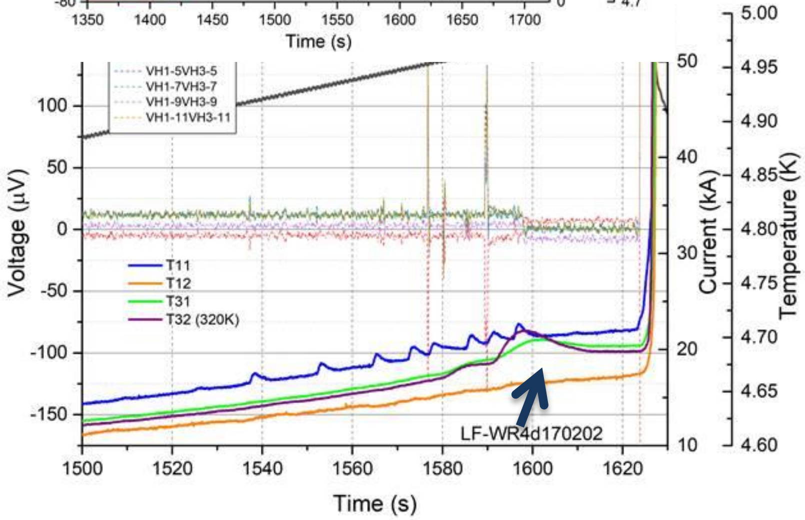


In some runs voltages spikes and temperature oscillations are even more evident

5.41T x 60kA → 324.6 kN/m

7T x 52kA → 364 kN/m





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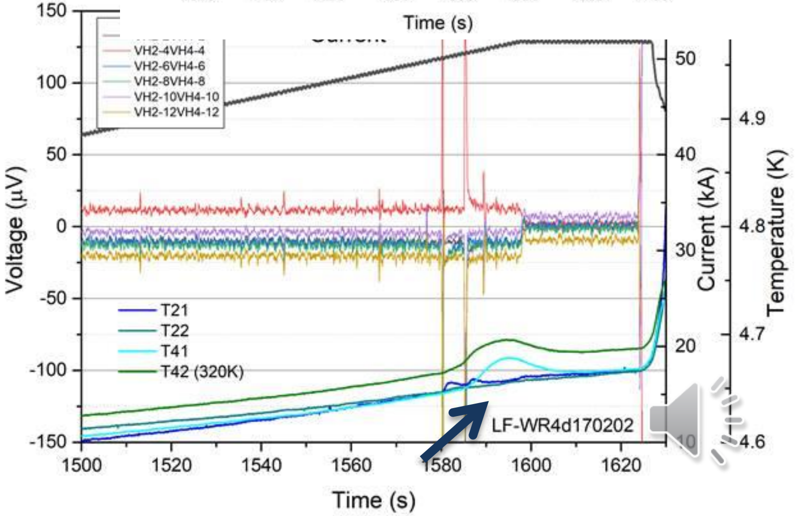
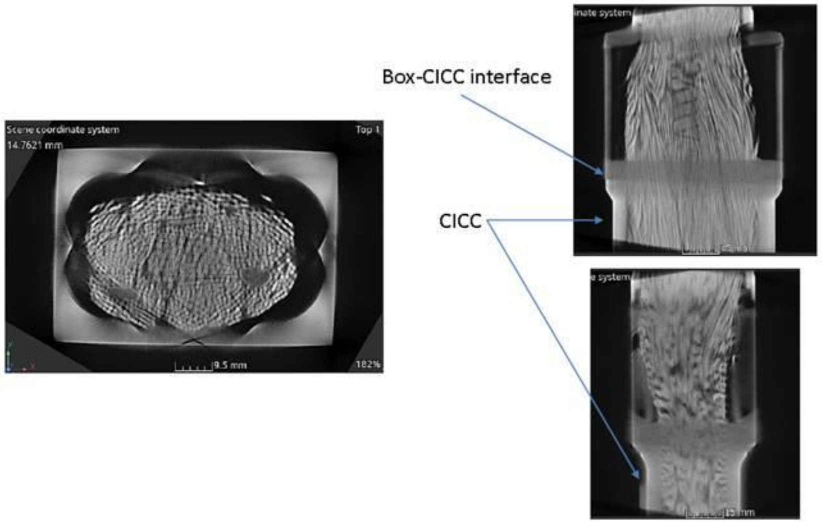


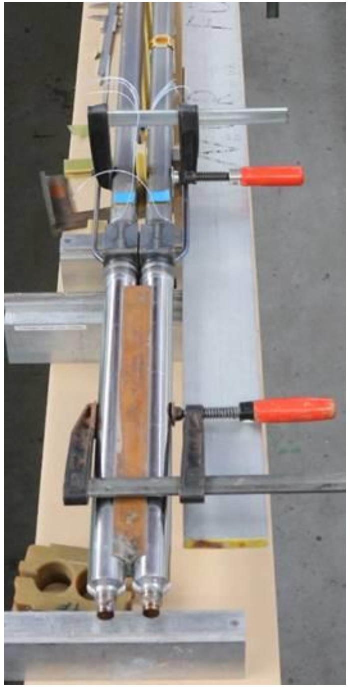
of a low-field prototype cor

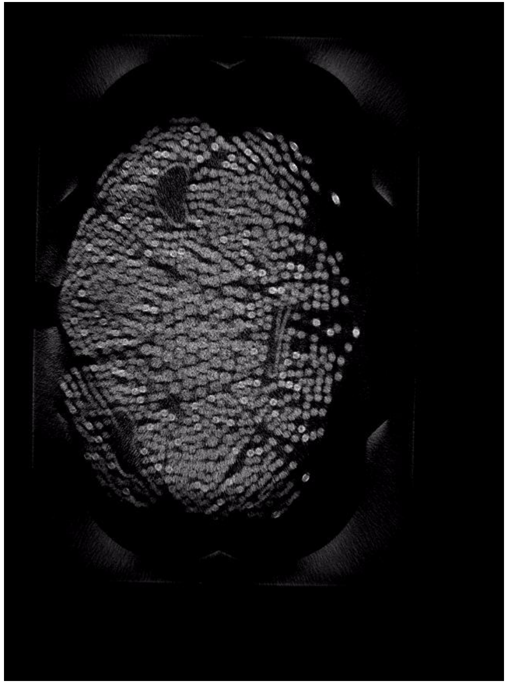
LF-WR4: X-ray microtomography analysis

Microtomography group of National Institute for Laser, Plasma and Radiation Physics, Bucarest (Romania)

- “Box” with CICC interface







Sample lenght ~ 400 mm
320 mm were XCT scanned

LF-WR4: comparison among similar E.M. loads

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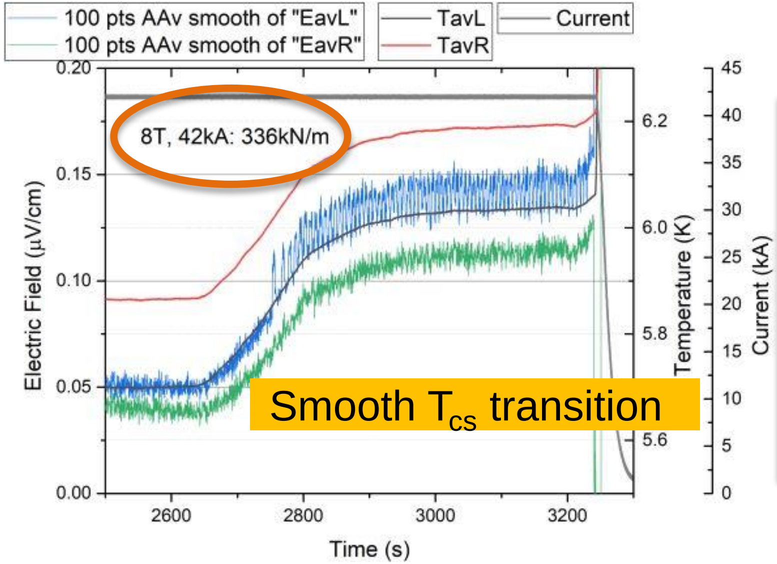
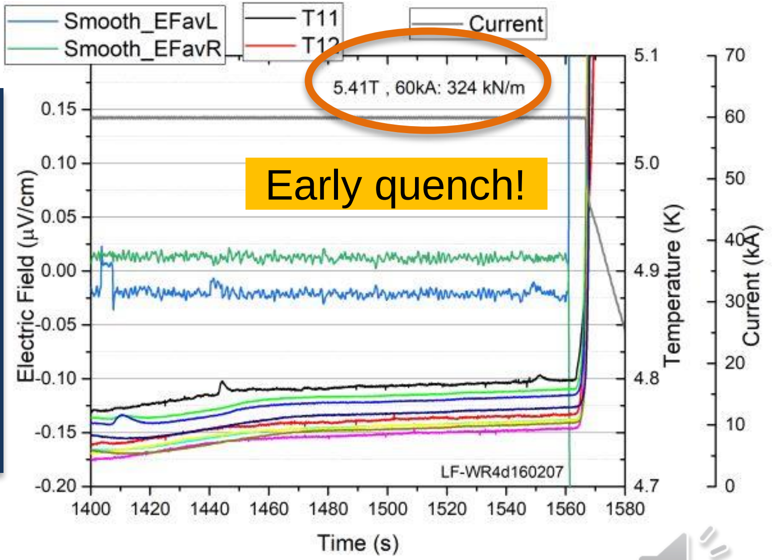
At the same E.M. load the measurements at higher current → quench

→ The issue seems not (only) the e.m. load, but especially the current:



#783 cycles of electromagnetic loads @ 9T X 40kA=360kN/m were applied to the sample



LF-WR4 DC results

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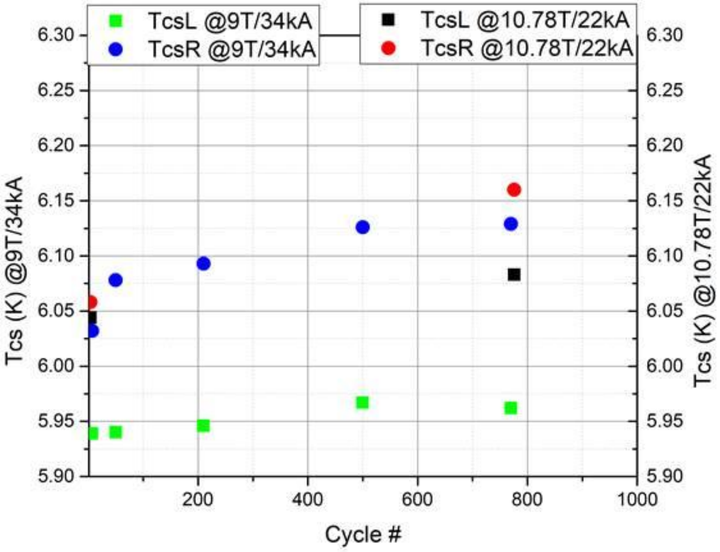
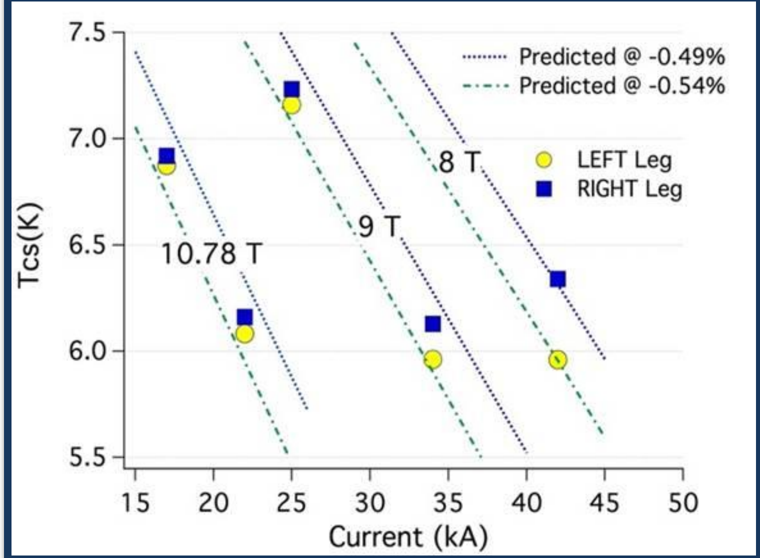
Measurements could not reach operating conditions but → at lower currents (34kA and 22kA) → **no degradation with cycling**





After cycling:

T_{cs} data described by ε_{eff} = - 0.54% to - 0.49%

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Inductive T_{cs} test before and after E.M. cycles

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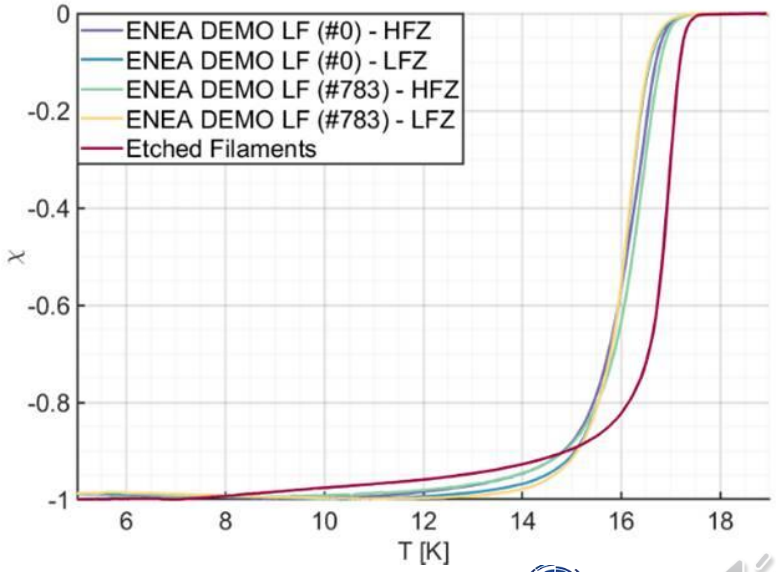
Pick up and excitation coils installed on the right leg: HFZ and LFZ → detect a signal proportional to the magnetic susceptibility of the conductor

I_{exc}=250 mA_{RMS} @11hz

inductive response of the conductor: recorded while slowly increasing the sample temperature from 4.2 K to ≈ 25 K and then decreasing it back to 4.2 K

Comparison between susceptibilities of the etched filaments and of the ENEA DEMO LF conductor at the beginning and at the end of the test campaign



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Tc and strain distribution inside LF-WR4

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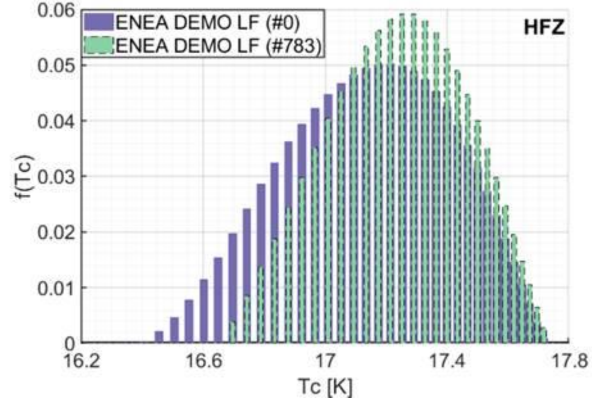

inductive measurements elaboration are by SPC

T_c distribution

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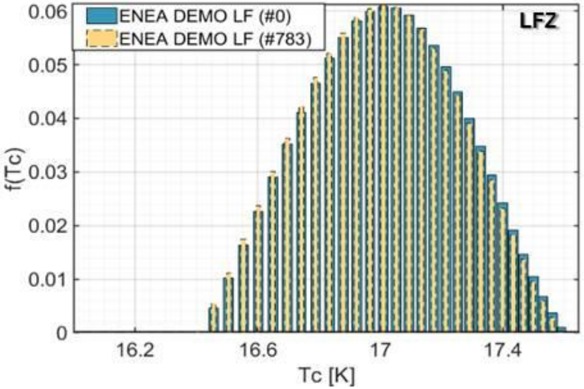
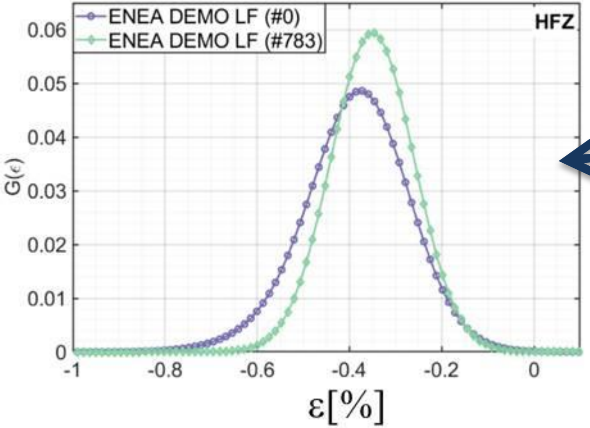
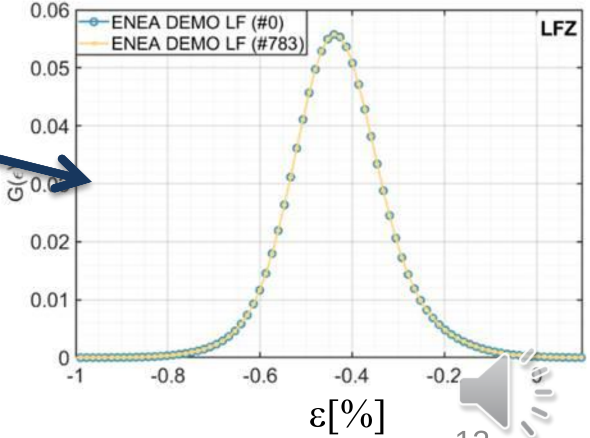




strain distribution

narrow ε_{th} distribution around the mean value → it does not broaden after cyclic loading → true both for HFZ and LFZ



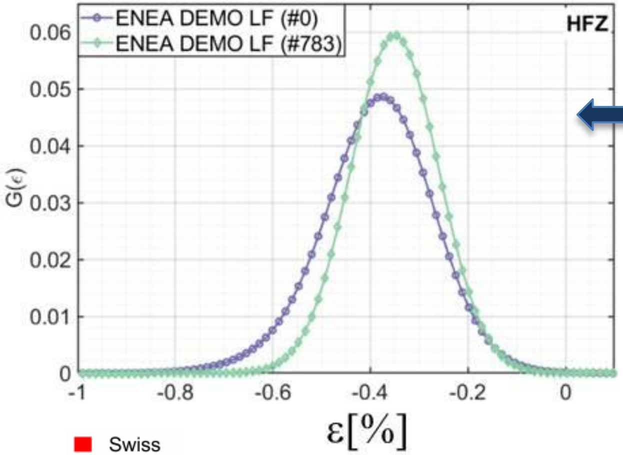
C. Calzolaio, "Irreversible Degradation in Nb3Sn Cable in Conduit Conductors," PhD Thesis, 2013.

Arend Nijhuis, 'TF conductor samples strand thermo mechanical critical performances tests', Final Report, MAG-MCD-4.3-T004-FD, EFDA_D_2M5SMM, Dec 2015, https://idm.euro-fusion.org/?uid=2M5SMM.

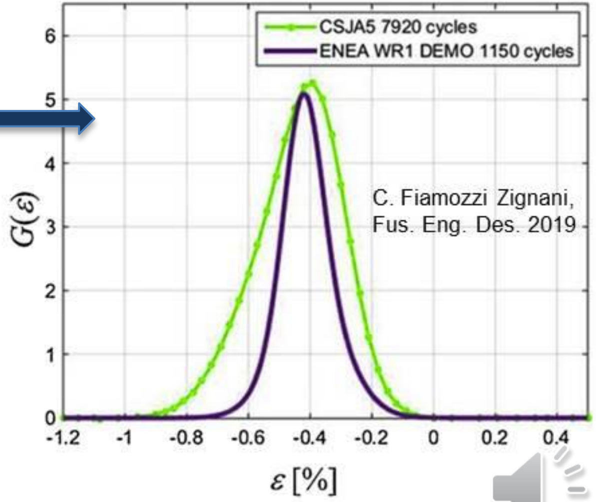
LF-WR4: mean value width of the strain distribution

	HFZ		LFZ	
cycle	μ [%]	σ [%]	μ [%]	σ [%]
#0	-0.38	0.10	-0.43	0.09
#783	-0.35	0.09	-0.43	0.09

relatively <u>low mean absolute value of ε_{th}</u> in compression compared to other types of conductors (e.g. the W&R ITER conductors)



Congruent with HF-WR1 results → same design approach: rectangular CICC with long twist pitch and low void fraction)



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Summary on LF-WR4 characterization

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- LF-WR4 prototype conductor tested at Sultan facility: both DC and AC characterization→ here only DC characterization is presented

- After microtomography and measurements analysis:

No strands damage, small movements in the collar are possible, but **at the same E.M. load and lower currents the transition appears smooth→ the quench is likely due to current sharing issue among strands**

DC characterization gave important feedbacks on LF CICC design →
Possible solutions: sc strands closer together or «overdesign» i.e. manteining a minimum fraction of sc in cross-section

CICC design with rectangular geometry, low V.F. and long twist pitch →
T_{cs} with relatively narrow strain distribution and stable vs cycling

Thank you

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