Quenching HTS Pancake Coils using Frequency Loss Induced Quench Protection System

Kikelomo Ijagbemi[1,2,3], C. Kim[1], P. Cheetham[1], Sastry Pamidi[1,2]

1. Center for Advanced Power Systems, Tallahassee, FL 32310, U.S.A
2. FAMU-FSU College of Engineering, Tallahassee, FL 32310, U.S.A
3. National High Magnetic Field Laboratory, Tallahassee, FL 32310, U.S.A

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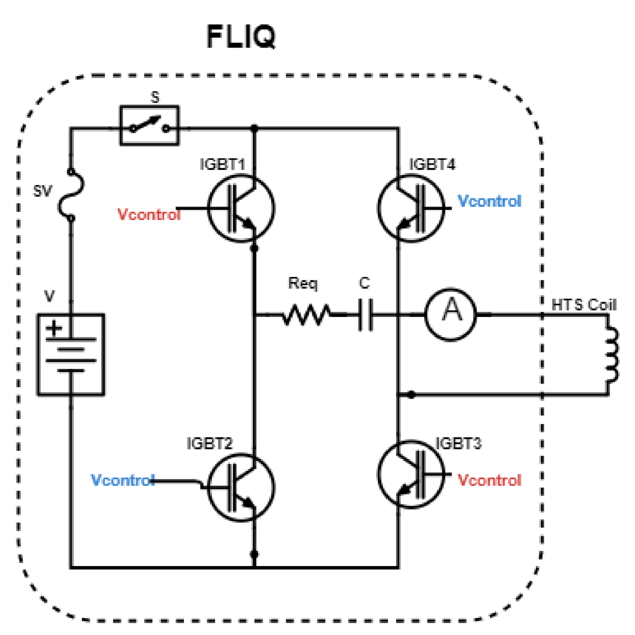
Abstract

We have been developing the Frequency Loss Induced Quench (FLIQ) protection system for high-temperature superconducting magnets. We have studied the sensitivities of the various FLIQ system parameters to understand the design of an effective quench protection system. FLIQ drives AC current in the magnet coil and generates AC losses. The heating associated with the losses quenches the HTS magnet safely. This distributed heating of the magnet will cause the field energy to dissipate over the entire volume of the magnet to minimize peak hot spot temperatures and compensate for the thermal margin caused by the normalized region.

FLIQ System

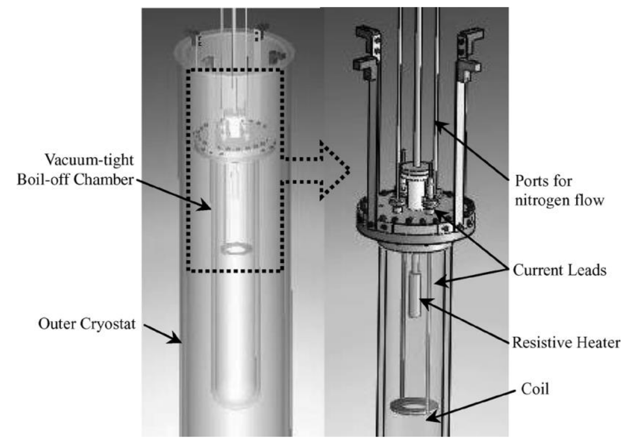


FLIQ Circuit

- The FLIQ based protection system includes coupling a current imbalance source to at least one coil subsection of an HTS magnet coil.
- To achieve this, FLIQ uses an H-bridge design with Insulated Gate Bipolar Transistor (IGBT)s, whose gates are driven based on the current flowing through the LC load. This allow the system operate at resonance.

AC Loss Measurement

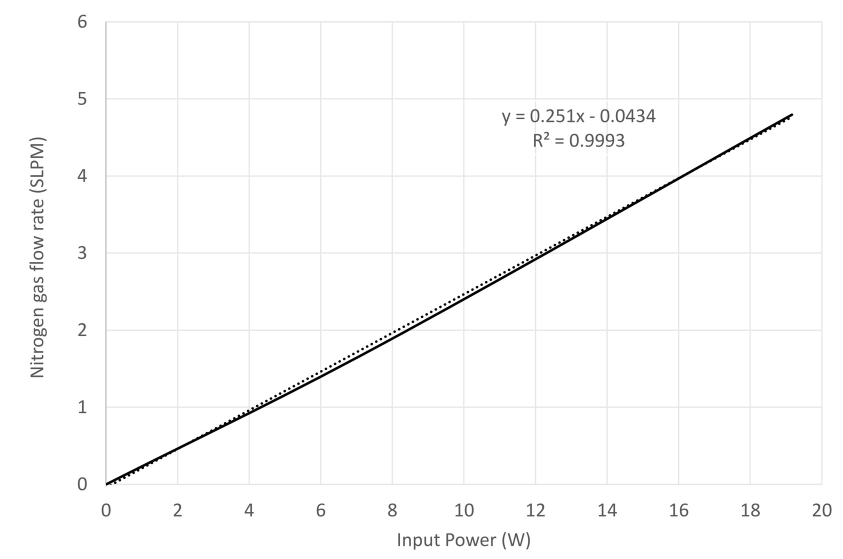
- There is uncertainty and complexity of AC Loss calculations during the quenching process.
- FLIQ system is tested on 2G HTS pancake coils in liquid nitrogen to understand the dynamics of quench and the energy involved.
- Calorimetric technique is used to measure the nitrogen boil-off rate and determine the heat energy deposited.
- The coil and resistive heater are enclosed in a sealed liquid nitrogen chamber and the nitrogen gas flow rate was measured. The boil off rate was translated into the heat energy.



Experimental apparatus used for AC loss measurements on superconducting coils using calorimetric liquid nitrogen boil-off technique [1]

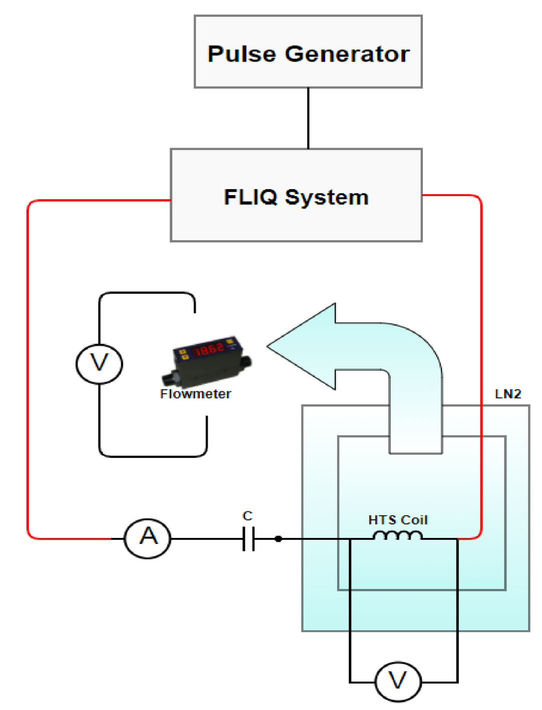
[1] J. Kim, C. H. Kim, G. Iyyani, J. Kvitkovic and S. Pamidi, "Transport AC Loss Measurements in Superconducting Coils," in *IEEE Transactions on Applied Superconductivity*, vol. 21, no. 3, pp. 3269-3272, June 2011, doi: 10.1109/TASC.2010.2089485.

Resistive Heater Calibration using the Setup



- A 64 Ohms resistive heater was used to determine the linearity of the liquid nitrogen boil-off measurement setup. The heater was calibrated up to 20 W heater power.
- The flow rate from the boil off was measured at room temperature using a nitrogen gas flow meter in standard liters per minute (SLPM).
- The slope of the flowrate versus power input was 0.249 SLPM/W, which agrees with the theoretical value .

Experimental Setup



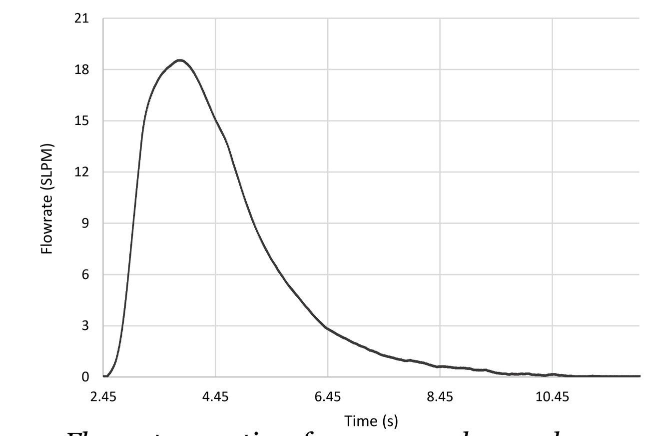
Experimental Setup

Coil Parameters	
Winding inner diameter (cm)	5.7
Winding outer diameter (cm)	8.2
Number of Turns	40
Conductor total (cm)	314.2
Coil Inductance (uH)	200
Max Current @77K (A)	73.2
Stored Energy at Max Current (J)	0.535

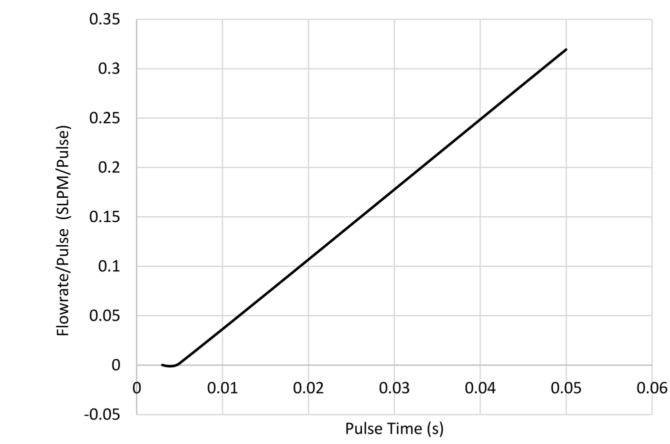
- The center of the bridge in the FLIQ system is across the series connection of the capacitor bank and the HTS coil.
- A pulse generator triggers the FLIQ system and determines the number of pulses and their duration.
- Energy is released in the coil and the resulting heat causes nitrogen boil off.
- The gas flow rate is measured at room temperature using a flow meter.
- The voltages from the setup are fed to the data acquisition system to record the measurements on a computer.

Discussion

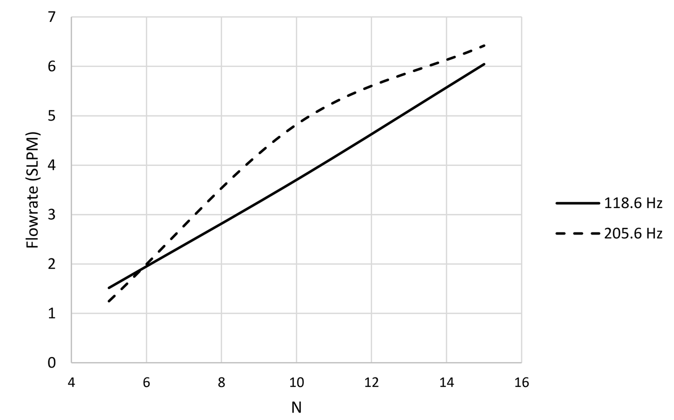
- The HTS coil was connected to the FLIQ circuit. The FLIQ operated at different pulse widths, frequencies and number of pulses.
- The frequency of the current was determined by the series connection of the coil and the capacitor bank.
- The pulse time is how long a pulse is on. As the pulse width increases, Nitrogen boil off per pulse increases.
- Nitrogen boil-off requires steady state (constant boil off with time)
- Due to the continuous operation of FLIQ, we only achieved a steady state condition after 77 seconds.
- Unfortunately, the coil degraded after the first set of measurements. We had to try several methods to establish steady state equilibrium.



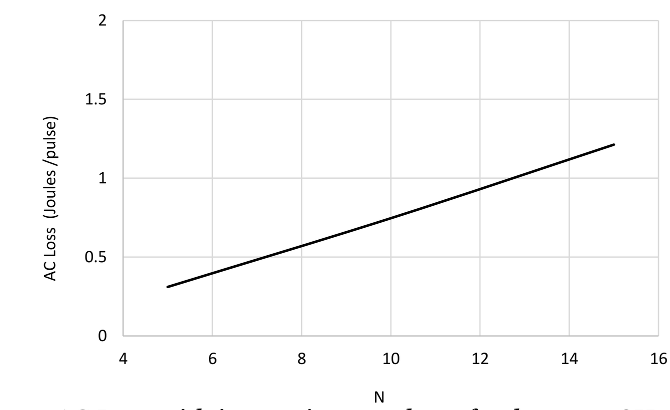
Flowrate over time for 20, 50ms long pulses



Flowrate with increased pulse length



Flowrate with increased number of pulse at different frequencies



AC Loss with increasing number of pulses at 118Hz

Summary

- Nitrogen boil off at 77 K (and helium boil off (at 4 K) can be used to understand the quench dynamics with FLIQ.
- It took several experiments to understand the process that established steady state just before quench
- Gas flow rate increases with the number of pulses(N). Higher frequency resulted in increased flow rate, as expected.
- Energy increased with higher number of pulses. 10 pulses, 50 ms long resulted in about 15 watts and 0.74 J/pulse.
- FLIQ is a useful tool in quench protection and more experiments will be performed on other HTS coils at the different frequencies and time.

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