Analysis of Magnet Quench Antenna Data

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Introduction
Quenching poses a serious problem for superconducting magnets operating at high current. It occurs when the material transitions from the superconducting to the resistive phase, which leads to heating and potential damage to the magnet. To understand and mitigate quenching, Fermilab’s magnet department is developing and testing superconducting magnet quench antenna arrays. The purpose of this project is to study anomaly events during magnet trainings before quenches take place by analyzing the collected data.

Quench Antennas
The quench antenna array consists of 4 panels, each with 20 parallel coils capable of detecting changes in magnetic flux which induce currents in the coils. Two panels are placed on top of each other, enabling the system to locate events by identifying where the two channels with the strongest signals intersect. (Fig. 1)

In each current ramp, the current was gradually increased until the quench occurred and voltage signals of the channels were recorded at a sample rate of 100kHz for hundreds of seconds.

Preliminary statistical analysis
1. To reveal the trend, we perform a double moving average with a window size of 50ms on the voltage signal and compare it to the ramping current. The change in voltage matches the change in current rate at the same time. Spikes (probably noise) in the moving average are observed to occur at a constant but extremely low frequency. (Fig. 3)
2. To identify and minimize noise, we apply FFT to the voltage signal over short intervals and over the entire ramp. It is discovered that the frequency spectrum is stationary and consists mostly of noise at multiples of 60Hz, which comes from the power source. (Fig. 4)

Unsupervised Autodetection of Events
Goal: develop an unsupervised algorithm to detect anomaly events without relying on predefined event features.
1. Remove the noise at multiples of 60Hz. The filtered data effectively highlight the events amidst the noise, increasing the event signal-to-noise ratio by about 250%. (Fig. 5)
2. Divide the ramp into 0.1s samples. With the first 10 principal components of the frequency spectrum, we use DBSCAN clustering to distinguish events from non-events and group similar events into the same clusters. (Fig. 6)
The algorithm successfully finds the obvious peaks as well as obscure anomalies. Events within a cluster exhibit high similarity. (Fig. 7)

Quench Location and Spatial-Temporal Distribution of Events
We locate the quench at the intersection of the two channels with the highest voltage at the quench time.
To show the spatial and temporal distribution of events and its relation with the quench, we apply the event detection algorithm on all the channels, and plot the events in spacetime. Fig. 8 is for visualization only. More careful verification is needed for the final result.

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