Abstract
The Swiss Plasma Center (SPC) has developed a layout of Toroidal Field (TF) coil for EUROfusion DEMO tokamak, based on the reference tokamak baseline of 2015. Each TF coil winding pack is wound with graded Nb3Sn conductors and consists of 12 single layers, connected in series by means of inter-layer graded joints. The design of inter-layer joints takes into account the react-and-wind (R&W) manufacturing technique for fabrication of TF coil winding pack, i.e., the inter-layer joint is prepared with use of two already heat treated Nb3Sn conductors. The development, preparation and test of inter-layer joint at SPC is performed in frame of R&D program for TF of EUROfusion DEMO tokamak.

The high-grade Nb3Sn TF conductor, operating at 63.3 kA and 12.2 T (Tcs=6.5K) was tested at SPC, and afterwards was used for fabrication of inter-layer joint. The developed TF inter-layer joint is an “overlap-type” joint, which can be fit within the dimensions of TF winding pack. Each strand of two conductors is copper clad by a thermal-spraying technique and then bonded together along the surfaces of cladded copper using with a high-frequency inductor.

Fabrication of Joint

- Two Conductor Ends:
  - Aluminum clamps
  - Sandblasting
  - Arc-spray cladding of Cu, 1 mm
  - Removal of aluminum clamps
  - Sandblasting
  - Arc-spray cladding of Cu, 2 mm
  - Misting: contact side ~1 mm
  - Narrow sides ~0.5 mm
  - Back side ~0 mm

- DB Process (SPC):
  - Overlapping of two prepared ends in the DB fixture, DB fixture is anchored to the h-profile aluminum beam
  - Ceramic blanket, plastic tent
  - Outside the DB fixture – cooling by Cu plates with water (5 l/s), 20°C temperature of conductors
  - DB parameters: 52.3 kHz, 4.6 kW, overpressure of Argon
  - In 1 hour: 690°C in the center and 690°C at the edge of fixture
  - 2 hours to complete DB process (trials with dummy conductors)
  - Natural cooling to room temperature

- Assembly of Joint in the Sample:
  - The sample with the joint is assembled with terminations similarly as usual SULTAN sample
  - The stabilizer protrudes with respect to the conductor butt to ensure the electrical contact of stabilizer at two joints
  - Such a connection is done by a copper bridge and indium

- Fabrication of Sample
  - The joint is pre-compressed using a 0.2mm thick stainless steel tape inserted between the outer jacket and the stabilizer, analogous to RW2 conductor
  - The nest jacket sections are TIG welded around the joint
  - The conductor containing the joint is connected to the already tested conductor RW2 by bottom joint

- Resistance of Joint
  - The initial resistance of joint at operating condition of 8 T field and of 63.3 kA current is 0.48 mΩ, the resistance increases to 0.61 mΩ after applied 1000 cycle load and becomes 0.54 mΩ after thermal cycle to room temperature. At operating 8T field and 63.3 kA current the temperature of joint increases by 0.04 K after cyclic loading and after thermal cycle as well. At maximal 10.9T background field: the resistance varies from initial 0.69 mΩ to 1 mΩ after cyclic loading and to 0.84 mΩ after thermal cycle.

ASSESSMENT: $R_{0}=R_{0(T=0)}+R_{0(T=8T)}/2$, includes the portions of conductor leaving the joint 450 mm and 600 mm Measurements: Initial, after cyclic loading (8 T x 63.3 kA, 1000 cycles) and after intermediate warm-up

The proper mechanical transition/support is required for those portions of conductor, which are at the sides of joint.

Conclusion
• The successful technique on preparation of high-current inter-layer joint, working at high magnetic field and suitable for TF coil winding process has been developed at SPC for TF coils of EUROfusion DEMO Tokamak
• The resistance of developed and tested joint at operating 8T field and 63.3 kA current is about 0.5 mΩ, less than required 1nΩ
• The measured joint AC loss is comparable to conductor AC loss at frequency >8Hz and almost doubled at frequency <0.3Hz, but the joint AC loss are reduced by a factor of two at operating 8 T field
• The transient stability test for joint was performed at operating conditions up to 17.6 T/s applied in 128ms, with a deposited energy of 264 J. No voltage take-off happened in the joint, RW2 conductor was quenched
• The design of joint should be improved at the conductors leaving the joint, providing the proper mechanical transition/support for the portions of conductor, which are at the sides of joint
• SPC plans to investigate the mechanical strength of this joint, including a cyclic tensile mechanical loading