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The latest observations from results of comprehensive computer simulation of the NHMFL 32T all-superconducting magnet quench tests

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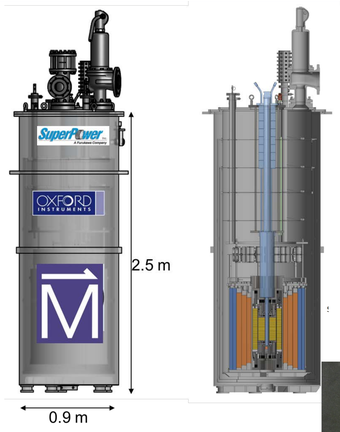
Abstract

The 32T all-superconducting user magnet comprised of a 17T REBCO tape pancake-wound two-nested-coil insert and a 15T LTS multi-coil outsert custom-made by Oxford Instruments, Inc. is now being quench-tested at the NHMFL. The magnet protected-quench behavior was simulated beforehand using a custom-written Fortran computer code. The predictions were used to plan the tests: they enable us to preset safer levels of transport currents and fields to start with and then to gradually complicate the test scenarios responsibly. All thinkable scenarios of the quench tests were simulated and analyzed carefully in detail. The simulation results have not been compared with the measurements in the insert coils yet. – As of now, the first measured data are just being processed.

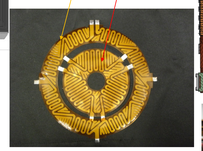
The magnet and its quench protection system

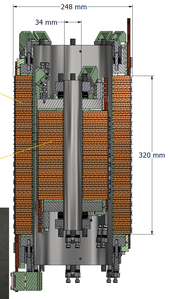


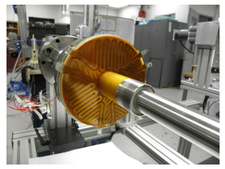
The magnet key parameters:

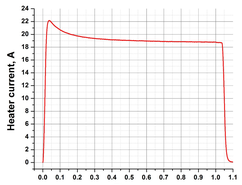
Center field	32 T
Clear bore	34 mm
Stored energy	8.3 MJ
Operating temp.	4.2 K

15 T / 250 mm bore LTS magnet (outsert)
17 T / 34 mm bore REBCO coils (insert, module/double pancake construction), REBCO tapes by SuperPower, Inc.
Separately powered, both actively protected (quench heaters).

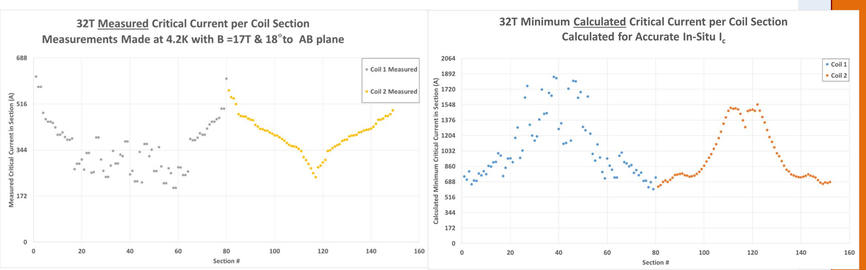








Distributed quench protection heaters between the modules; fired by a set of batteries, a ~1s long pulse.



The actual layout of the insert coils. All pancakes, and even pancakes' sections, are wound with unequal tapes (with somewhat different Ic-values). The "least-quality" tapes are used for the internal modules, but to quench them by the heaters is not easy, since the field angle is very small in the middle resulting in the Ic-value increase in-situ.

Crying need for insert quench protection

The model

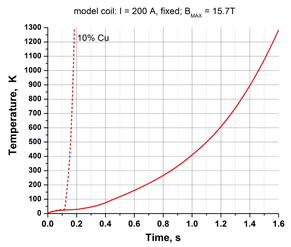
$$\left(A_{Cu}C_{Cu}+A_{SC}C_{SC}+A_{ins}(C_{ins}+f\gamma_p^{He}C_p^{He})\right)\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(A_t\kappa_t\frac{\partial T}{\partial x}\right)+\left[A_tQ_J+A_tQ_{AC\ LOSS}\right]+\sum_{i=1}^{4}\frac{P_i}{\delta_i}\kappa_i^{(ins)}(\overline{T}_i)\left(T^{(i)}-T\right)+P_{1(2)}Q_{HEATER},\ [W/m]$$

x - the coordinate along the spiral path of supercond. tape within a given pancake.

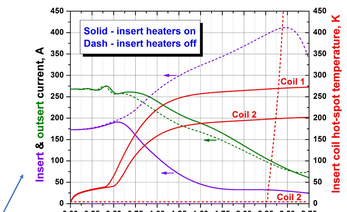
$T=T(x,t)$ – the tape temp.; the tape cross-section area : $A_t=A_{Cu}+A_{SC}$

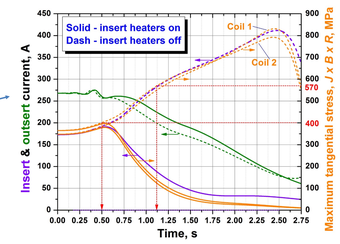
A_{Cu} – the tape copper matrix cross-section area; A_{SC} – the cross-section area of other materials of the tape, incl. hastelloy substrate, etc.; the insulated tape heat capacity : $A_{Cu}C_{Cu}(T)+A_{SC}C_{SC}(T)+A_{ins}(C_{ins}(T)+f\gamma_p^{He}(T)C_p^{He}(T))$, $[J/(m\ \ K)]$, also includes the heat capacity of helium in the winding at constant pressure, f is the helium proportion of the insulation in terms of volume. The helium density $\gamma_p^{He}(T)$ is considered temp. dependent to mimic the helium vaporization process. The last 2 terms : axial (inter-pancake) and radial (within a pancake) transverse heat transfer and heat flux from the heater (beforehand calculated using a custom-made high accuracy 2D model); P_i is the contact perimeter.

The NHMFL practical fit functions [Ref.] are used to calculate the Ic-value depending on the field magnitude & angle, and temperature, using a correction factor for each pancake.



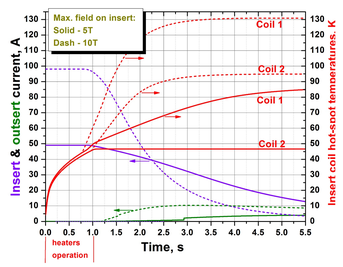
Typical hot-spot temperature evolution in the event of a quench due to a local, point defect. Current is fixed (quench detection failure).

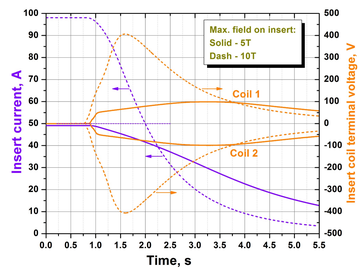




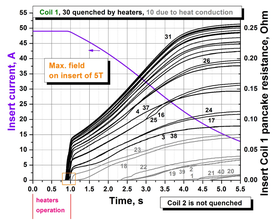
The magnet is at full field. Outsert quenches and its protection system is promptly triggered (fast discharge mode). The insert heaters must be fired, too. What will happen if the insert heaters are not fired and if fired promptly as it should be?

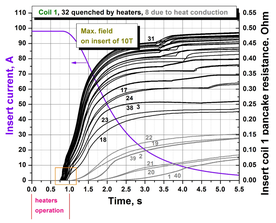
A test to start with: insert alone (outsert is idle), relatively low field (stored energy); insert all heaters are deliberately fired simultaneously

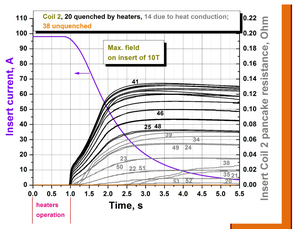




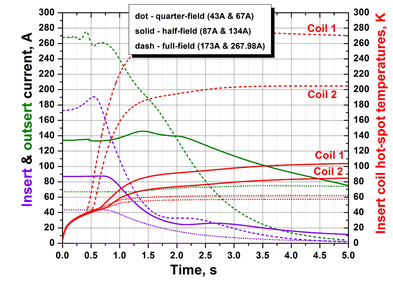
Insert coils quenching by pancake resistance:





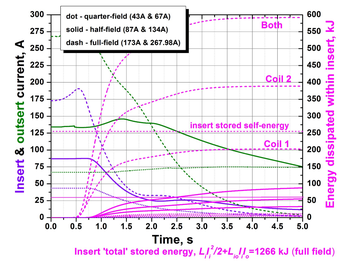


Predictions for probable full and partial field tests of the entire magnet (both insert and outsert are on);
34% higher insert heater power, insert and outsert heaters are deliberately fired simultaneously

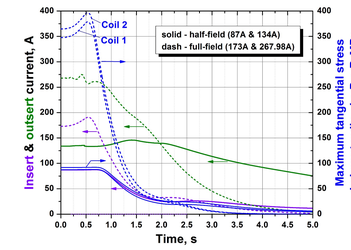


Both Coil 1 & Coil 2 are quenched by heaters

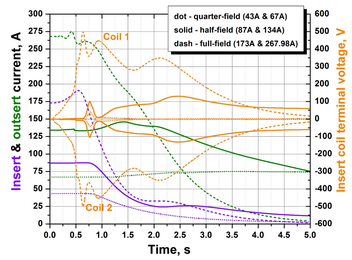
More energy dissipates in insert than self-stored.

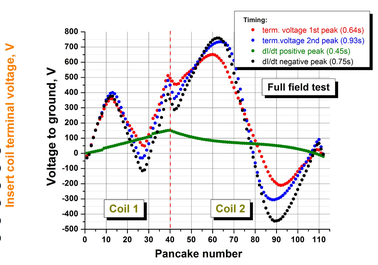


Do we need more heater power?



Are voltages acceptable?





Reference: D.K. Hilton, A.V. Gavrilin and U.P. Trociewitz, "Practical fit functions for transport critical current versus field magnitude and angle data from (RE)BCO coated conductors at fixed low temperatures and in high magnetic fields", Superconductor Science and Technology, Volume 28 , Number 7, 2015

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