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Helical Coil Design and Development with 100-kA HTS STARS Conductor for FFHR-d1

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There is considerable progress in conceptual design studies of the helical fusion reactor FFHR-d1. The continuously wound helical coils (major radius 15.6 m) employ the 100-kA-class HTS (high-temperature superconducting) STARS (Stacked Tapes Assembled in Rigid Structure) conductor using a simple-stacking technique of YBCO tapes. A prototype STARS conductor reached 100 kA at 5.3 T and 20 K. A bridge-type mechanical lap joint is developed to realize the "joint-winding" that connects and winds segmented conductors. The joint resistance measured in the sample assures that an additional electricity of <3 MW is required in the cryoplant for cooling 3,900 joints. 3D printing confirms that the unit length of a segmented conductor can be a helical pitch in maximum. If one joint is fabricated in one day, the onsite winding would be completed in <3 years. Vacuum pressure impregnation is skipped in the HTS option. High cryogenic stability of HTS intrinsically reduces the quench risk and the massive copper stabilizer further enhances the stability. The sample did not quench when the current density in the copper stabilizer was <85 A per square mm. Numerical analysis is being conducted to verify these characteristics. In case of a quench of the helical coils, a numerical simulation shows that the hot-spot temperature is <200 K with a discharge time constant of 30 s and a ~20 s delay for a normal-zone to expand. When an emergency discharge starts, the voltage generation is <3 kV if the two helical coils are divided into 30 blocks. A good organic or inorganic insulation should be installed between the stainless steel jacket and copper stabilizer. Helium gas flow through the four corners of the conductors is considered for the cooling scheme. The nuclear heating by fusion neutrons is more intense on the inboard side of the torus because of the thinner blanket space than on the outboard side. A pair of sub-helical coils, named "NITA coils", with opposite-directed currents, are used to enlarge the blanket space to 1.08 m. The maximum nuclear heating is ~3 W along the longitudinal cooling path of ~18 m on the inboard side. In contrast, the joule heating at a joint is ~9 W, which is cooled by ~0.3 g/s of helium gas flow through the outboard channels. Numerical simulation is conducted to examine the flow distribution in multi-paths with non-uniform heat generation.

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