Quench Current-boosting Device (QCD)

FNAL has developed and commissioned a capacitor-based, 0.4 F up to 1 kV, device which can discharge through a powered superconducting magnet at operator’s timing [1]. It aims to affect magnet training by effectively boosting the magnet current, for instance at quench detection time, beyond the quench current. It expands on the idea probed in [2]. It also acts to protect the magnet similar to CLIQ [3]. QCD includes those important features: does not change the current profile across the magnet and does not introduce oscillations, thus emulating a regular ramp but at a very high ramp rate at short timescale (~ 20 ms). Tests on a superconducting magnet at FNAL demonstrated the concept works.

Data and simulation (using LTspice) of the magnet current after detection of the first spontaneous quench. Resistance growth in the simulation was modelled based on post-quench data analysis.

Magnet current after quench detection

Spontaneous quenches at nominal ramp rate of 20 A/s. Red line-markers indicate the peak of the boosted current. Four thermal cycles were conducted, and vertical lines show their borders.

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Future of QCD techniques

QCD acts well on magnets with low inductance. To study its effect on large magnets we took as an example a HL-LHC quadrupole (~35 mH) and simulated the response with a varying resistive profile based on the present magnet’s, its resistance and RRR relations between the two magnets. The existing QCD can boost the current in the large magnet by a little but if twice as high voltage can be sustained by the magnet the results are very substantial at 500-600 A boost. The present QCD can not provide this higher voltage and is rather to be used for further investigation within the parameter space of QCD: mainly shape and duration of boost relevance for (elimination of) training. It is worth noting that according to [5] coils train independently within magnets. In that case CLIQ should also affect training and good coils which see higher currents, due to oscillations up, will end up with no training quenches after CLIQ is consistently applied.

QCD and magnet performance

The magnet underperformed reaching ~70% Short Sample Limit at 4.5 K and 1.9 K. However, it forgot its training after a thermal cycle (TC) which allowed us to conclusively demonstrate training elimination by applying QCD. The effect was also seen in the first TC alone in the test transition to 1.9 K. Acoustic data confirmed that the well-known Kaiser effect observable during magnet training is suppressed by QCD indicating the Lorentz force follows closely the current boost.

Coil examination before and after the tests indicate some non-conformities which were not fully resolved, resulting in uncommon visual coil damage in the outer layer. All limiting quenches were observed there and quench antenna analysis [4] also points to this outer layer area being “weak”, including at the first quench.

References


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