Louca Bottura's presentation summary

Background (from ref, ref, ref and ref)

•Cycled superconducting (SC) accelerator magnets have been considered as a natural way to increase the maximum energy achieved in synchrotrons.

•The motivation behind the cycled SC magnet research was to exploit existing installations to increase the beam energy, or to achieve the same energy as accelerators are built with resistive[1] magnets but in rings of smaller size and reduced cost.

•Although resistive magnets were the established and relatively easy technology, the SC magnets had a clear advantage of size and cost over resistive magnets.

•A rising concern on long-term availability and cost of energy increased the number of studies on the use of SC magnets to improve the efficiency of installations based or resistive magnets.

•Despite the increase in complexity due to the additional cryogenics and protection systems, the use of SC magnets ensures secure long term operation of experimental installations that depend strongly on the availability of electric power.

•The PS upgrade (PS2) showed opportunities for SC magnet technology and its main objective was focused on energy efficiency. CERN therefore ran a focused program aiming to demonstrate the technology required to build Fast Cycled SC Magnets (FCM) with high energy efficiency.

Overview of the Fast Cycled Magnet (FCM) Demonstrator Program at CERN (summary)

Project aim, Genesis (and Revelations)

•The operation cost of resistive magnets (used in the majority of accelerator centers, especially in the cycled injector complexes) is proportional to electric consumption. The main objective of FCM was to demonstrate cycled operation at ~2T, ramped to flat-top in 1 s or less and suitable for reliable operation over ~1E8 cycles

•The SC dipole design has the potential of cutting the total power consumption by a factor of 2 compared to an optimised resistive dipole.

•The project timeline was presented, together with the material cost and personnel plan. The CERN DG White Paper (2006-2010) launched a study of the PS upgrade (PS2). In June 2006 the SC magnet R&D was proposed as option of the PS upgrade, and the R&D started in June 2007. The strand and cable procurement and test, magnet design and associated R&D took place from 2008 to 2009, and the magnet and test station construction from 2010 to 2011. The magnet test was performed in 2012.

Short re-cap on magnet design and construction

•The advantages on the magnet design concept were the warm[2] iron (avoid large cryogenic load) and the access to the beam-pipe. Additionally, the force-flow cooled[3], vacuum impregnated SC coil was mechanically solid, and there were lower beam loss and lower field and AC loss due to the fact that the coil was placed in the iron's shadow.

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[1] There are three main magnet types; permanent, resistive (air cored or iron yoke) and superconducting. Resistive magnets have a limited field strength and require a very stable power supply. Water cooling is necessary to remove the heat. The resistive magnet does not require cryogens, but needs a constant power supply to maintain a homogenous magnetic field, and can be quite expensive to maintain.

[2] Warm iron reduces the amount of coldmass on which the heat and radiation are deposited. Therefore the heat load on the system is reduced by a large amount [ref].

[3] A force-flow-cooled magnet is built with conductor that has the cooling channel embedded within it or on the perimeter of the winding [ref].

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•The disadvantages of the magnet design concept were the limited space for thermal screen and vacuum vessel (cryostat) and the difficulty to support EM forces.

•The magnetic design was presented. The magnetic field in T was shown with respect to the current for the central magnetic field and the peak field in the coil. The magnet construction (coil, cryostaded coil assembly, yoke, SC cable etc), the strand and cable characteristics were presented and also the FCM performance summary (flat-top field: 1.8 T, field ramp-rate: 1.5 T/s, AC loss < 5 W/m).

Main test highlights

•In the powering summary it was shown that there was 1 quench up to 6 kA and three more for up to 7.5 kA. The critical temperature (Tcs) results showed that the behavior of the two coils was very similar and that the magnet behaves like the cable.

•There was one quadrant power supply. The ramp-up was at nominal 6 kA/s and the ramp-down was limited by the R/L of the circuit at 3 kA/s. The cycling tests were performed in trains of 10 minutes at ~4.8 K, 3 g/s and P=3 bar supercritical helium[4] cooling. The results of the two cycles (one with duration of 3.5 s and one with nominal cycle duration of 2.4 s) were compared.

•The data from Tcs measurement at different ramp-rate were reduced to a reference temperature of 7 K (average temperature correction of 2,300 A/K was applied). There was no observed ramp-rate dependance in the resulting data set.

•There was stable cycling at 0.5 K from the expected cable critical current for 2,600 cycles. The change in current did not affect the temperature of the inlet and outlet coils.

•The expected AC loss was 0.15 W/coil, compatible with the estimates.

•The measured field was in a good agreement with the calculations (the magnet was not optimised for field quality).

•The mechanics were well-understood and far from its limits

Conclusion and perspectives

The FCM magnet concept was shown to be suitable for fast cycled injector magnet. There was no performance issue (1 quench to nominal field). The operation was stable beyond the performance envelope. Within 20,000 cycles close to the nominal operation conditions there were no spurious quenches, nor observed degradation. The losses in the coil were below the measurable level of magnet (4 W/m). High Temperature Superconductors (HTS) could even be more beneficial in terms of ease and efficiency (cryostat design and cryogenics).

[4] Helium at pressures above the critical pressure of 2.2 atm.