Soldered and diffusion-bonded splices between Nb_3Sn Rutherford cables for graded high-field accelerator magnets

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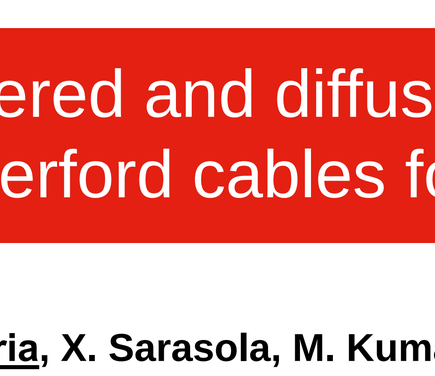
1) Splices between cables for FCC

- High field (HF) magnets might require coil grading to increase magnetic field and decrease magnet cost → splice between HF and LF
- Splice characteristics:
  - Low resistance (<1 nΩ) @ B>10 T, I/I_c>1/3
  - Good mechanical strength
  - Low space availability if internal joint

C. Lorin et al., IEEE, 2018

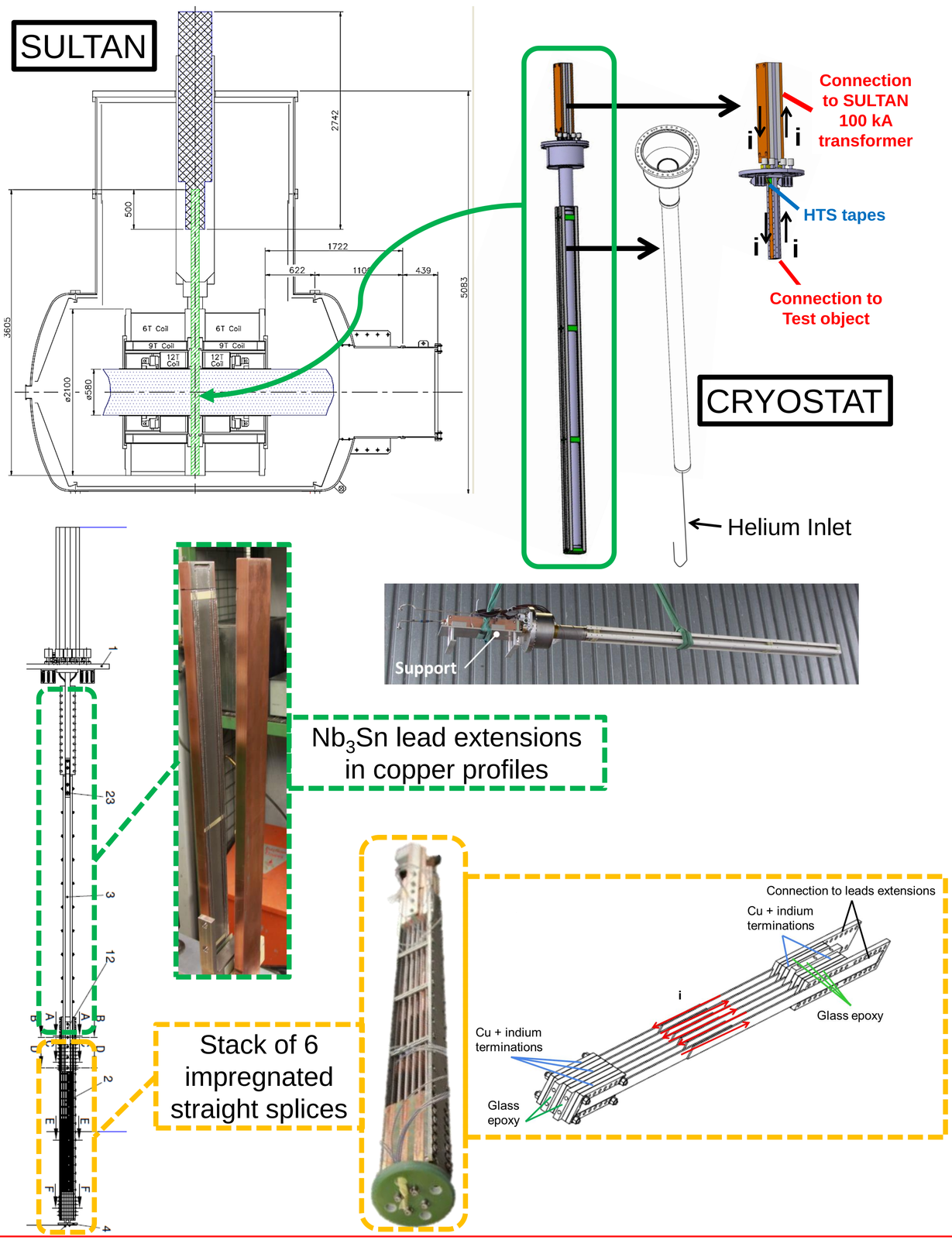
Internal vs external joints

Courtesy C. Lorin



2) SULTAN facility and sample holder

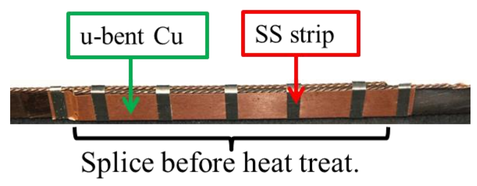
- Field generated by 3 pairs of horizontal split solenoids:
  - Bmax=10.905 T in test well
  - Homogeneity (2%) along ±200 mm
- Test environment:
  - Vertical test well, rectangular pipe 144 mm x 94 mm
  - Max sample current 100 kA through NbTi trafo
- Sample cryostat
  - 2880 mm-long cylindrical stainless steel chamber (OD = 88.9 mm, ID = 83.7 mm)
  - Temperature regulated 4.5 - 50 K using forced-flow helium (p_{He}=10 bar)
  - HTS current adapter connects test environment to trafo
- Splices tests:
  - Possibility to test stacks of straight splices samples
  - Bent splices integrated in low-number-of-turns model coils

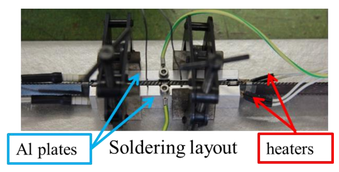


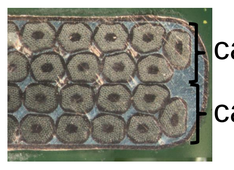
3) Soldered internal splices

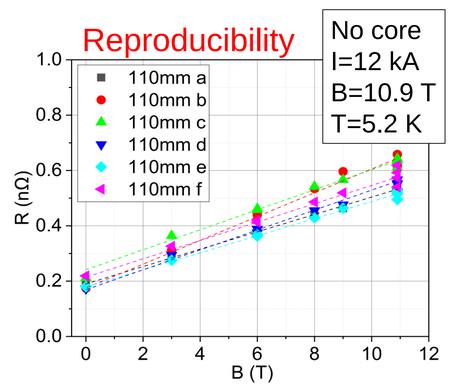
SULTAN test

- Splice after heat treatment (carried out in Ar atmosphere; cable with glass-fiber and mica)
- Cable used MQXF (40 strands, steel core, 109 mm twist-pitch, 1.53 thick, 18.16 mm wide)

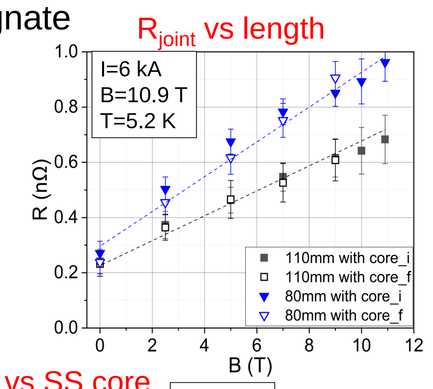


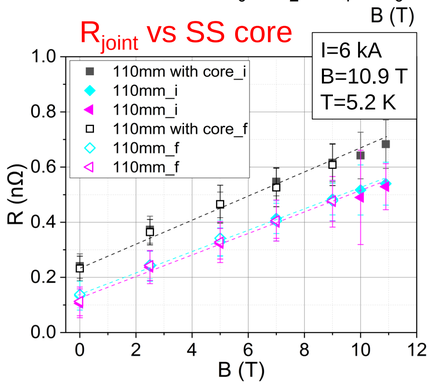






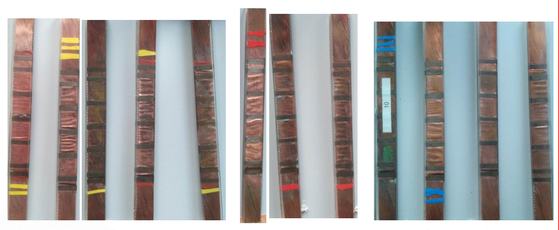
- Straight samples preparation:
  - (core removed)
  - Wrapping splice with 50 μm Cu foil
  - Crimping with stainless steel strips
  - Soldaflux K ($ZnCl_2$+NH_4Cl) @ room temperature
  - Solder wire Sn95Ag5 while heating
  - Put samples into stack and impregnate





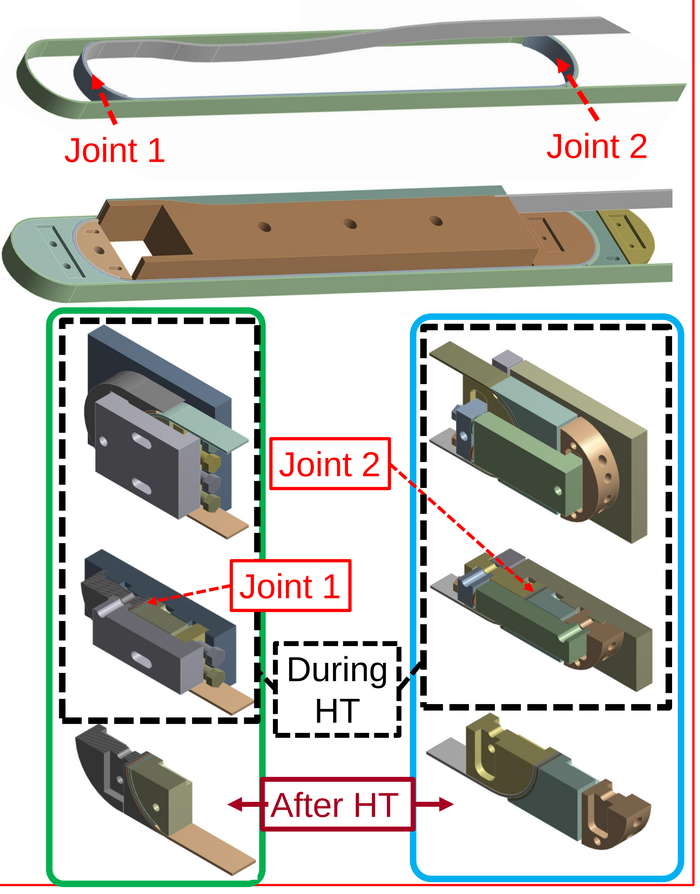
Corrosion tests

- Only aggressive flux gave good splices → potential corrosion
- Monitoring corrosion of samples
  - Rinsed with hot water after splice
  - Rinsed with acidic solution
  - Rinsed with basic solution
- Samples were impregnated with araldite 10 days later



4) Diffusion-bonded (DB) internal splices

- Joint during heat treatment (HT) with need of high p≈30 MPa
- No flux → "clean" splice
- Successful tests in SULTAN on straight samples: 0.3 nΩ @ 10.9 T
- Next step test bent splice. Clamps design criteria:
  - p distribution uniformity
  - Combine steel and Inconel to gain p with thermal expansion
  - Integration in coil for winding continuity
  - Demountability



5) Conclusions

- Grading HF Nb_3Sn dipoles might be beneficial to decrease the cost.
- Cryostat and HTS adapter can be used in SULTAN to test straight and bent splices.
- Soldered splices reach target resistance, but only by using aggressive flux. Its corrosive effects on impregnated splices is being monitored.
- Tests on straight diffusion-bonded splices show that that they are a potential "clean" solution. Their feasibility in bent geometry will be tested in a small dipole to test in SULTAN.

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