MAG-4.2-T011-D002
Test of R&W Prototype Joint

WPMAG Final Meeting 2019

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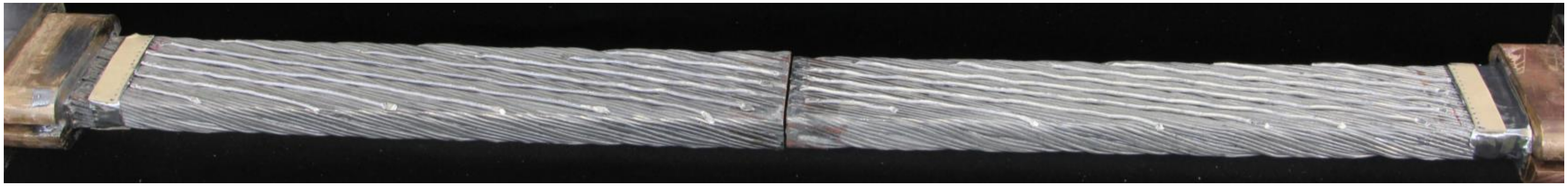
Outline

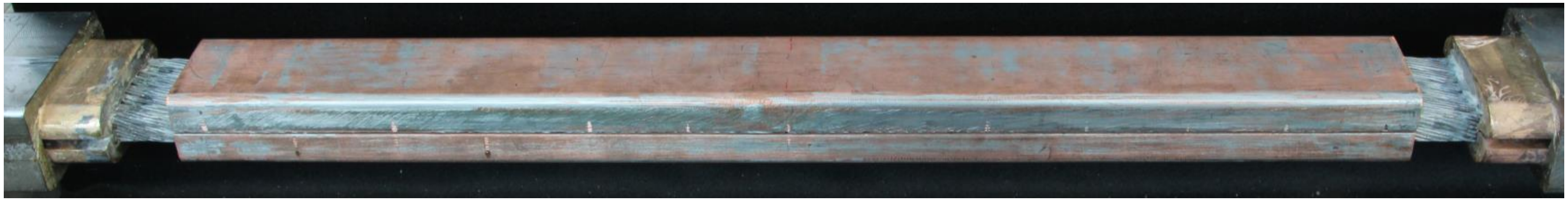
- Background of RW2 joint
- RW2 joint using diffusion-bonding technique (RW2J2)
  - Assembly
    - Cables preparation before bonding
    - Diffusion bonding
    - SULTAN sample
  - Test results
    - Electrical resistance
    - AC losses ⊥ and ∥ to the broad side
  - Conclusions and perspectives

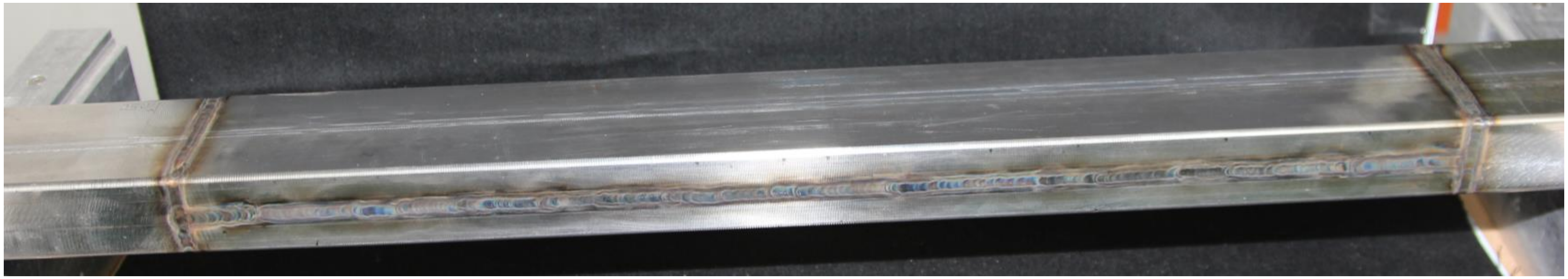
EPFL

Background of RW2 Joint

- In 2017 failed test of a butt-joint with superconducting bridges (RW2J1). Resistance 3-13 nΩ at 0-11 T







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RW2J2

- Inter-layer joint for React&Wind cables → joint during winding
- Overlap geometry

- Target $R \leq 1\ n\Omega$ at operating conditions, $B = 8\ T$ and $I = 63.3\ kA$
- Diffusion bonding joint (N.B. cables already heat treated) → no solder, no flux agents, no indium wires.
- Techniques/tools compatible with in situ assembly, including:
  1. Copper spraying method to flatten the surfaces
  2. Clamp to keep pressure, ≈30 MPa
  3. Oven to keep temperature, ≈650 °C

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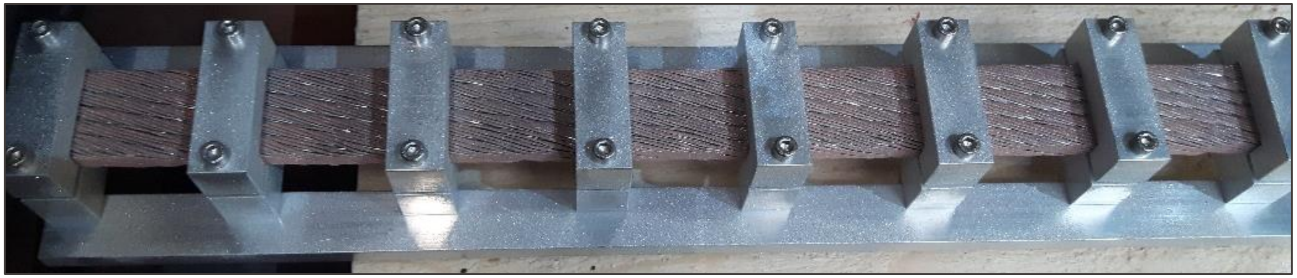
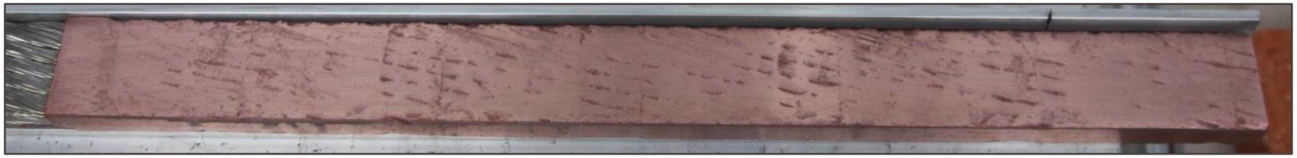
RW2J2 – 1. Thermal copper spray



- Aluminum clamps & bars as support
- Sandblasting & copper-spray in multistage
- Surfaces milled flat

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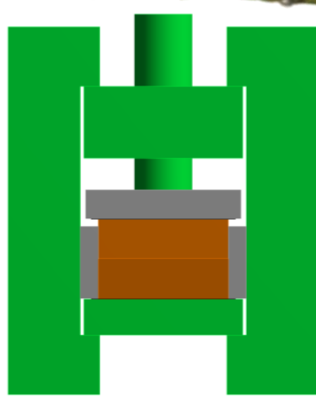
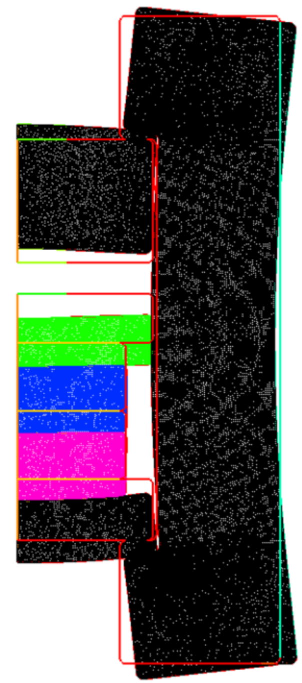
RW2J2 – 2. Clamp

- Target joint pressure @ 650 °C is 30 MPa
- Clamp design criteria:
  - Disassembly after diffusion-bonding
  - Joint pressure homogeneity
  - Choice of materials such that $p=24\ MPa$ @ 20 °C → $p=30\ MPa$ @ 650 °C



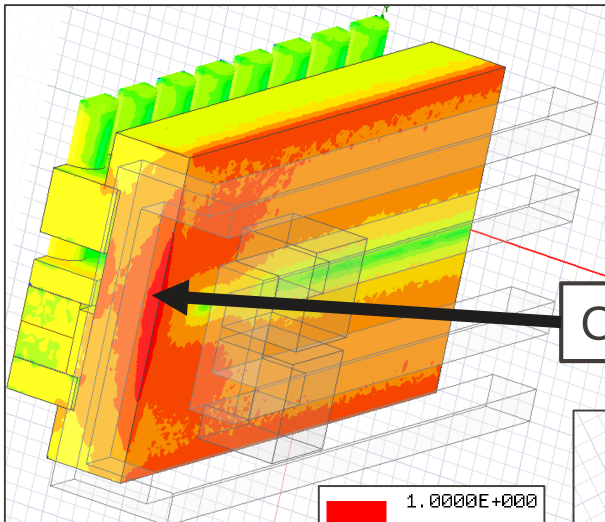
Materials:
- Inconel 600
- Stainless steel
- Glass-fiber
- Cable



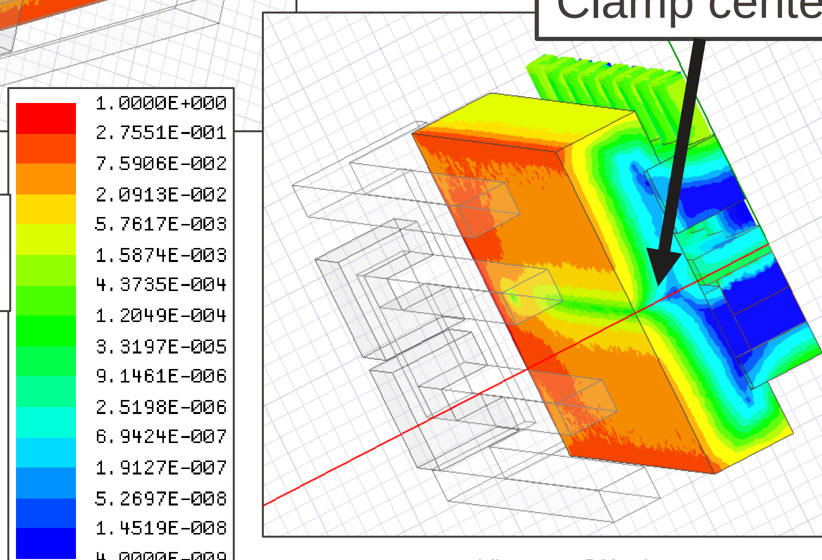
Displacement amplification factor=50

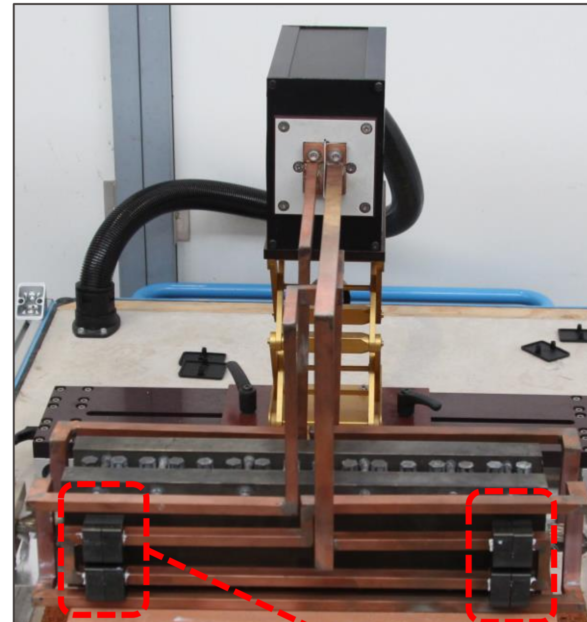
RW2J2 – 3. Oven to keep temperature (I)

- Portable inductive copper oven
- Inductors optimized → cable temperature as homogeneous as possible



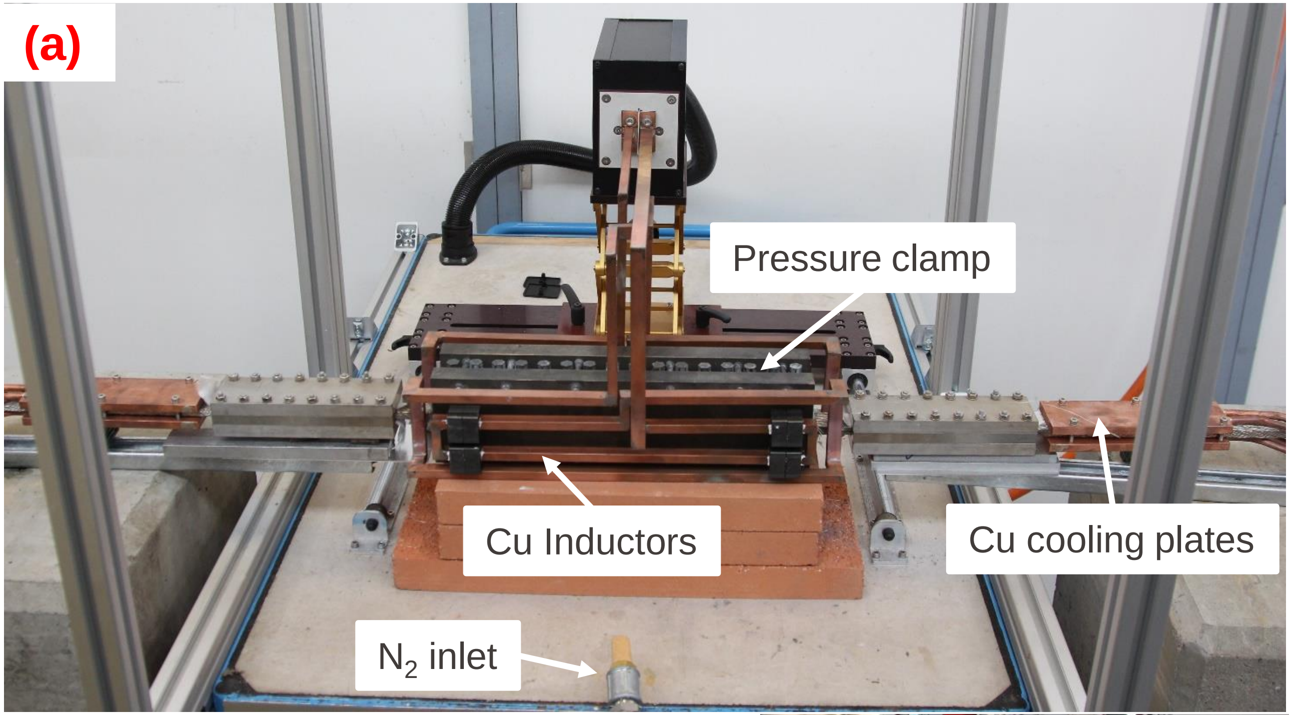
- $f=52.3$ kHz
- $P=4.6$ kW

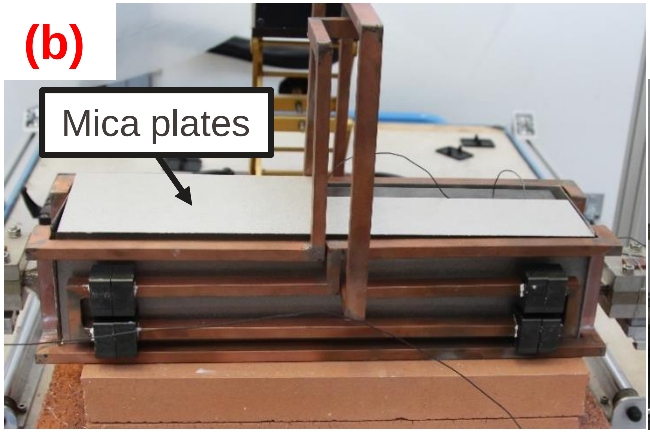


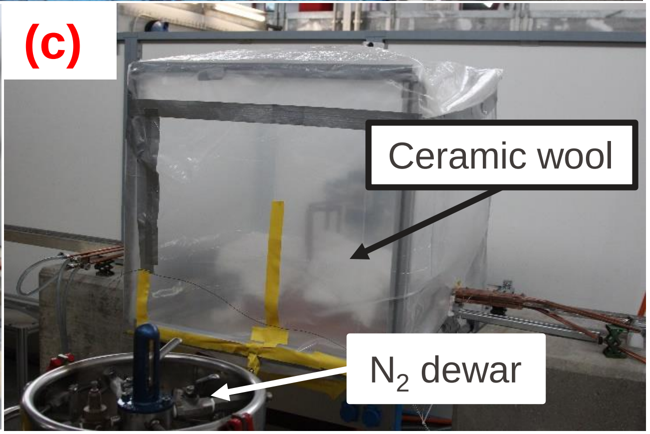


Ferrite blocks focus field lines

RW2J2 – 3. Oven to keep temperature (II)







a) Oven and cable ends active cooling

b) Mica plates shield from thermal radiation.

c) Inert atmosphere with N_2

- Cable T @ steady-state ($P=4.6\ kW,\ f=52.3\ kHz$):
  - 690 °C @ cable center
  - 620 °C @ cable ends
  - 20 °C @ Cu plates
- Times:
  - 1.5 h to get steady-state
  - 2 h of diffusion-bonding
  - 6 h cool-down

$f=52.3\ kHz,\ P=4.6\ kW$

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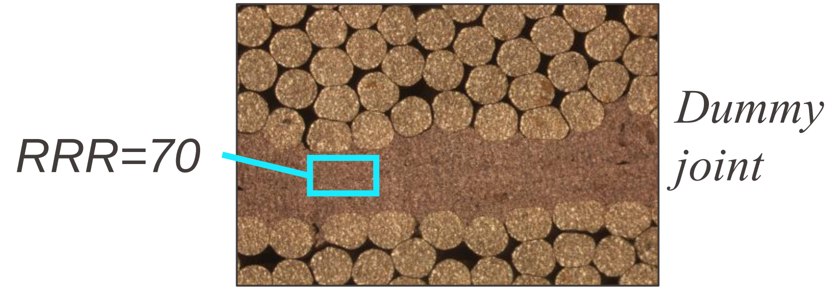
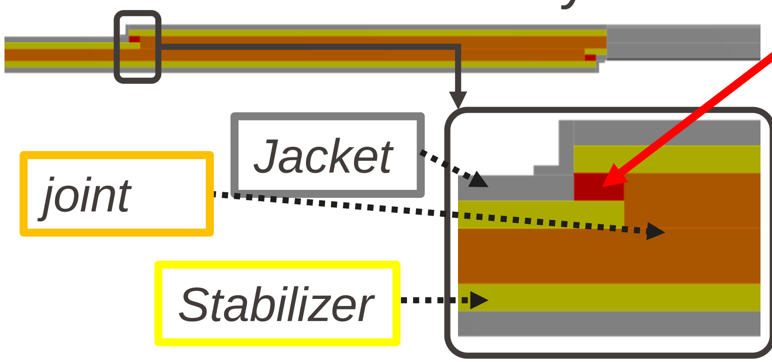
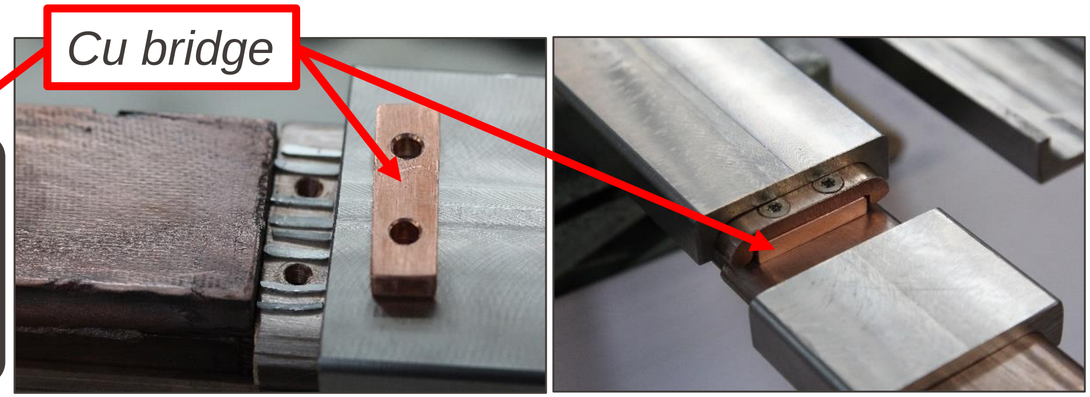
RW2J2 – SULTAN sample

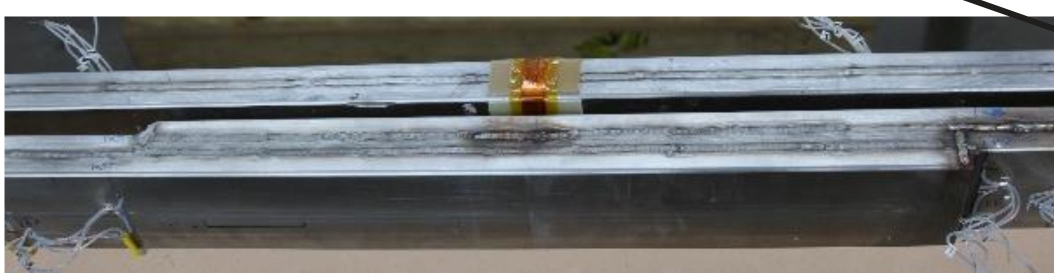
- Stabilizer is machined according to joint dimensions
- Copper bridge with indium ensures full matrix stabilizer electrical continuity

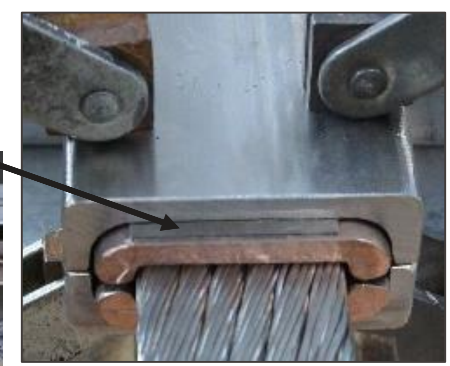






- Cable preload with thin steel foil between jacket and stabilizer
- Steel end caps and bars are welded to the jacket





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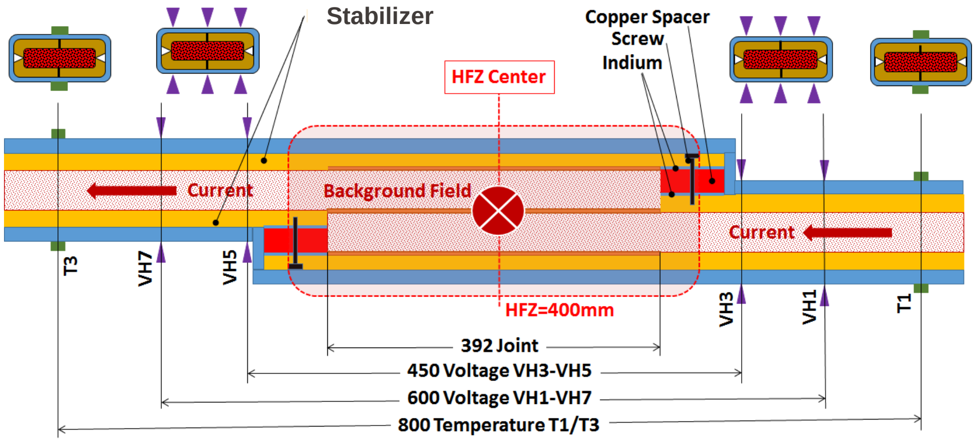
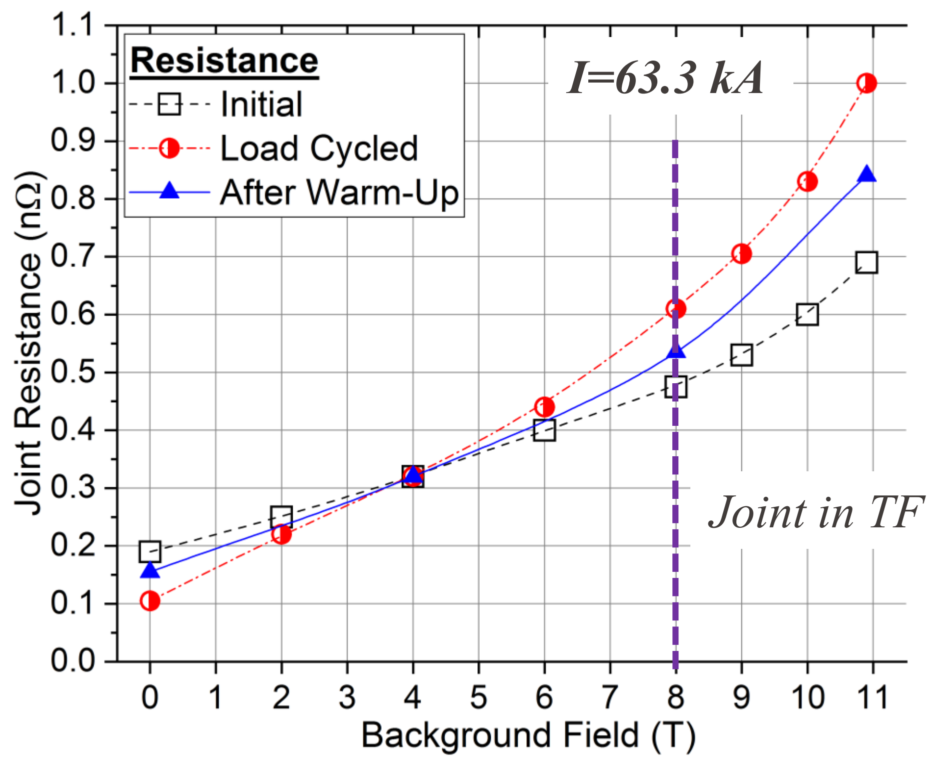
Test results – Electrical Resistance



- V-taps arrays at 450 mm and 600 mm. *R* @ different *I-flat-top* and *B*

- *R(B)* behavior according to Cu magneto-resistance for the "initial" curve
- Higher difference between R_{450mm} and R_{600mm} after cycling (8Tx63.3kA=506 kN/m). We suspect damage @ joint sides



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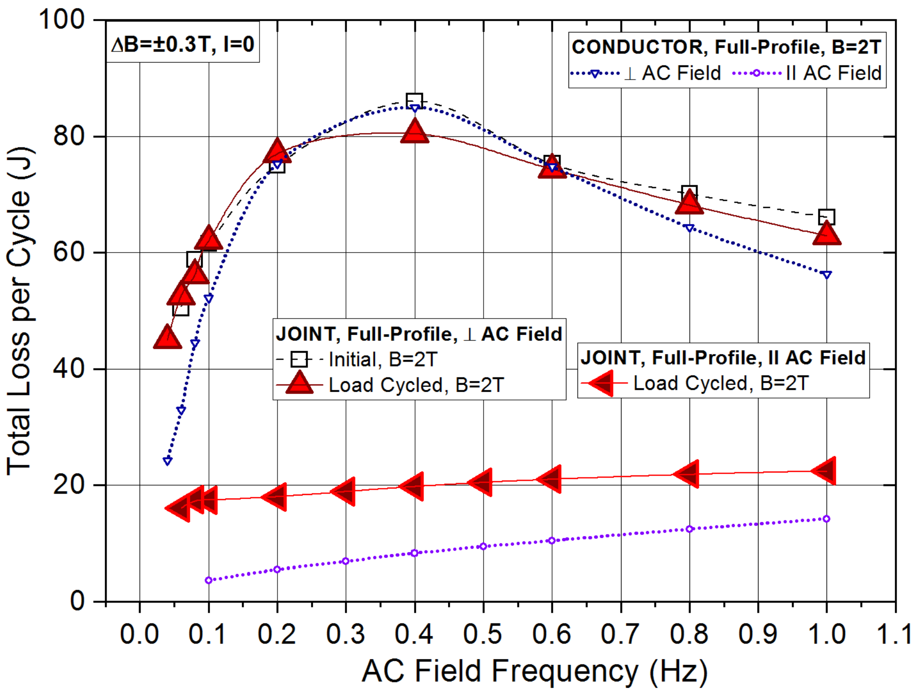
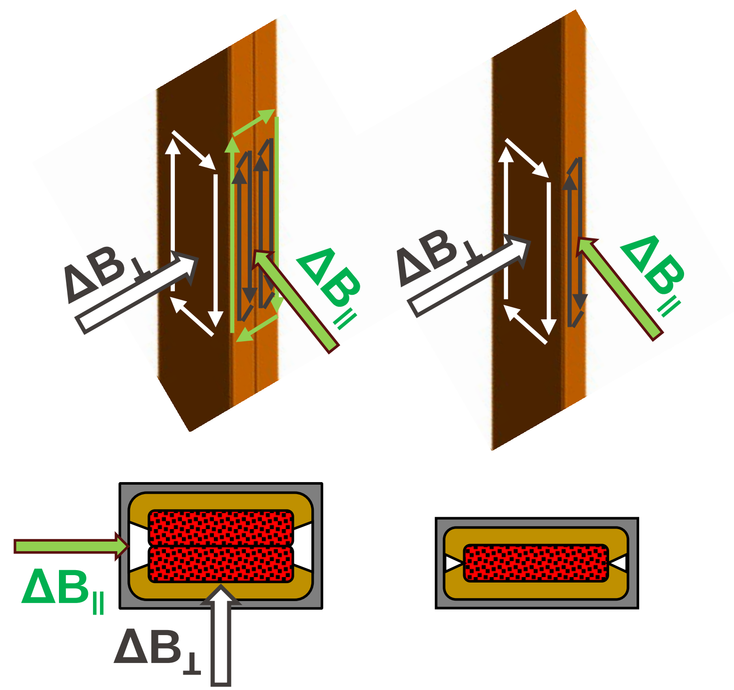
Test results – AC losses and Transient Stability Test

- Comparison between joint and conductor at B=2 ± 0.3 T sinusoidal pulse
- AC field ⊥ broad face
  - No screening @ lower f → joint AC losses ≈ twice as conductor ones
  - Screening @ higher f → joint and conductor losses are similar
- AC field ‖ broad face: new current loops make comparison with conductor not scalable
- Transient stability test at B=8 T, I=63.3 kA → quench in conductor leg if $dB/dt>17.6$ T/s in 128 ms. Deposited energy in joint 65 J





Conclusions and perspectives

- MAG-4.2-T011-D002 completed
- We have a joint reference for layer-wound DEMO RW magnets

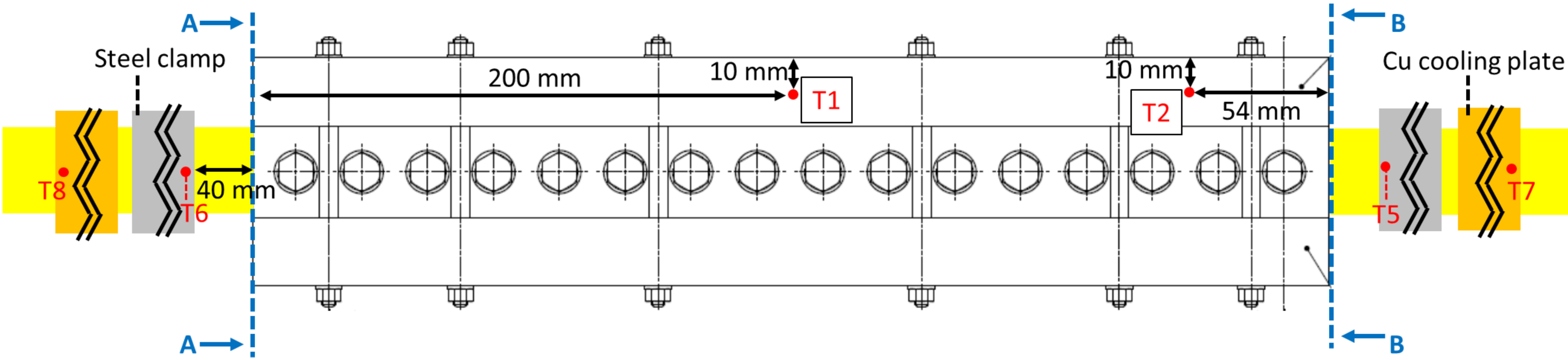
Further R&D

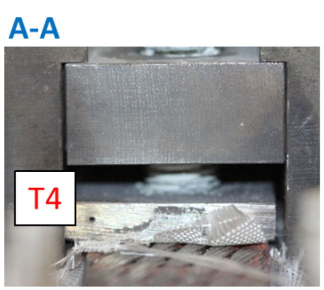
- Further characterization of the joint
  - Mechanical tests with KIT (TS for KIT)
  - Micrographs to study joint uniformity
- The mechanical design of the joint (jacket, stabilizer, fillers) can be improved
- A new joint may be prepared using RW3 late next year

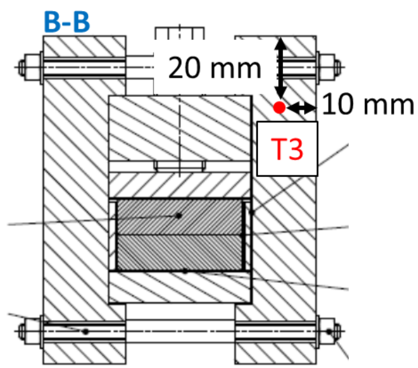
Backup

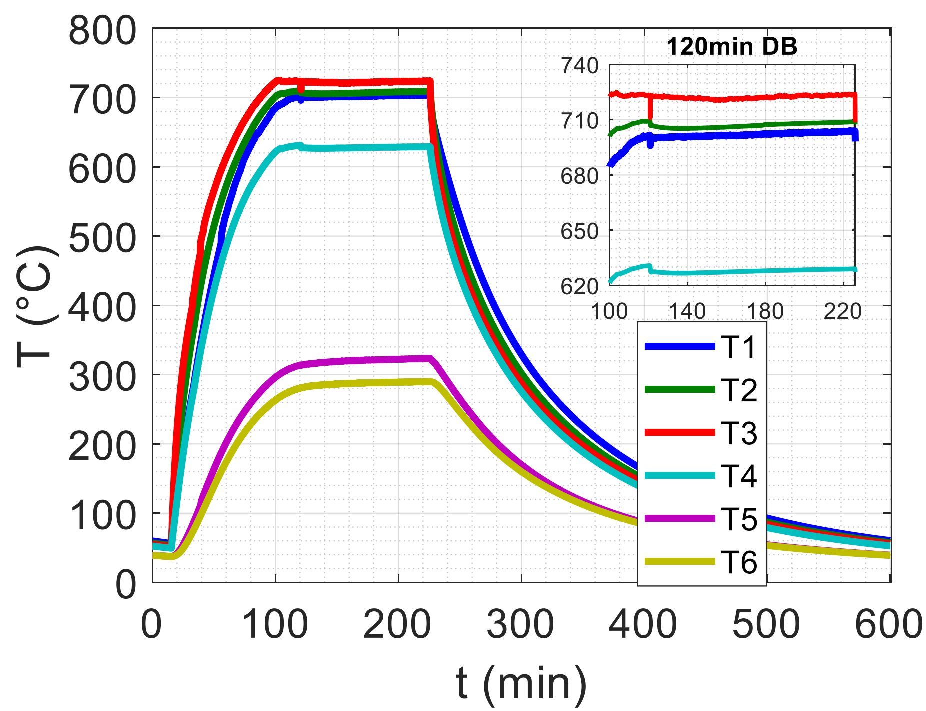
- Measuring RRR sprayed copper

- Diffusion bonding temperature distribution









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