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Cryogenic Cooldown Performance of the GE HealthCare (HTIC) Compact 7 T MRI Magnet

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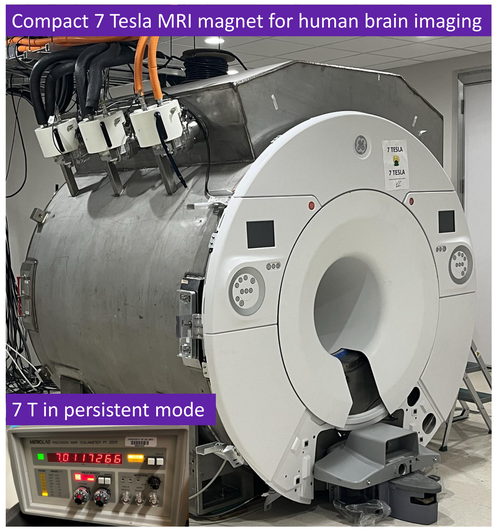
Abstract

A compact 7 Tesla ultra-high field and fully sealed low cryogen magnetic resonance imaging (MRI) system has been developed for human brain imaging at the GE HealthCare Technology & Innovation Center (HTIC), Niskayuna, USA. The cold mass (magnet coils + coil support structure) has been cooled down to 4 K using only 12 Liters of liquid helium liquified with three SHI GM type RDE-412 two-stage cryocoolers. A gas tank has been charged to 15 MPa with pure helium at room temperature. Helium vapor is liquefied with several recondensing cups in contact with the cryocooler second stage. Recondensing liquid helium is collected in a liquid tank from where liquid helium flows into a closed-loop thermo-siphon system in thermal contact with the cold mass. The first stage of the cryocooler cools the thermal shield down to 40 K. Several pre-cooling lines are wrapped around the cold mass externally connected to an open-loop Bluefors/Cryomech MPC600 fast cold helium circulation system (CHCS). All three cryocoolers and the CHCS operate in tandem to cool the cold mass down to 50 K within 16 days. Upon reaching 50 K, the CHCS is turned off and cooldown continues with all three system cryocoolers, reaching a base temperature of 4 K within 5 days. This research explains the cryogenic cooling technique adapted for a compact 7 T MRI magnet. The cryogenic system performance during the magnet ramp to the designed magnetic field will be discussed as well.

Introduction

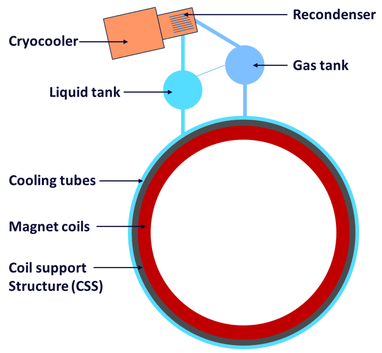
The compact 7.0 T (C7T) is an actively shielded low temperature superconducting (NbTi) MRI system developed under the NIH award U01EB027696. The C7T is dedicated for human brain imaging with a warm bore of 62 cm and the total weight and footprint (mechanical & fringe field) like a clinical whole-body 3.0 T MRI system. The C7T provides better human brain imaging capability and accessibility than existing whole-body 7 T MR scanners. The cryogenic system of C7T magnet requires less than 1% of liquid helium where liquid/gaseous helium remains sealed inside the cooling system without any vent stack. The cold mass cools down using closed-loop thermo-siphon cooling system which liquefies 12 Liters of liquid helium at 4.2 K after recondensation with the three units of SHI GM type RDE-412 two-stage cryocoolers. The open-loop pre-cooling lines have also been installed on the magnet cold mass which are externally connected/disconnected to an open-loop Bluefors/Cryomech MPC600 fast cold helium circulation system (CHCS). Magnet cools down to 50 K in 16 days with GM cryocoolers and the MPC600. The MPC600 is then turned off and disconnected to continue with the magnet cool-down using only GM cryocoolers which takes a further 5 days to cool down to less than 4 K temperature. It takes 21 days total to cool the magnet below 4 K.

Compact 7 T MRI magnet

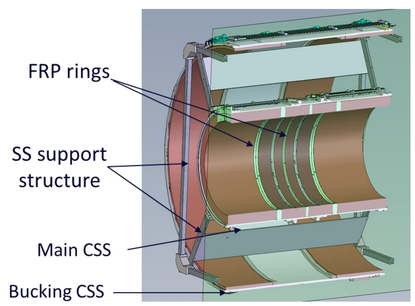


Design parameter	Value
Center field	7.0 T
Peak field	7.7 T
Helium volume	12 Liters
Operating current	448.1 A
Homogeneity	0.6 ppm @ 26 cm DSV
Magnetic energy	16.5 MJ
Axial force (max)	922 kN
Stray field (5 G line)	5 m (axial) x 3 m (radial)
Gradient (max)	140 mT/m
Slew rate	820 T/m/s
Dimensions	2.25 m (L) x 2.25 m (W) x 2.39 m (H)
Weight	~ 8 tons

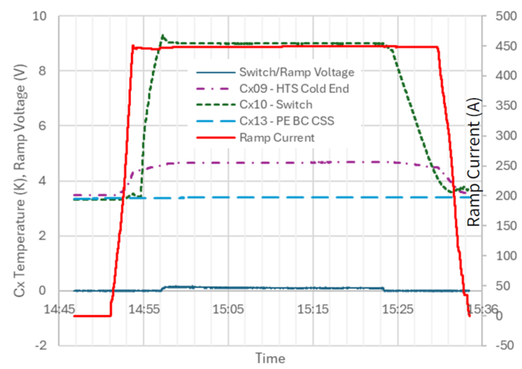
Cryogenic closed-loop fully sealed cooling system of C7T



Cross section view of the C7T cold mass (magnet coils + CSS)



Thermal profile of the C7T magnet during ramp to 7 T field



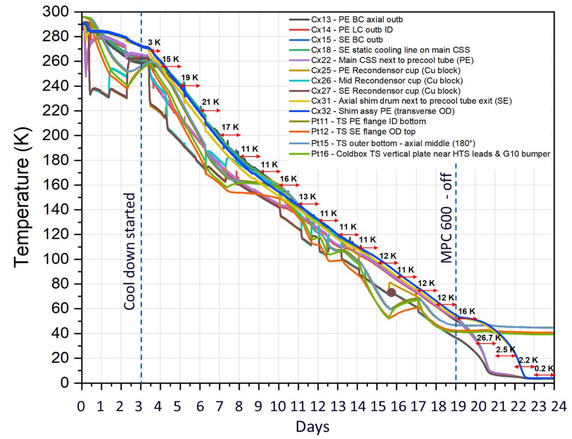
Summary

A fully sealed, thermo-siphon, closed-loop cryogenic system has been successfully developed for the C7T magnet. The cold mass has been cooled down to a temperature range of 3.4-3.8 K using three cryocoolers. In addition, more than 18 Liters of liquid helium have been collected in the liquid tank, with a helium gas charge pressure of 15 MPa at room temperature. The C7T magnet has been ramped to 7 Tesla magnetic field and parked in persistent current mode without any thermal issues. The magnet ride-through test provided a better understanding of magnet operation in the event of a cryocooler failure or a power outage.

Cryogenic performance

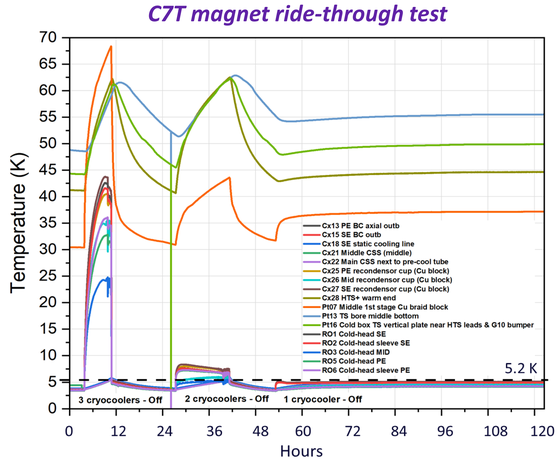
Pre-cooling, 300 K to 50 K using three GM cryocoolers and MPC600 CHCS in 16 days then 50 K to 4 K using only three GM cryocoolers in 5 days. The total cool-down time is 21 days. The thermal shield cools down to 39-44 K whereas the cold mass cools down to 3.4-3.8 K.

C7T magnet cool-down



The liquid tank dryout temperature is 4.54 K and quench threshold temperature of the magnet is 5.2 K. When only one cryocooler is turned off, the cold mass temperature remains at 4.7 K with 6.8 Liters of LHe, allowing the magnet to ramp down to 5 T (almost a 50% reduction in total stored energy) before quenching. Ride-through times when only 2 and all 3 cryocoolers off are 11 hrs and 5 hrs respectively. The most likely event is the failure of only one of the compressors.

C7T magnet ride-through test



Acknowledgments

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