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Thu-Af-Po.10-03: [Invited] Towards a reduced Helium content cryogenic cooling scheme at 4.5 K for CERN's FCC-hh accelerator

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In the framework of the Future Circular Collider (FCC) study at CERN, a conceptual design of a cooling scheme for Nb_3Sn-based accelerator magnets operating at 4.5nbsp;K is proposed for the FCC-hh (hadron) configuration. This alternative, at a higher operating temperature than the baseline at 1.9nbsp;K using Heliumnbsp;II, is motivated by a strong commitment to a more energetically sustainable machine, while ensuring compatibility with the tunnel structure envisaged for the FCC-ee (lepton) configuration, and providing a technically viable solution for the required superconducting magnets.
In the proposed cryogenic scheme, cooling is achieved by a forced flow of supercritical helium at 3nbsp;bar, 4nbsp;K, through channels embedded into the cold mass structure. The same stream runs along the entire magnet cooling sector, warming up as it absorbs heat generated by or deposited on the magnets. To mitigate the intrinsic temperature increase, the supercritical stream is periodically re-cooled by heat exchange with two-phase helium reservoirs at a lower saturation pressure than the supercritical stream, at intervals coherent with the cell lattice. This creates a saw-tooth temperature profile along the sector, and a quasi-identical cryogenic environment for each of the cells. On the return line back to the cryoplant, small portions of the returning mass flow are expanded into the two-phase area to fill the re-cooling stations. The characteristics of the helium gas recovery line of the re-cooling stations determine their saturation temperature, and as a result, of the supercritical helium stream. The temperature rise in the fluid is limited to 4.5nbsp;K to allow for sufficient temperature margin for magnet operation.

The study is carried out for the latest configuration of the FCC-hh machine, considering Nb_3Sn superconducting magnets with an operational magnetic field of 14nbsp;T, for a center-of-mass energy of 90nbsp;TeV with a magnetic filling scheme of 87%. The updated heat loads are presented, and the system parameters, along with longitudinal and expected radial temperature gradients in the magnet structure, are evaluated. The move from 1.9nbsp;K operation, making extensive use of Heliumnbsp;II, towards 4.5nbsp;K using single-phase helium significantly reduces the overall cryogenic power consumption by at least 30%, and the machine's helium inventory by 50% with respect to the baseline scenario at 1.9nbsp;K. Other advantages, such as a simplification of the cold mass structure and the relaxation of access exclusion zones due do the more manageable helium content in case of release are analyzed and compiled. The challenges associated with this cryogenic cooling scheme, which has so far not been implemented in such a large-scale accelerator, are addressed.

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