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JT-60SA Tokamak Toroidal Field Coils Quench Analyses with STREAM New Analytical Model

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For the commissioning of JT-60SA Tokamak (Japan, beginning of 2021, Project decided in the framework of Broader Approach to ITER Tokamak Project), all the superconducting coils have to be energized with a set of reduced and then nominal current after they became superconducting at 4.5 K cooling temperature with supercritical helium forced flow in Cable-In-Conduit Conductors (CICC).
An important Issue is to predict the Joule Energy for the Toroidal Field Coils (TFC), in case of an incidental quench –transition from superconducting to resistive state- arises, as well as the respectively "hot spot"temperature, the maximal conductor temperature reached during the quench development.
For this analysis a Superconductor Thermohydraulical and Resistive Electrical Analytical Model (STREAM) new code has been developed. This code takes into account in first phase an isentropic compression of the so called "cold"helium volume by the "hot"or "heated"volume in the coil; the second phase being an expulsion (over pressure threshold) trough exhaust circuit of helium with limits to the sound velocity or atmospheric pressure. The propagation of quench, considering the "normal length"(quenched length of superconductors) is governed also by analytical and explicit correlation and model. STREAM analytical model permits more rapid quench calculation than SuperMagnet code (CryoSoft, CERN, finite element numerical model), including THEA (Thermohydraulic 1-D CICC) and Flower (external cryogenic cooling circuit model) which has also been used for comparison.
Some analyses have been performed on the acceptance quench test realized at the Cold Test Facility (CTF, CEA Saclay in 2018) on the spare coil TFC02. The quench test Joule energy has been evaluated with STREAM and SuperMagnet. The different calculation results, in particular helium temperature and pressure in upstream and downstream manifold are presented here and are in good agreement with the measurements.
In Tokamak configuration at nominal current and at maximal magnetic field location (at inlet of CICC over few meters), the initiation of the quench (with Minimum Quench Energy - MQE) is set as input on each first turn of the 12 Pancakes of the coil's Winding Pack. The integrated and detailed Joule Energy value depends strongly on the number of the entirely and rapidly quenched pancakes (maximal quench propagation velocity near 16 m/s). The maximal conservative quench Joule energy is determined to be near 7 MJ (12 times the maximal energy per pancake), which has to be compared and added to the eventual eddy currents losses, equal to 11 MJ, in the whole 18 TF Coil thick casing in case of a fast current discharge.
This analysis has been useful also for the JT-60SA Tokamak magnets energization and commissioning phase. This analysis confirms also, among others, that STREAM analytical model is valid for CICC coils cooled by forced flow of supercritical helium and can be useful for tokamak magnets protection during quench event and safe operation (WEST and ITER).

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