Investigation spikes MBHA-001

Gerard Willering
Franco Mangiarotti
Gaëlle Ninet
Vincent Desbiolles

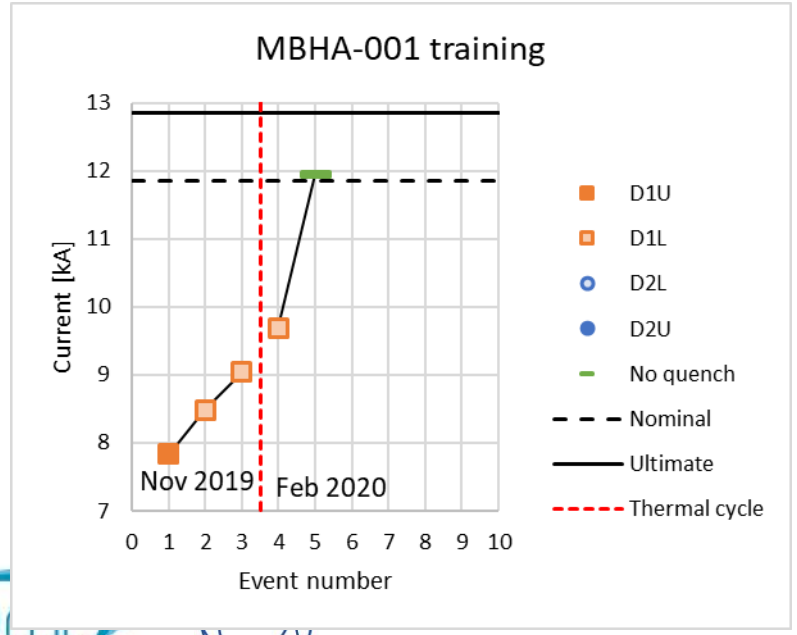
updated 26-02-2020

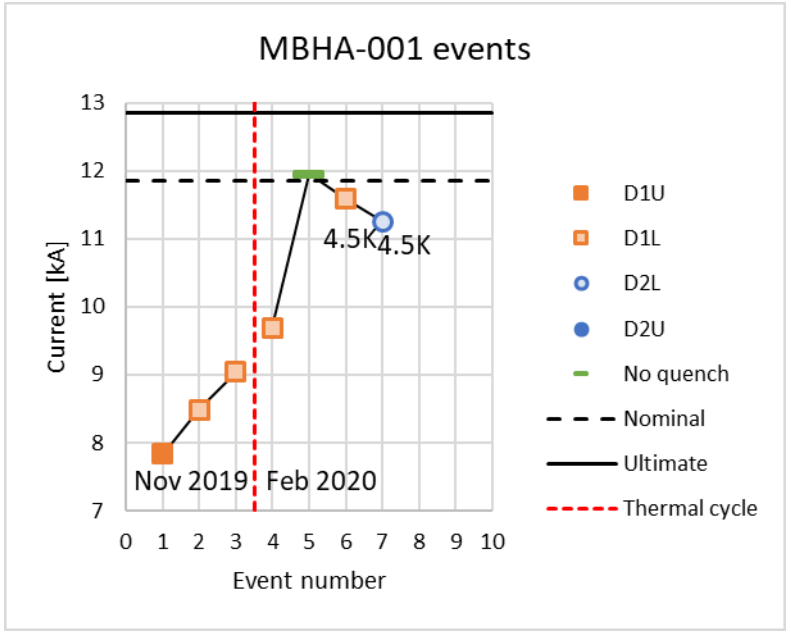
Test status MBHA-001

First results
1.9 K, HV test coil-ground is OK!!
All other HV tests at 1.9 K are OK too.
Training completed

- Only 4 quenches to reach 11.95 kA target. Stable for 5 minutes
- Then two “detraining quenches” at 4.5 K. both small precursor
- V-I measurements show no issues with the conductor up to 11.95 kA with <0.5 µV precision

Only problem: Spikes returned.





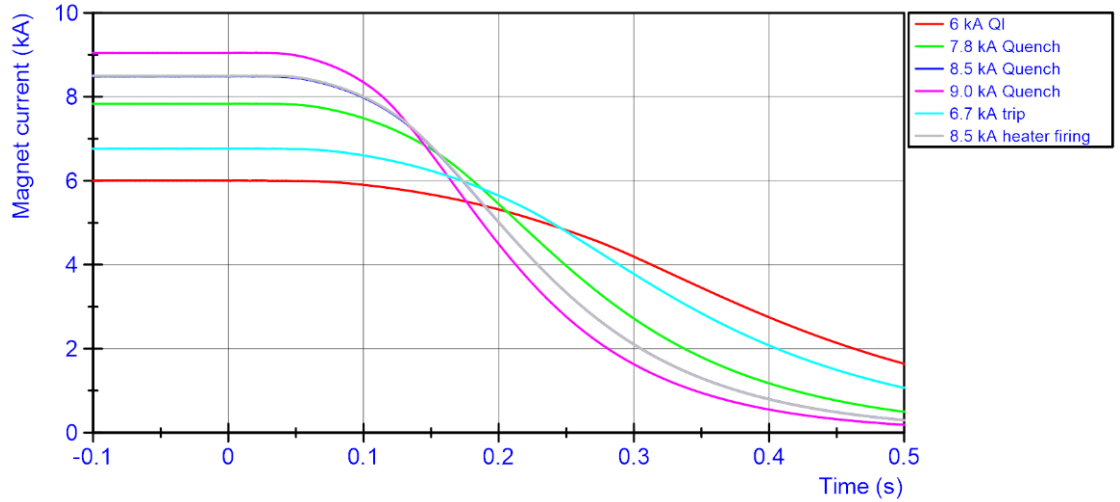
Contents

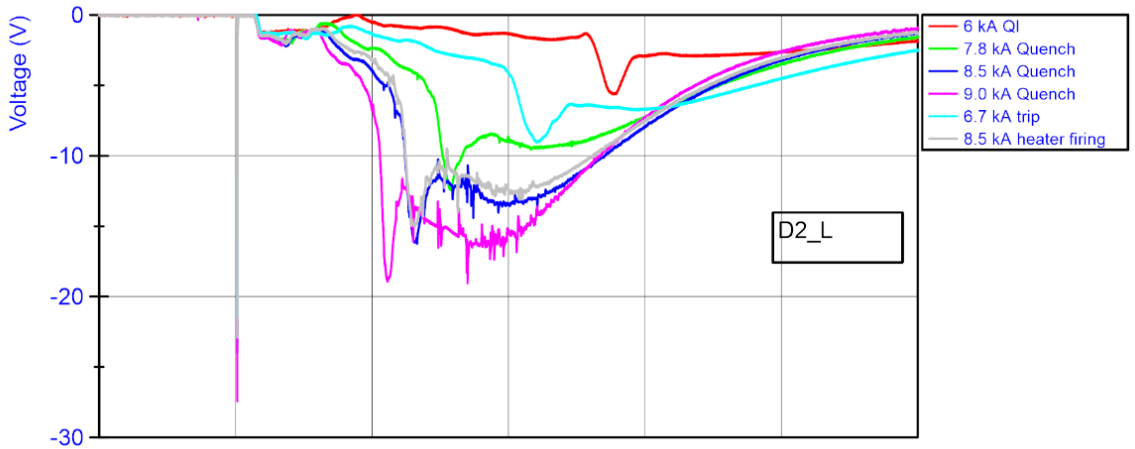
Spike appearance
Spike characteristics
Possible causes
- Wiring inside magnet
- Wiring outside magnet
- Measurement electronics
- Mechanical movements
- Electromagnetic signals (Flux jumps)

What to do next

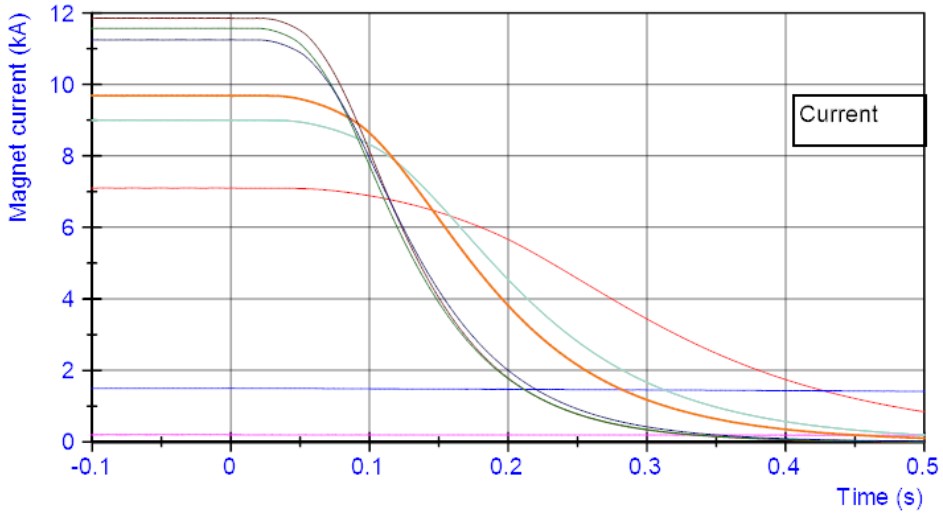
Spike appearance

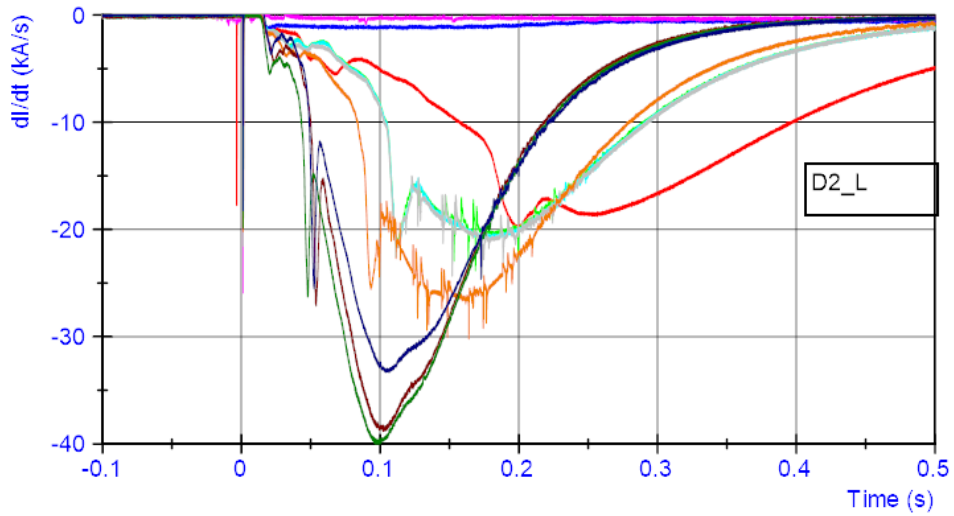
In November 2019

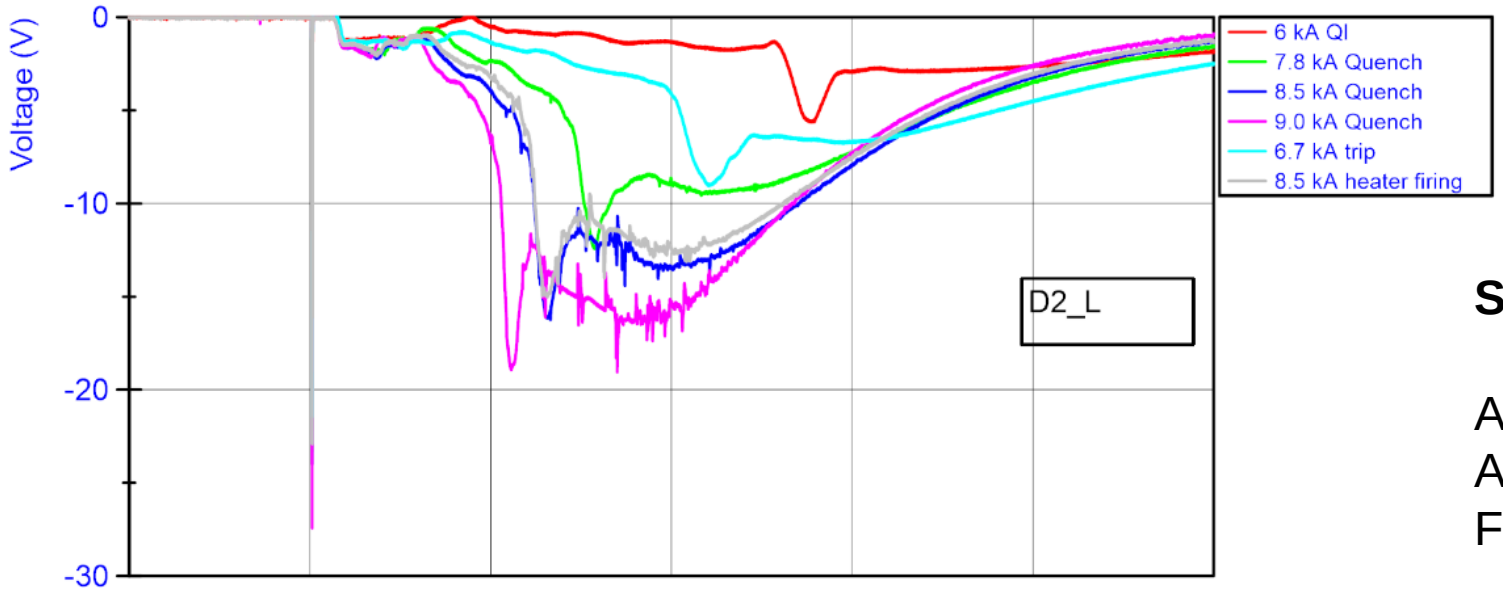


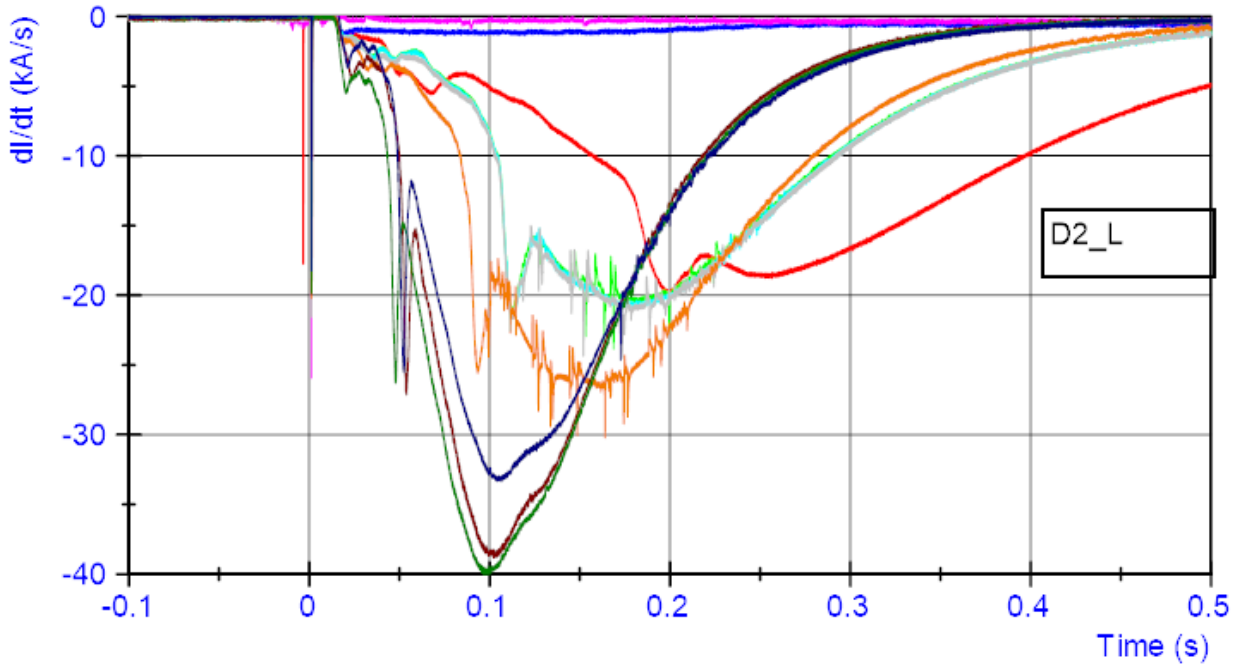


In January 2020









Suprisingly repetitive

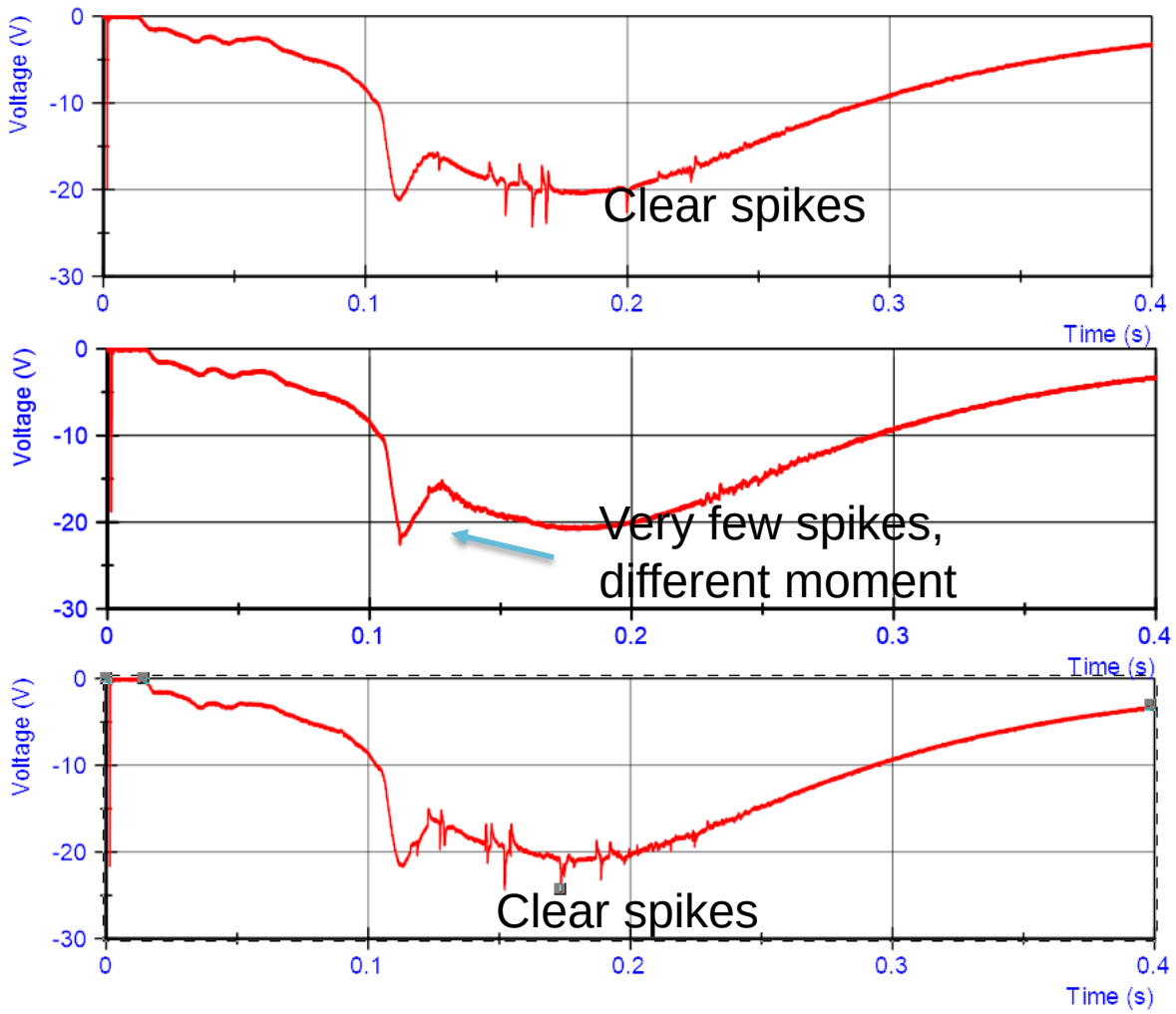
At low currents, no events
At 7.8 some events,
From 8.5 to 9 many events

At high currents mostly absent, but not completely absent

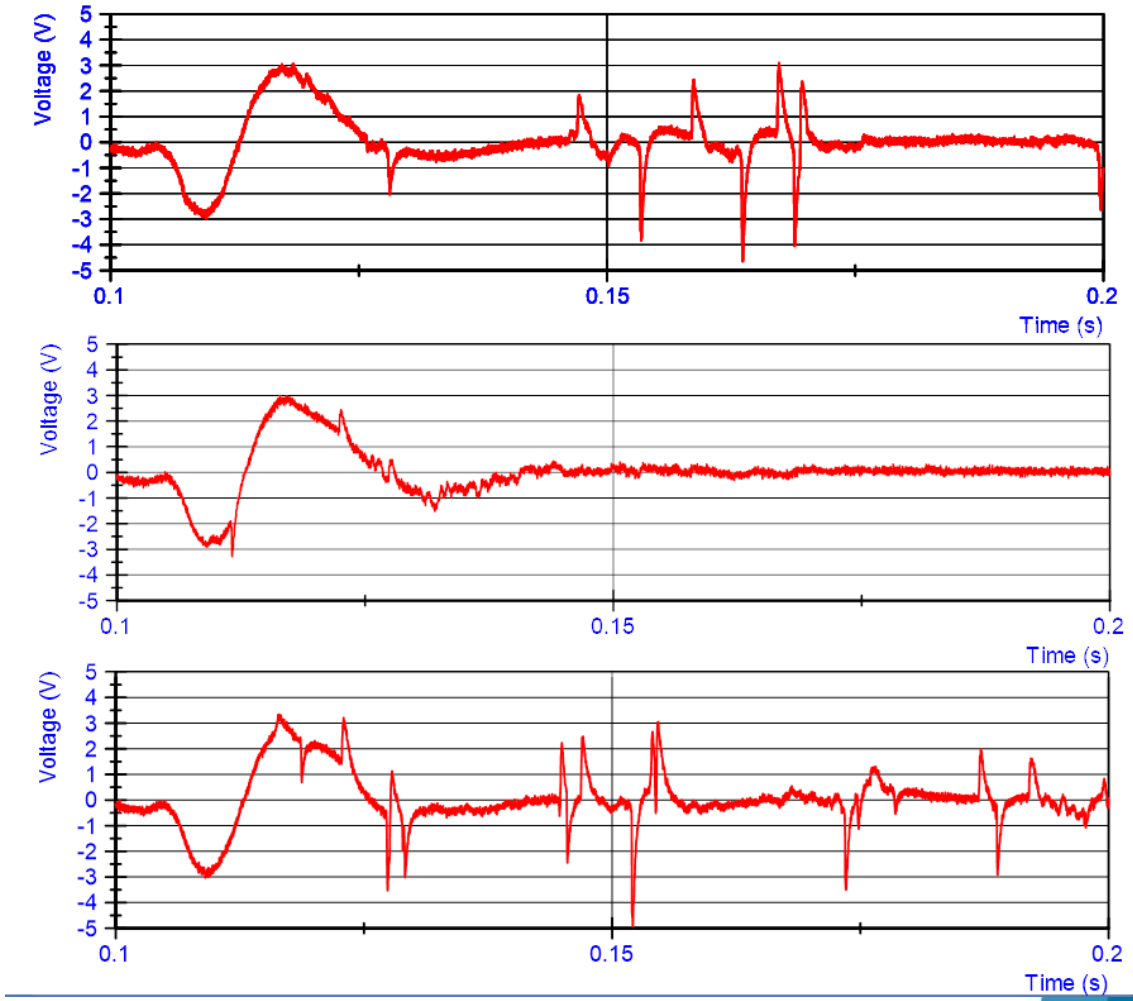
At 4.5 K at high current:
Mostly absent

Three identical discharges

On Monday 3 discharges were performed at 9 kA.

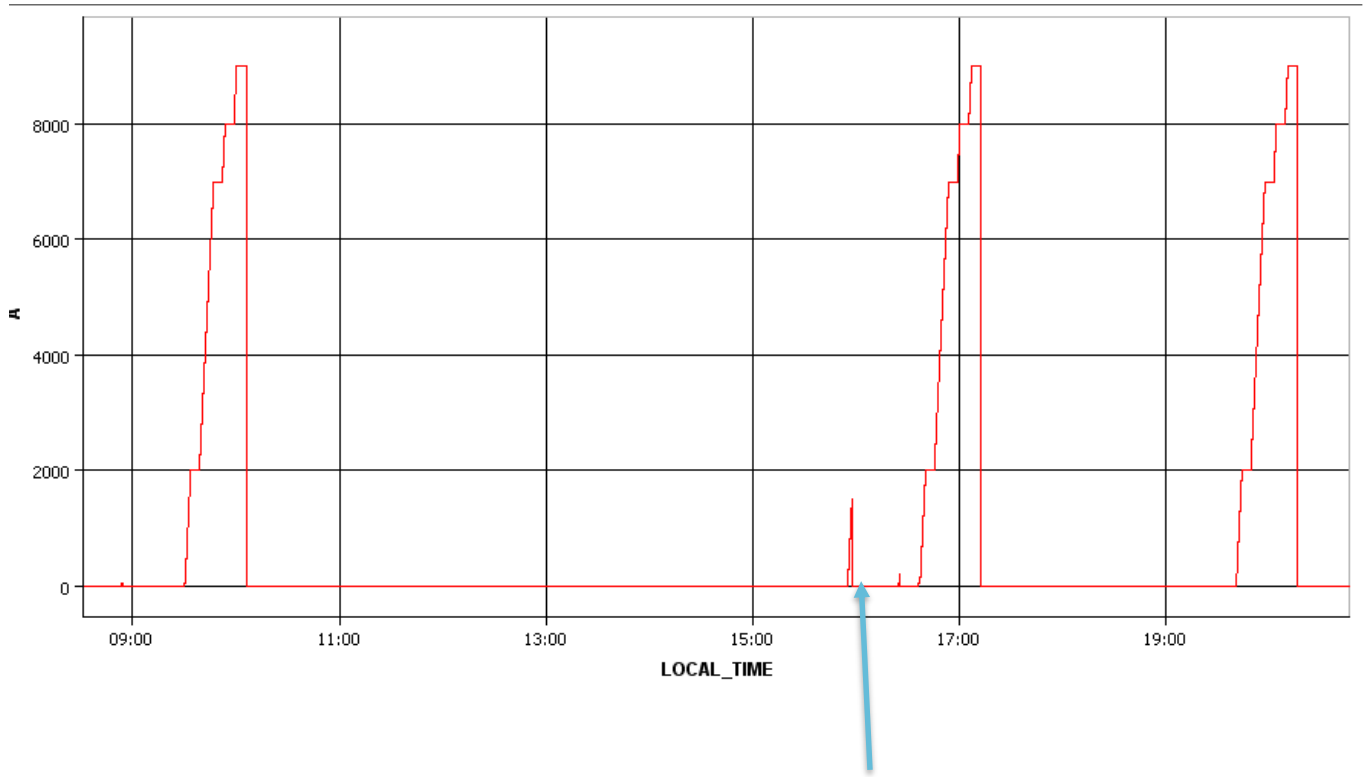


Zoom on spikes after 50 Hz high-pass filter



Three identical discharges

Difference for the discharges from 9 kA



Low current trip at 1.5 kA
(coil not fully quenched)

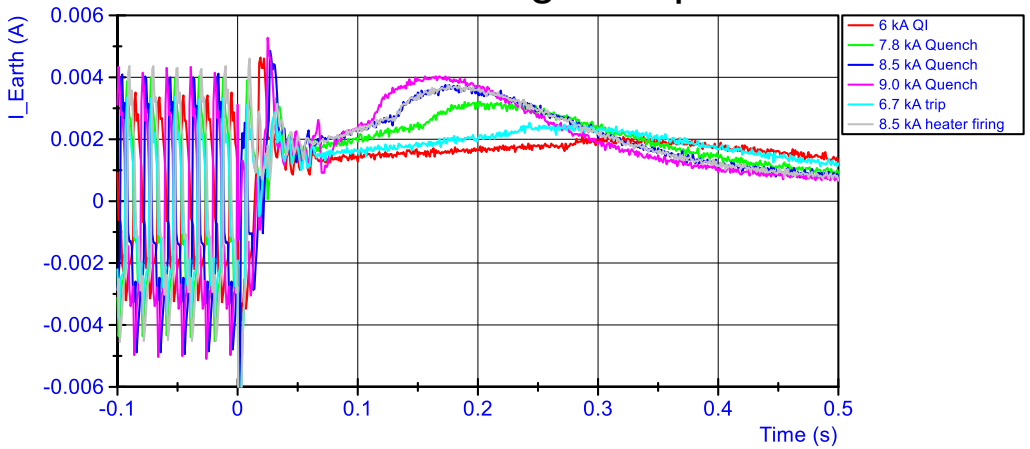
Between 1 and 2 a cable was replaced

Between 2 and 3 no change, except that there was a trip before discharge 2.

Investigation to causes

Done in November 2019

No earth currents during the spike events

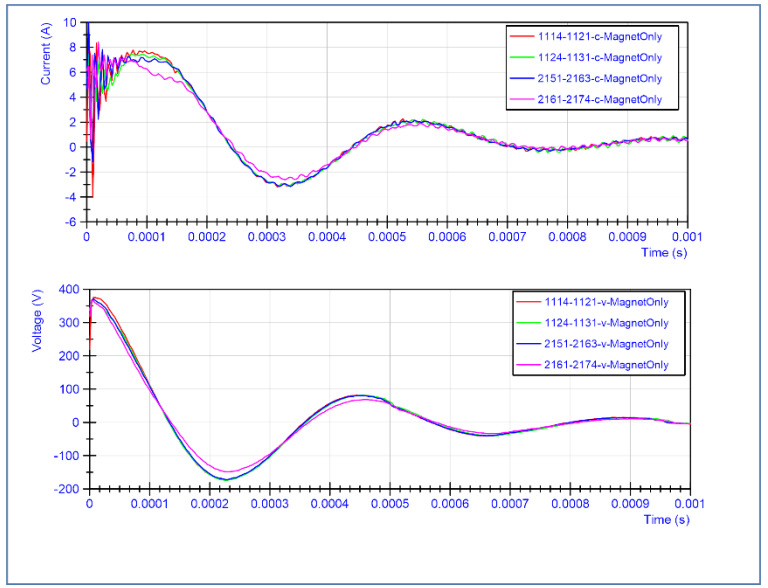


Done in November 2019

Capacitive discharges at 400 V over the “suspected” V-taps

1. Magnet through IFS box (no external cabling)
2. Including all instrumentation and DAQ and QPS and DMM electronics

No difference between the two tests!!



Investigation to causes

Wiring inside the magnet

- Capilary has been completely replaced.

Wiring outside the magnet

- Wiring outside the magnet has been thoroughly checked.
- **Magnet MBHA-002 had no spikes.**

(Tested in January, same test bench, same wiring, same cabling, same data aquisitions electronics, same quench detection crates, etc.)

Is there some physics we don’t understand?

What about flux jumps/electromagnetic effects

- Flux jumps needs superconductivity: is there still some part of the coil superconducting at the moment of spikes?
- What about the signal characteristics?

Two clues to investigate further

- Spikes different after low current discharge (different magnetization)
- At high current events much less spikes
- At 4.5 K mostly absent (only checked high current events)

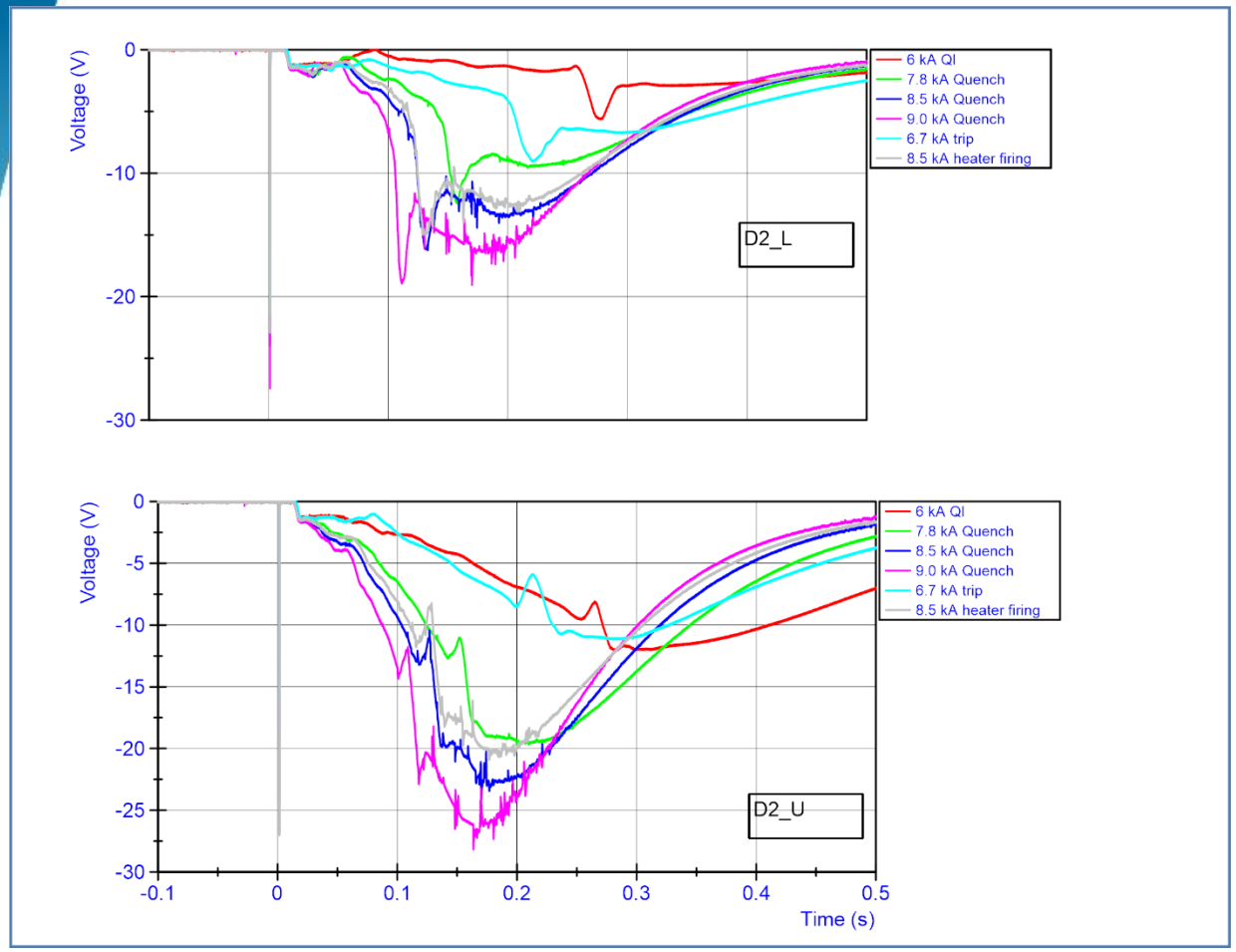
What about mechanical movements?

- Unloading / changes in forces / changes in geometry?

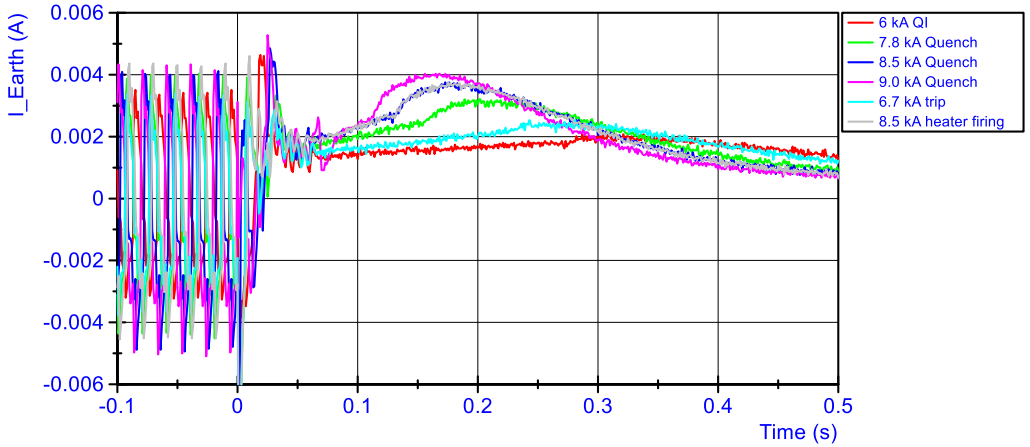
What next

To verify wiring and cabling outside the magnet:

- Connect minimum of instrumentation and protection to exclude any electronics/wiring outside magnet
- Perform other type of cycles to see when the spikes appear
- Perform 9 kA discharge at 4.5 K
- .....
- …..
- ….
- ….



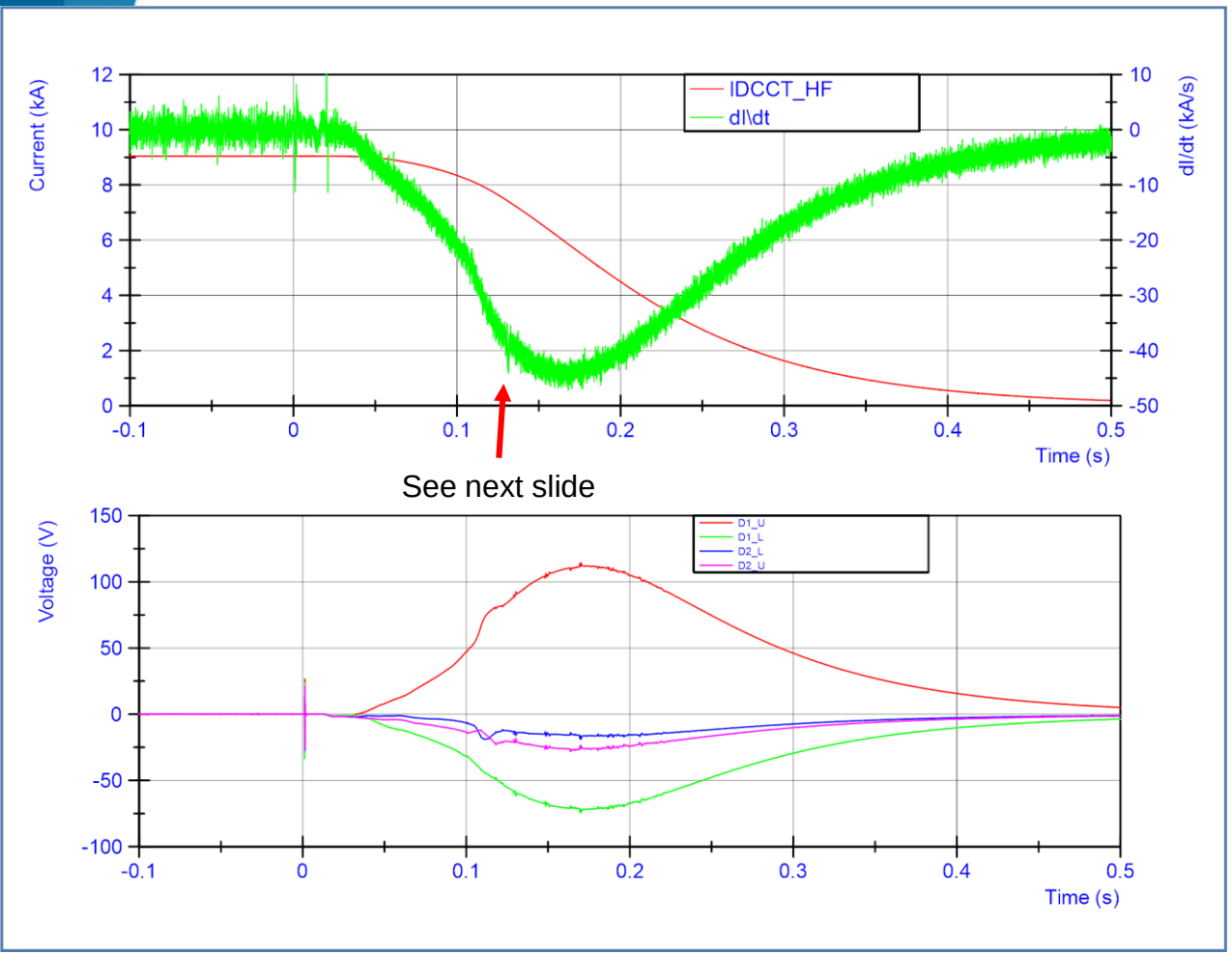
Voltages with spikes in aperture 2.
Visible in all quenches above 7.8 kA.



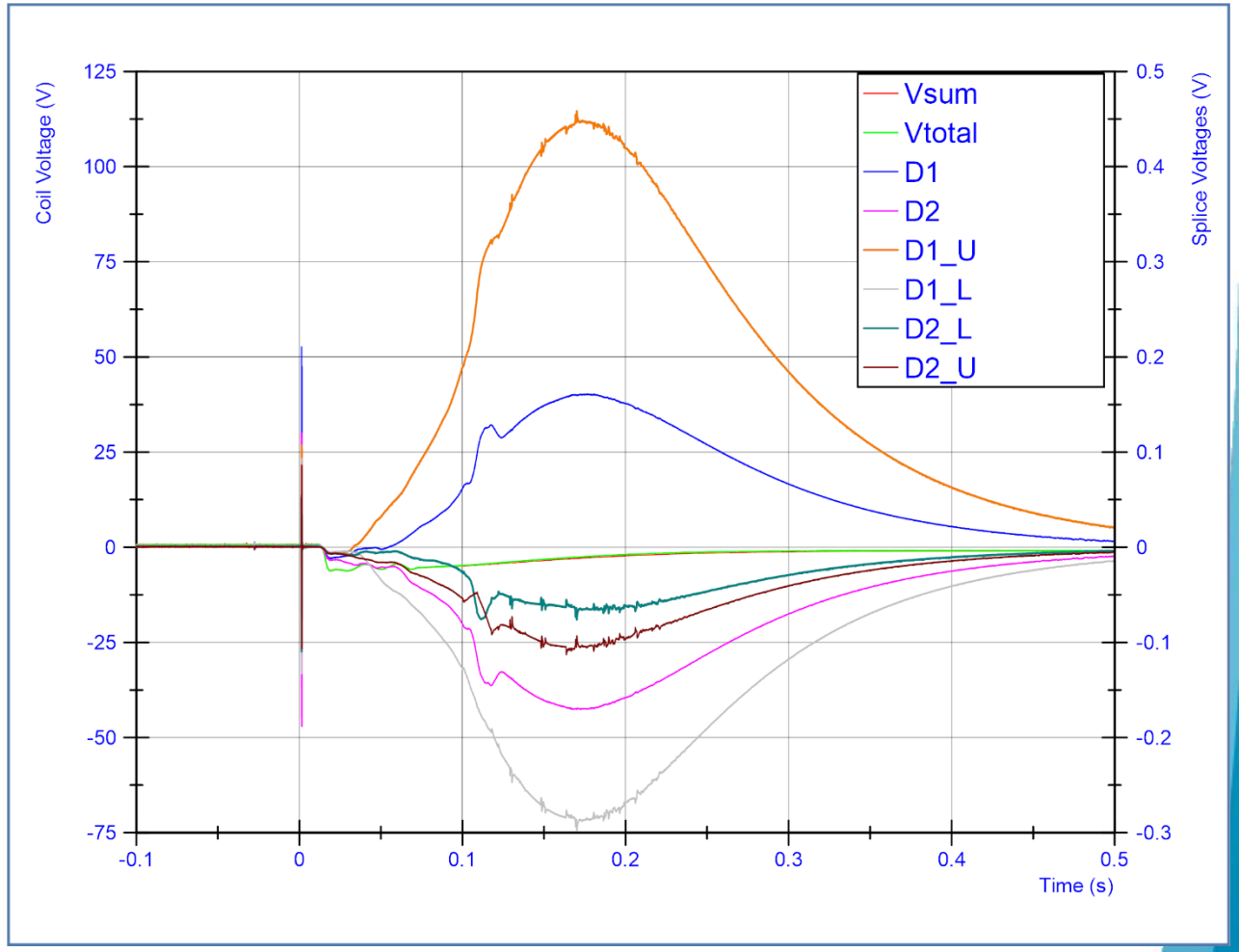
Earth current measurement shows nothing notable.

In the next slides we analyse the 9 kA Quench

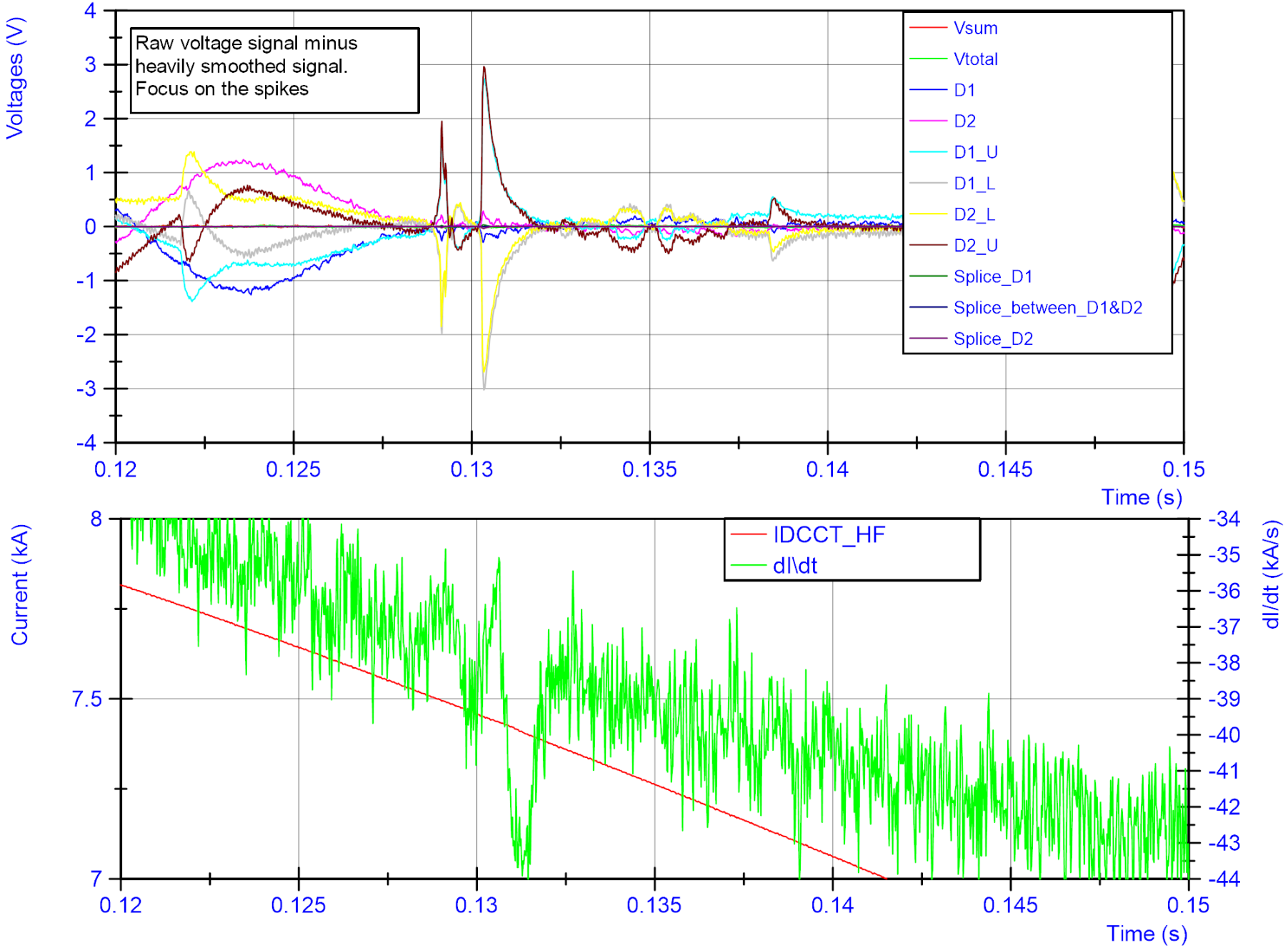
Analysis 9 kA quench.



See next slide



Spikes visible direct voltage of each coil (D1_U, D1_L, D2_L and D2_U).
The total voltage and the voltage over each aperture (D1 and D2) are smooth.

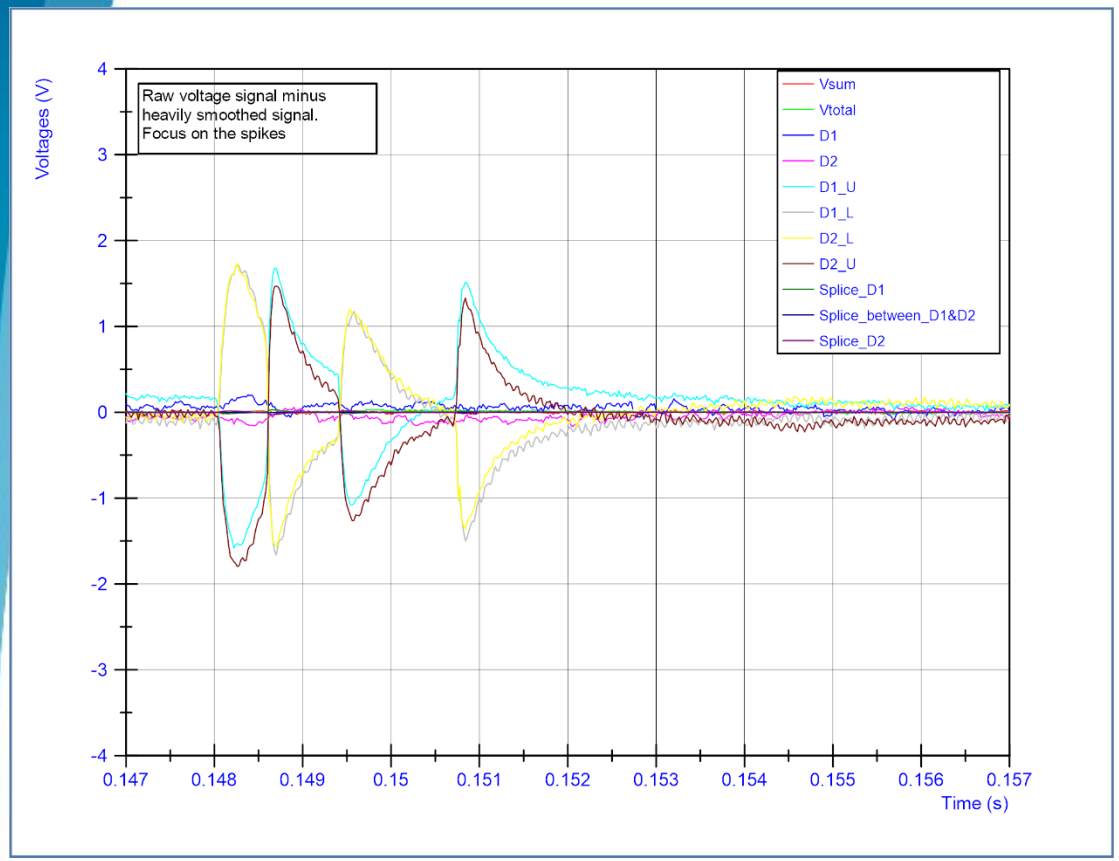


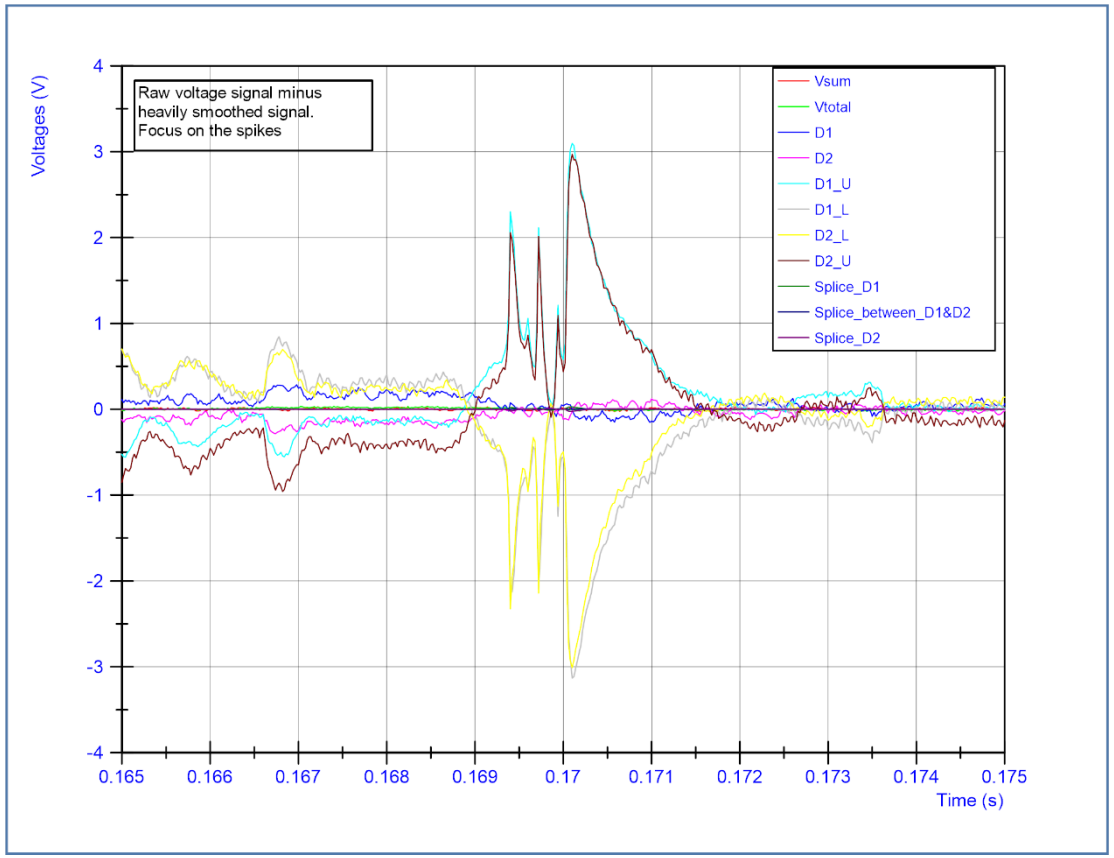
By removing the base signal (high-pass filter), we can focus on the spikes in the signal.

D1U spike identical to D2U

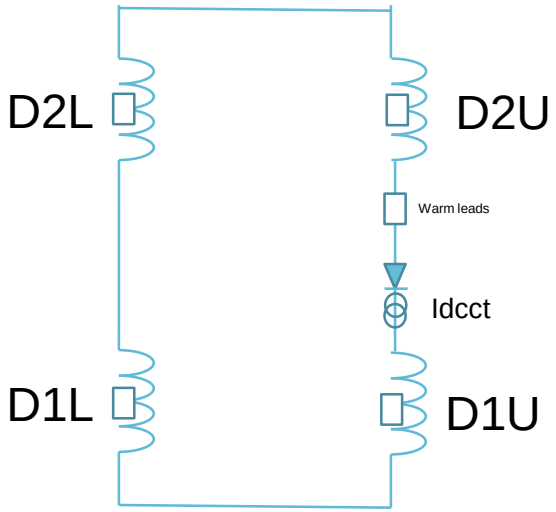
D1L identical to D2L

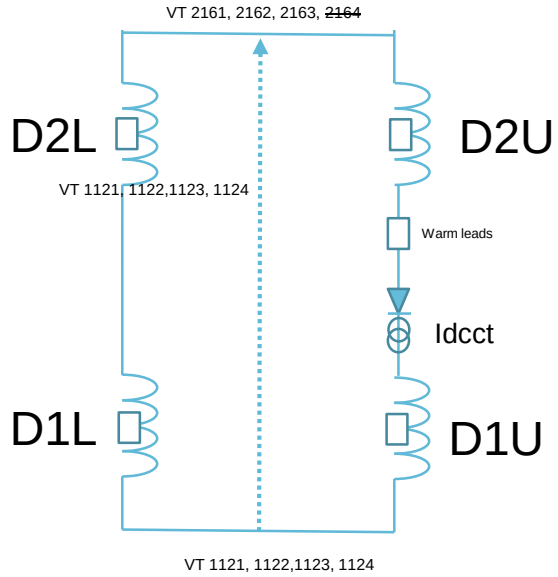
Other examples





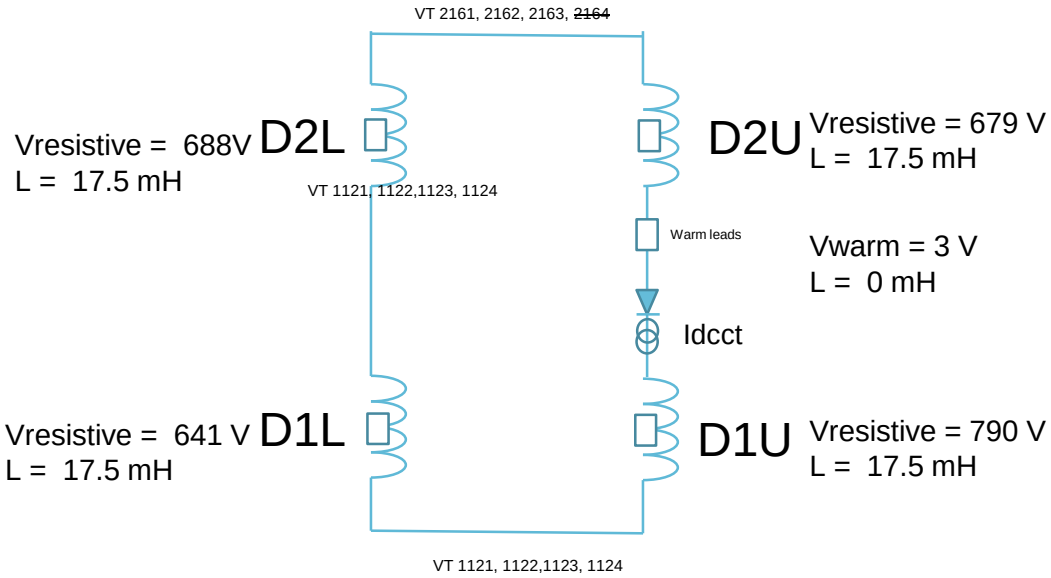
No earth current visible. .
Symmetry in signals may suggest an intermittent short between the midpoint of Aperture 1 and the midpoint of aperture 2.



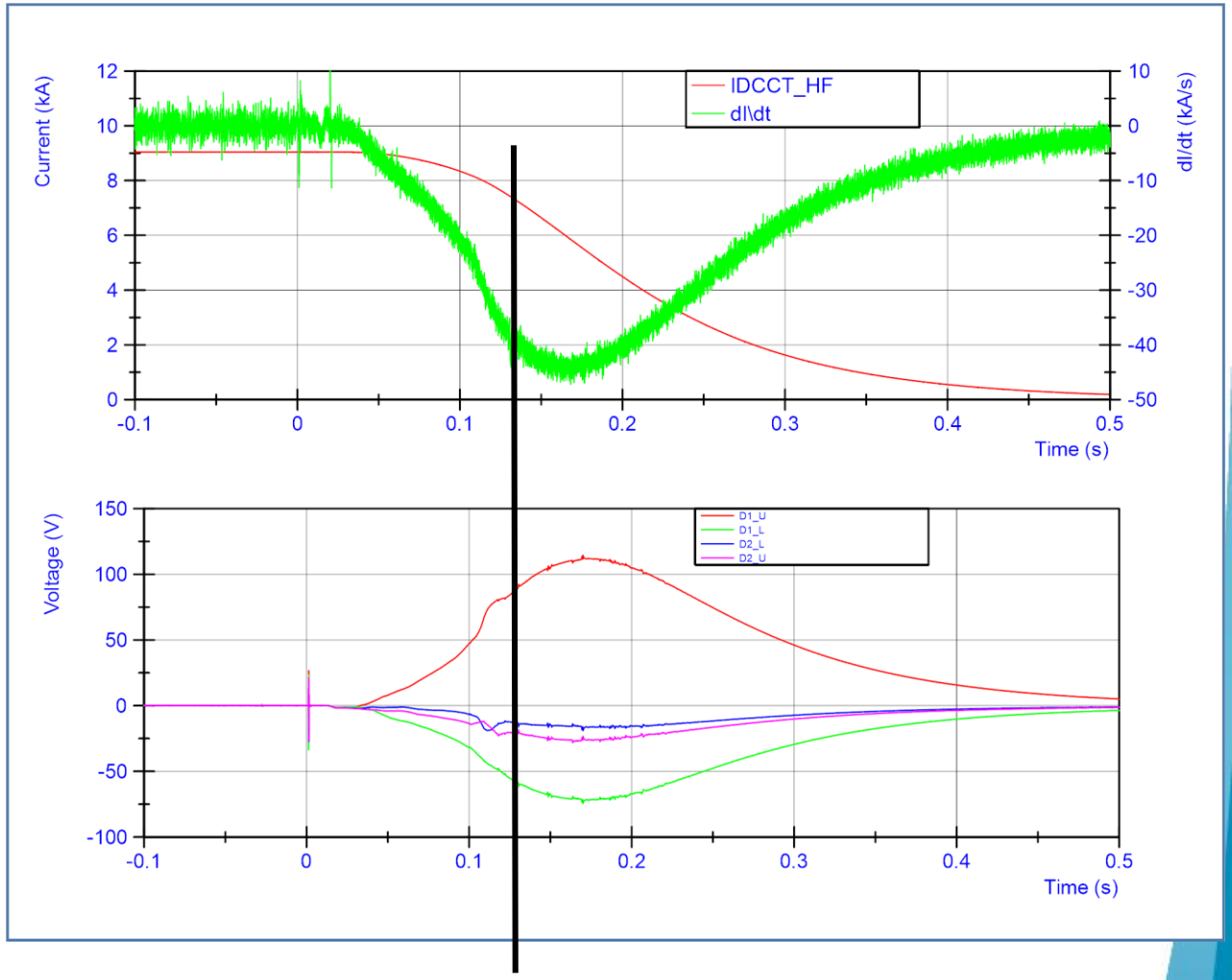


Note that at this stage the coils have a resistance, but not all the same.

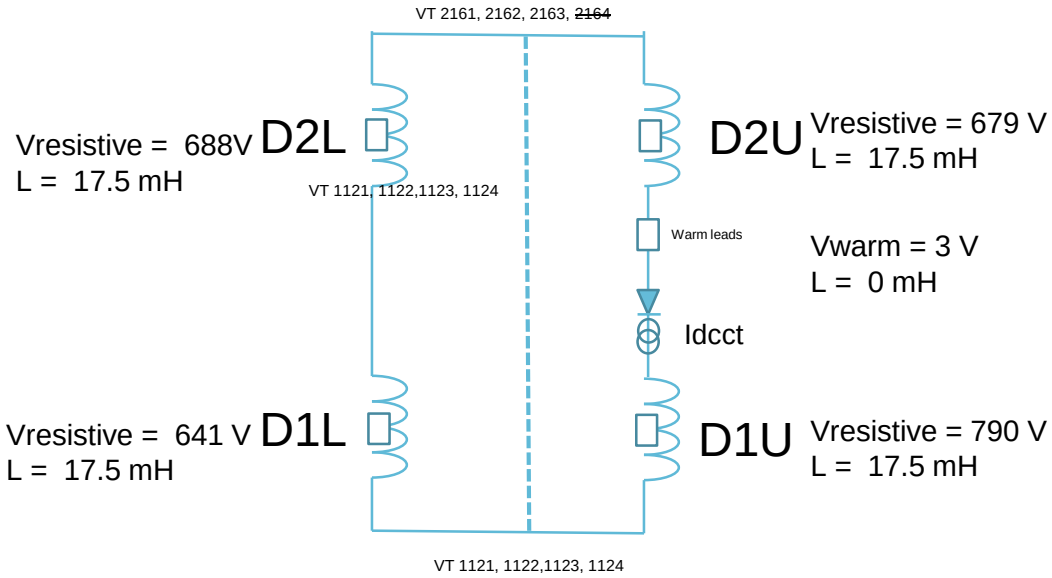
Could this short explain the signals?

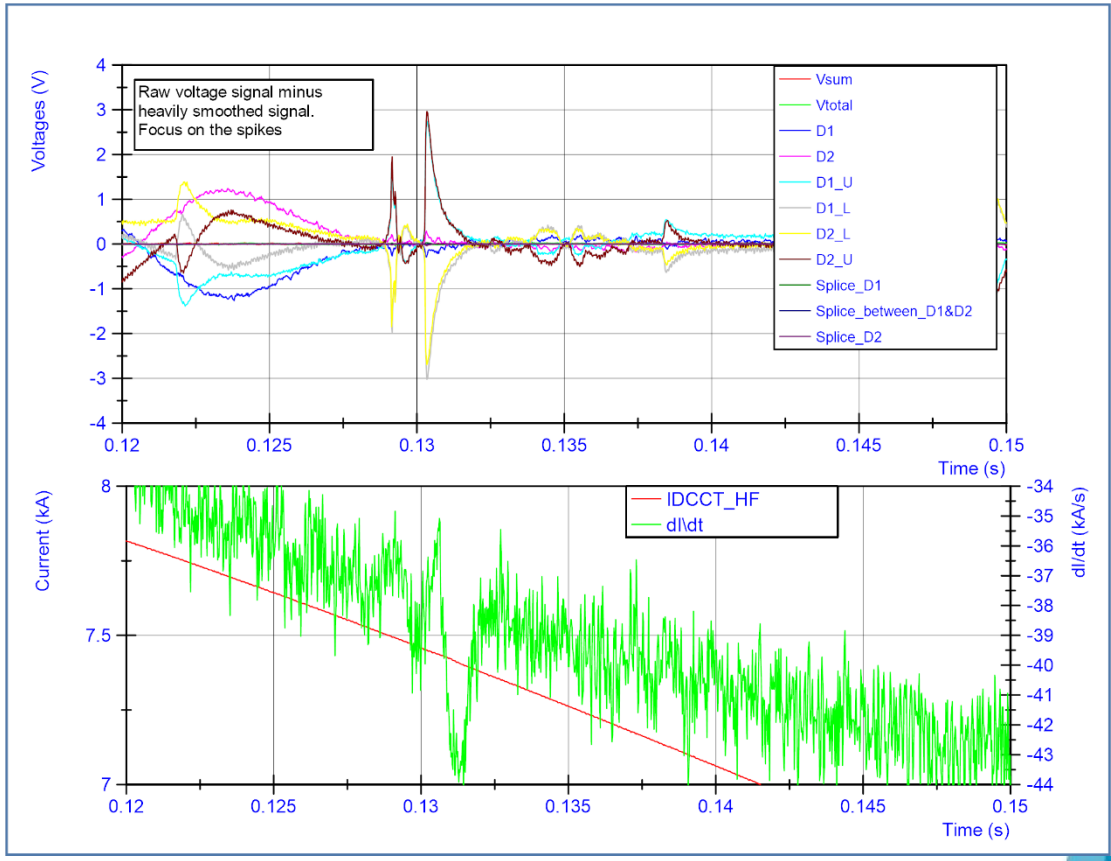


Modeling using measured voltage imbalance.



Reference moment for the model.





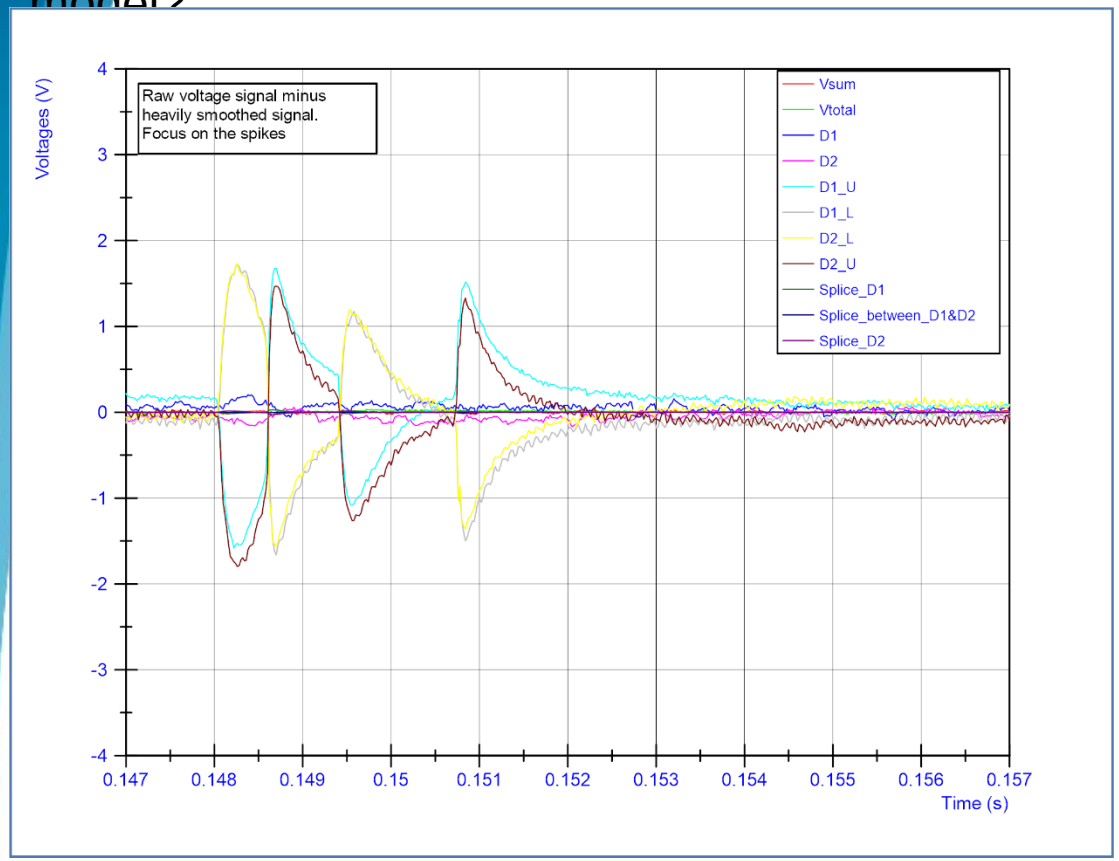
Before the short, Vres = 2800 V, L = 70 mH, dI/dt = 40 kA/s.
Introduce a short (with 0 resistance)
Left branch with D1L+D2L has Vres = 1329 v, L = 35 mH, dI/dt = -37.9 kA/s
Right branch with D2U+Vwarm+D1U has Vres = 1492 V, L = 35 mH, dI/dt = -42.1 kA/s.

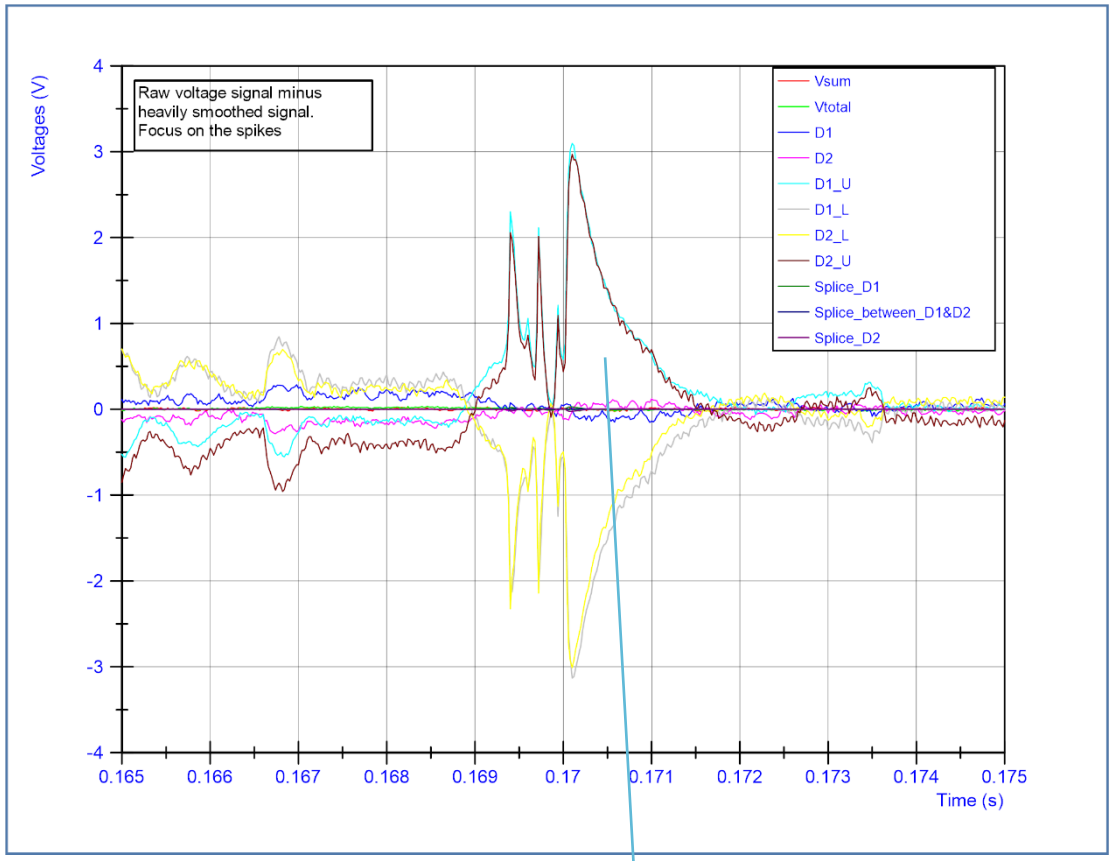
No surprise: symmetry
-40 kA/s ± 2.1 kA/s

This would mean that the short would start carrying the difference in current between both magnets, going up by 4.2 kA/s, however the current through the short is limited to V/R. The voltage over the supposed short is 71 V (measured).

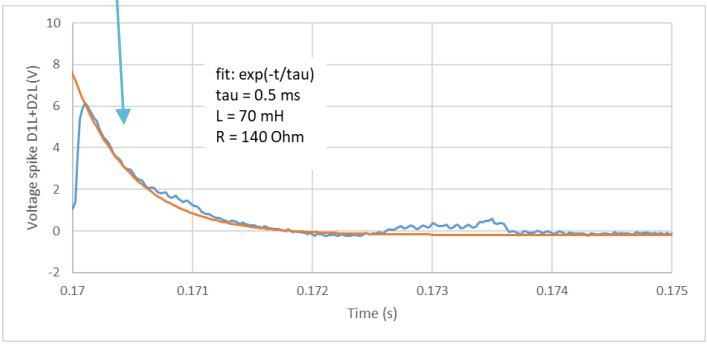
Another excercise: use spikes in voltage (assume inductive) to calculate current flowing through short. In this case (at 0.131 s) the current is 80 mA.
At 71 V this would give a short resistance of 900 Ohm.
(assuming that the 71 V would not decrease)

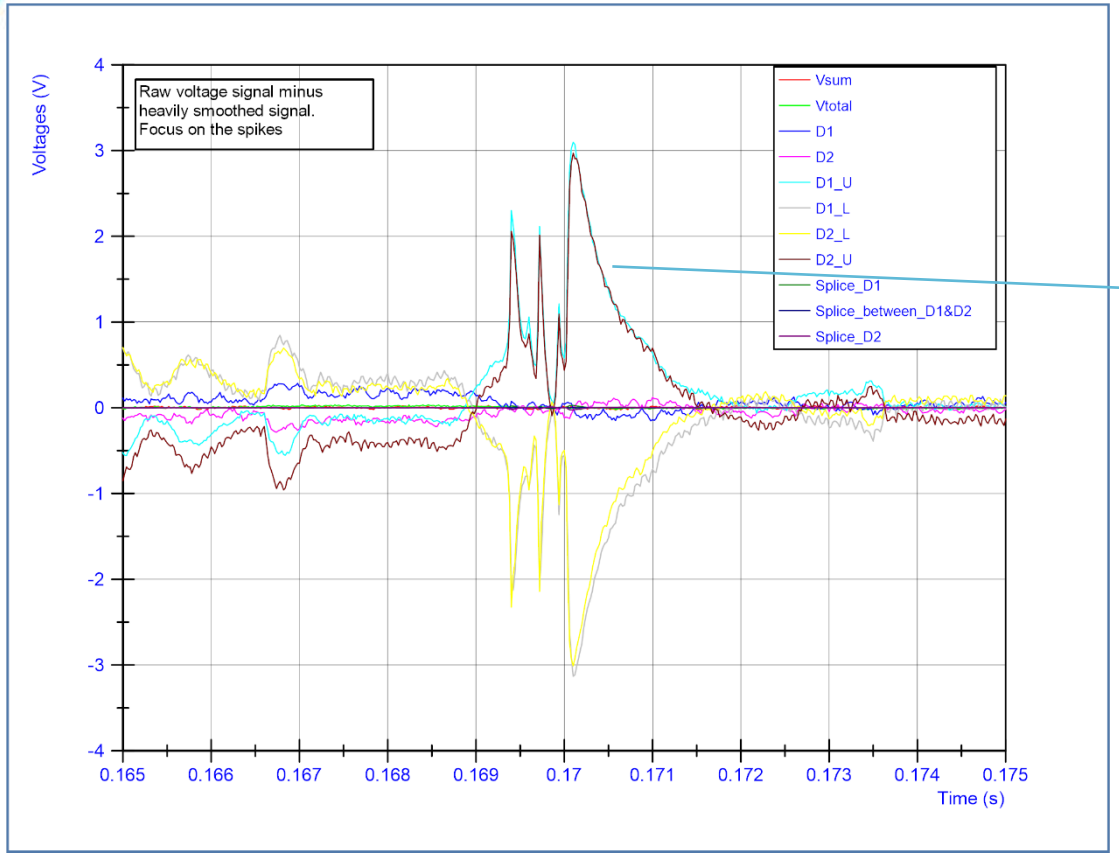
How to explain the variations using the proposed model?



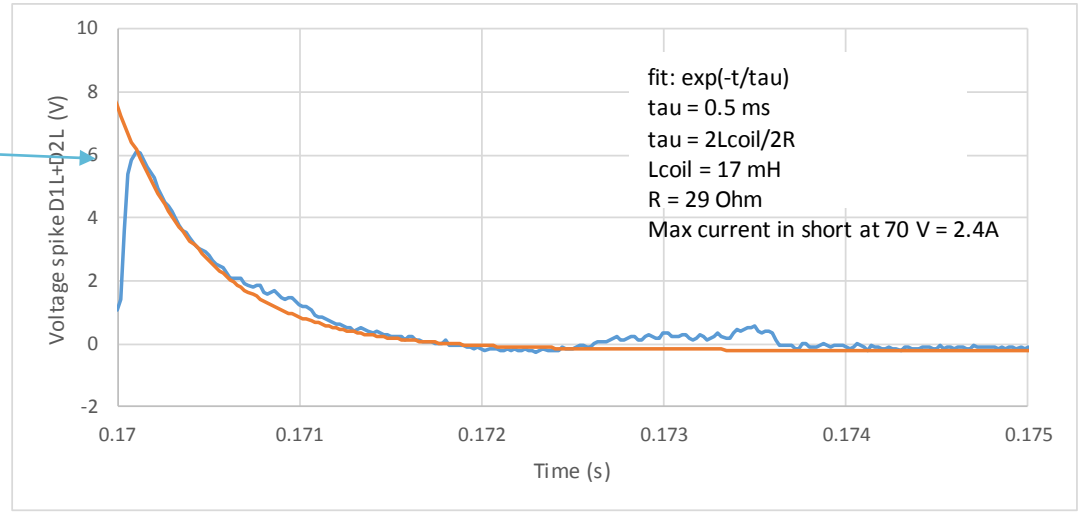


When D1U and D2U are positive the short appears/becomes less resistive.
When negative, the short disappears/becomes more resistive.

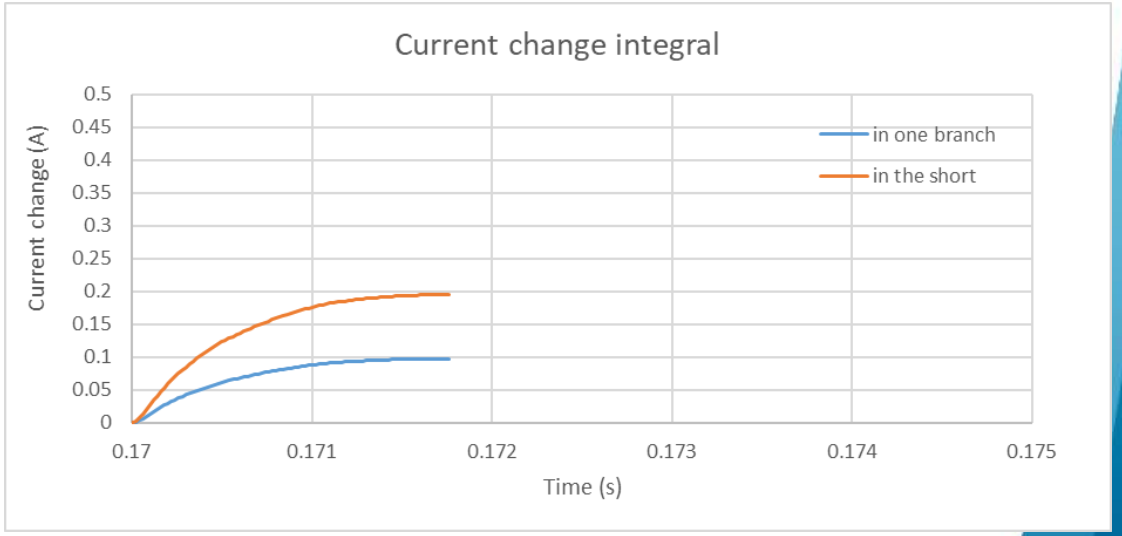


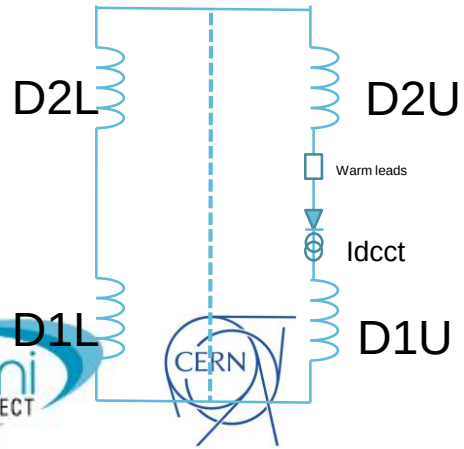


Method 1: time constant and L/R

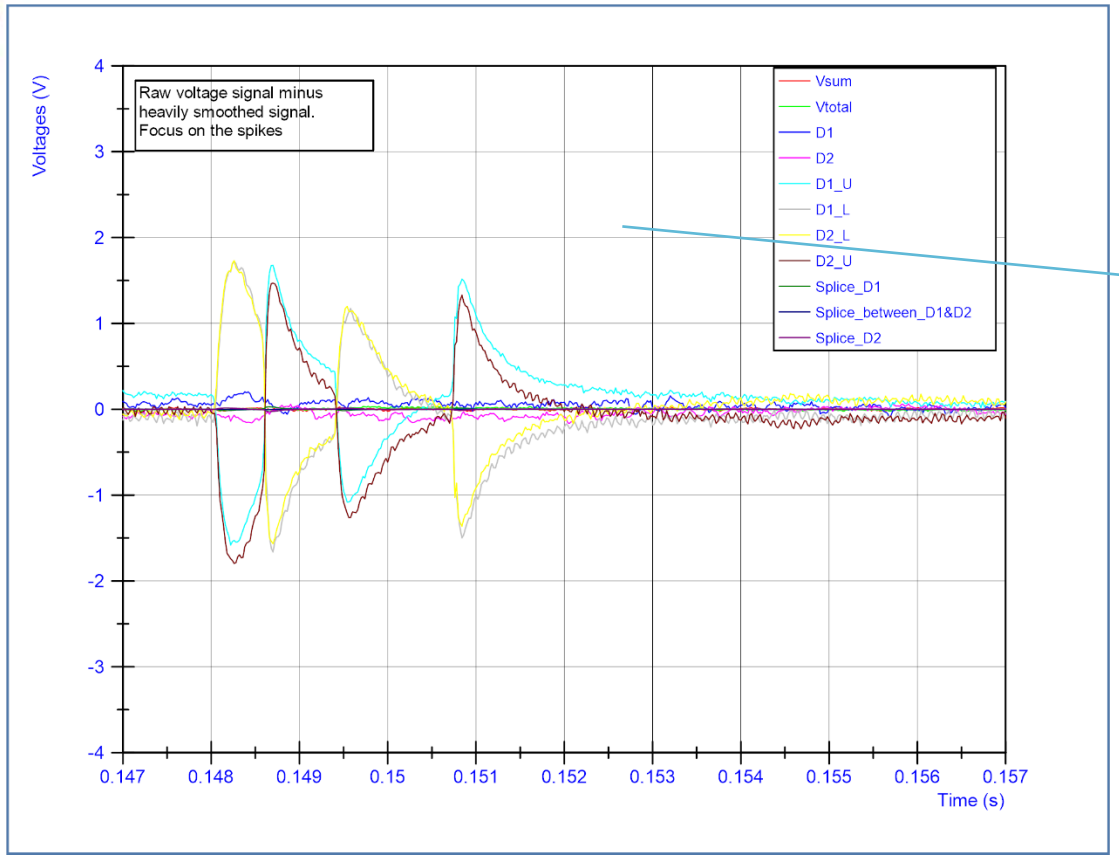


Method 2: integrate dI/dt and see current change (use V/L)

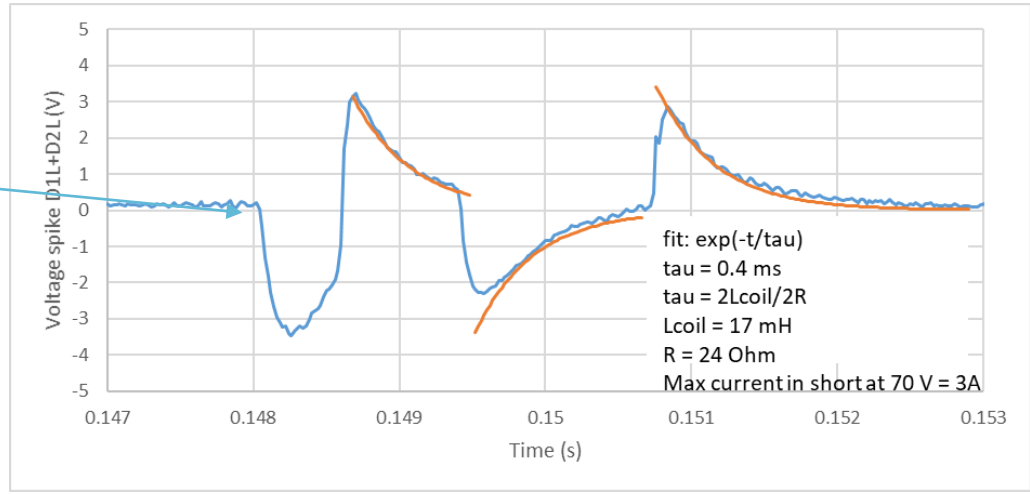




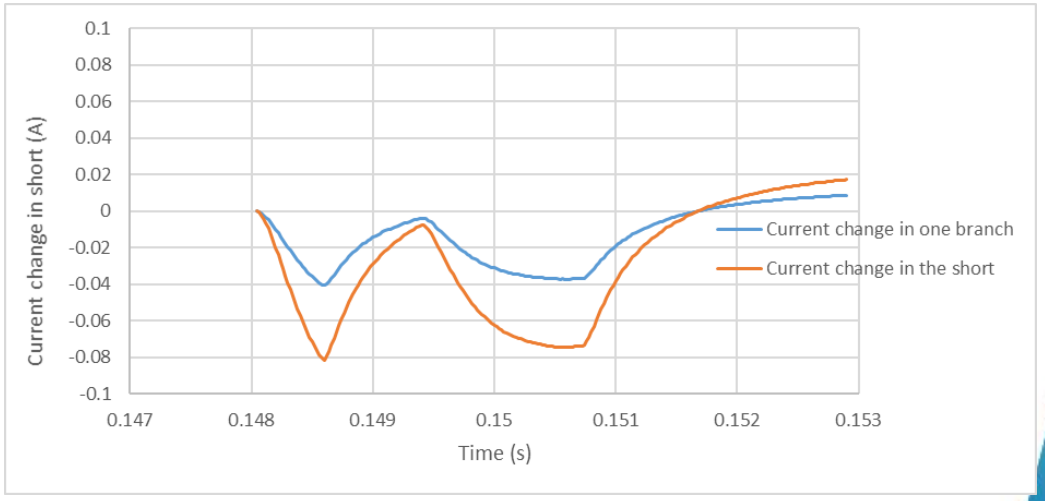
HiLumi HL-LHC PROJECT

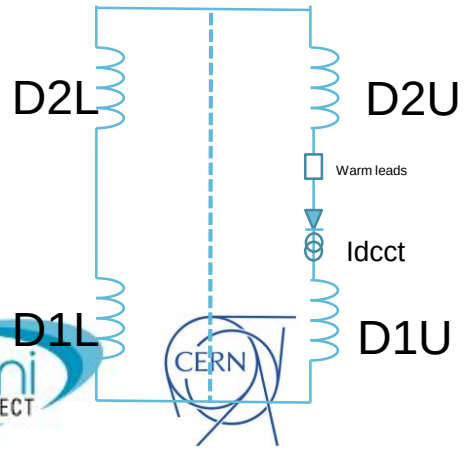


Method 1: time constant and L/R

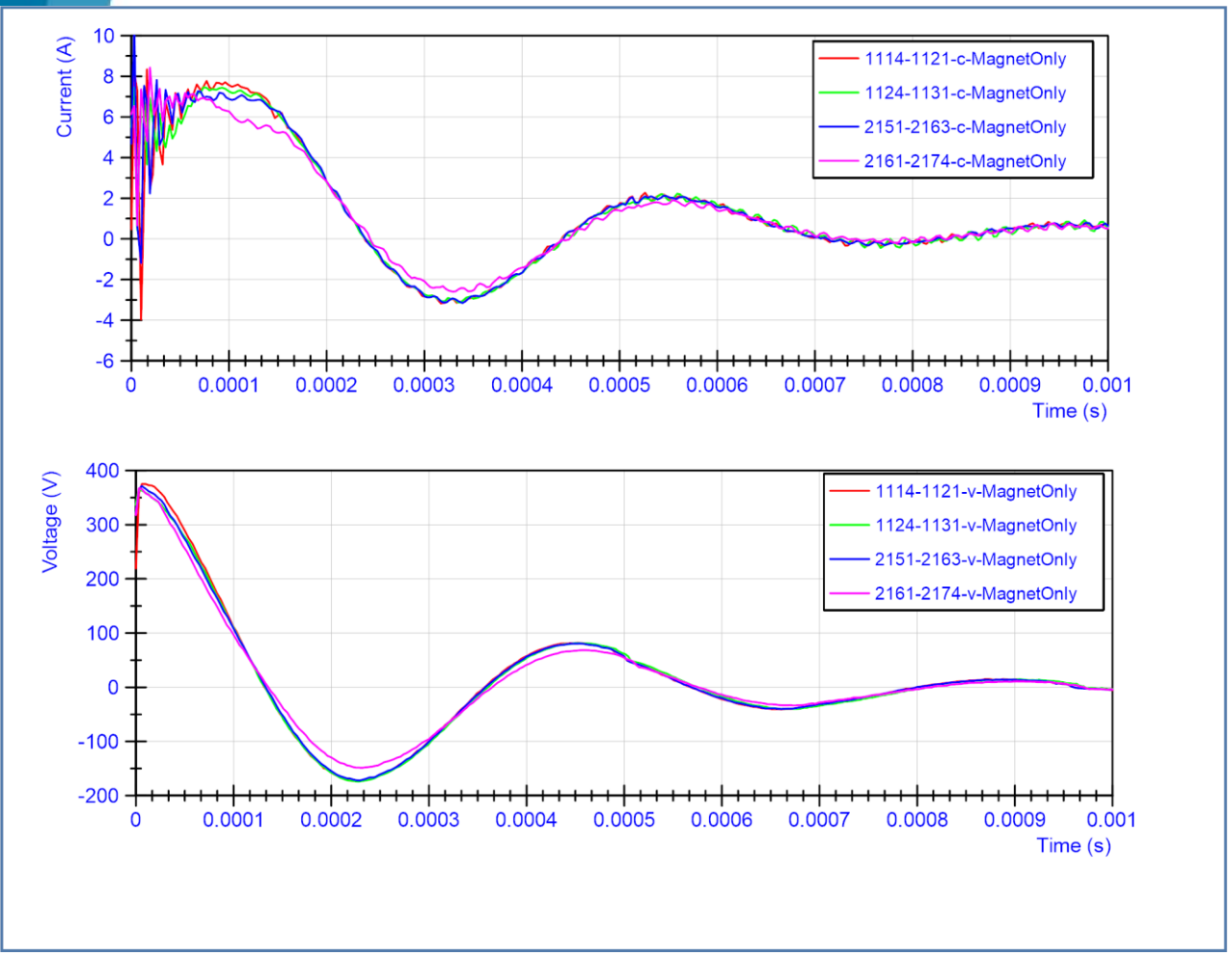


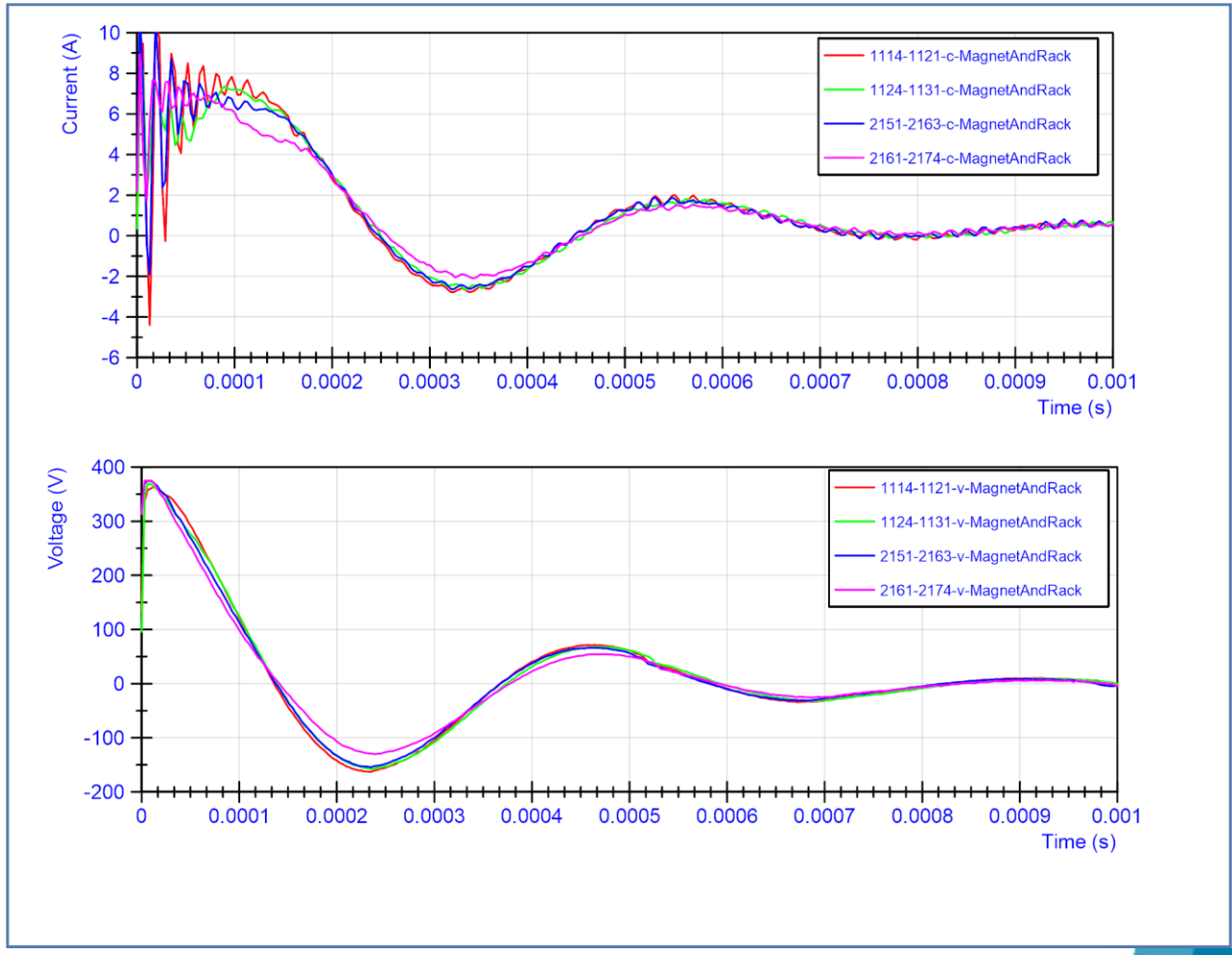
Method 2: integrate dI/dt and see current change (use V/L)





Capacitive discharges at 400 V through the voltage tap leads

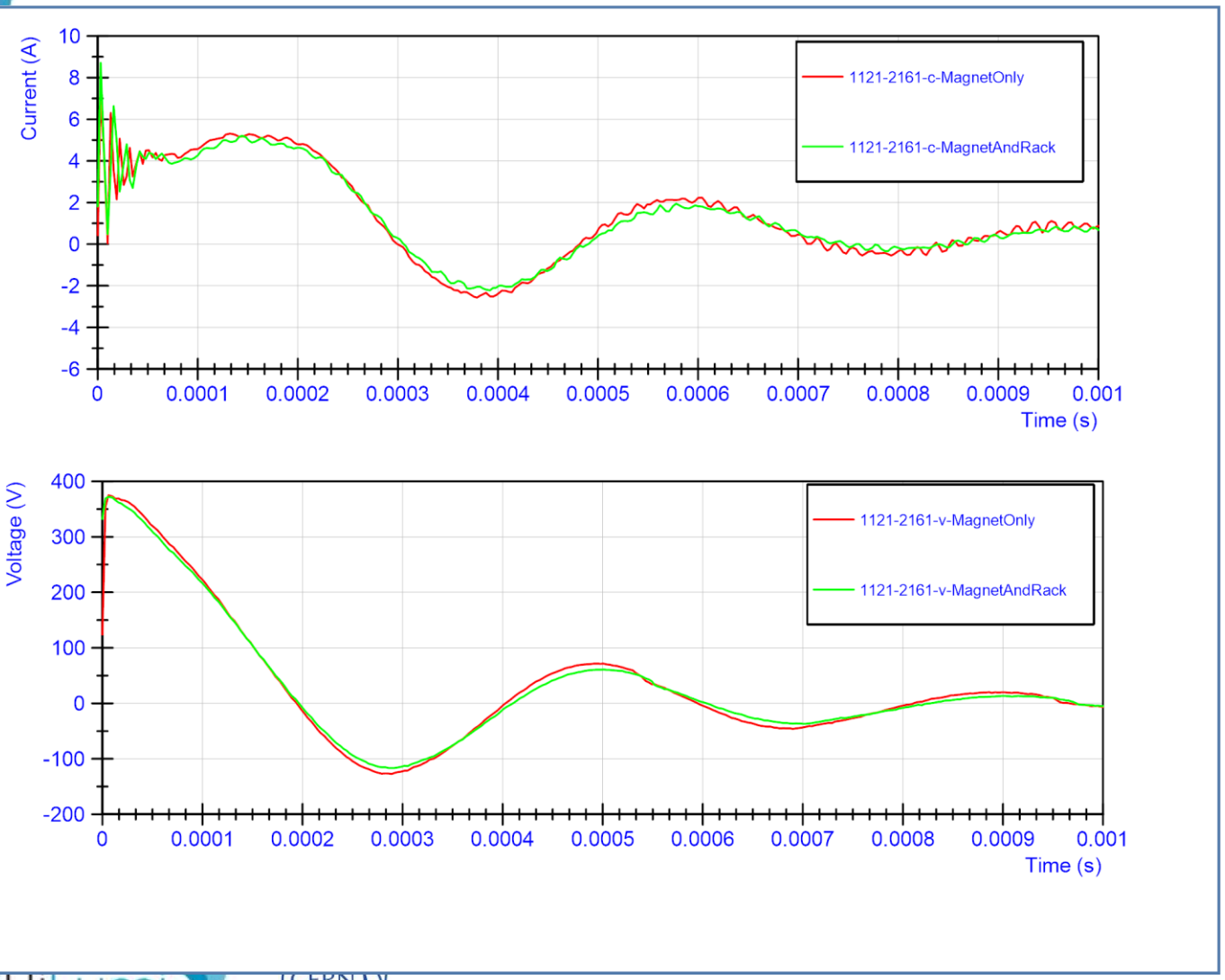




When looking at the magnet only, coil D2U (vt2161-2174) is different than the other coils.
This is similar to MBHB.

When connecting the full measurement rack (to exclude there is a problem inside), we do not see a large difference.

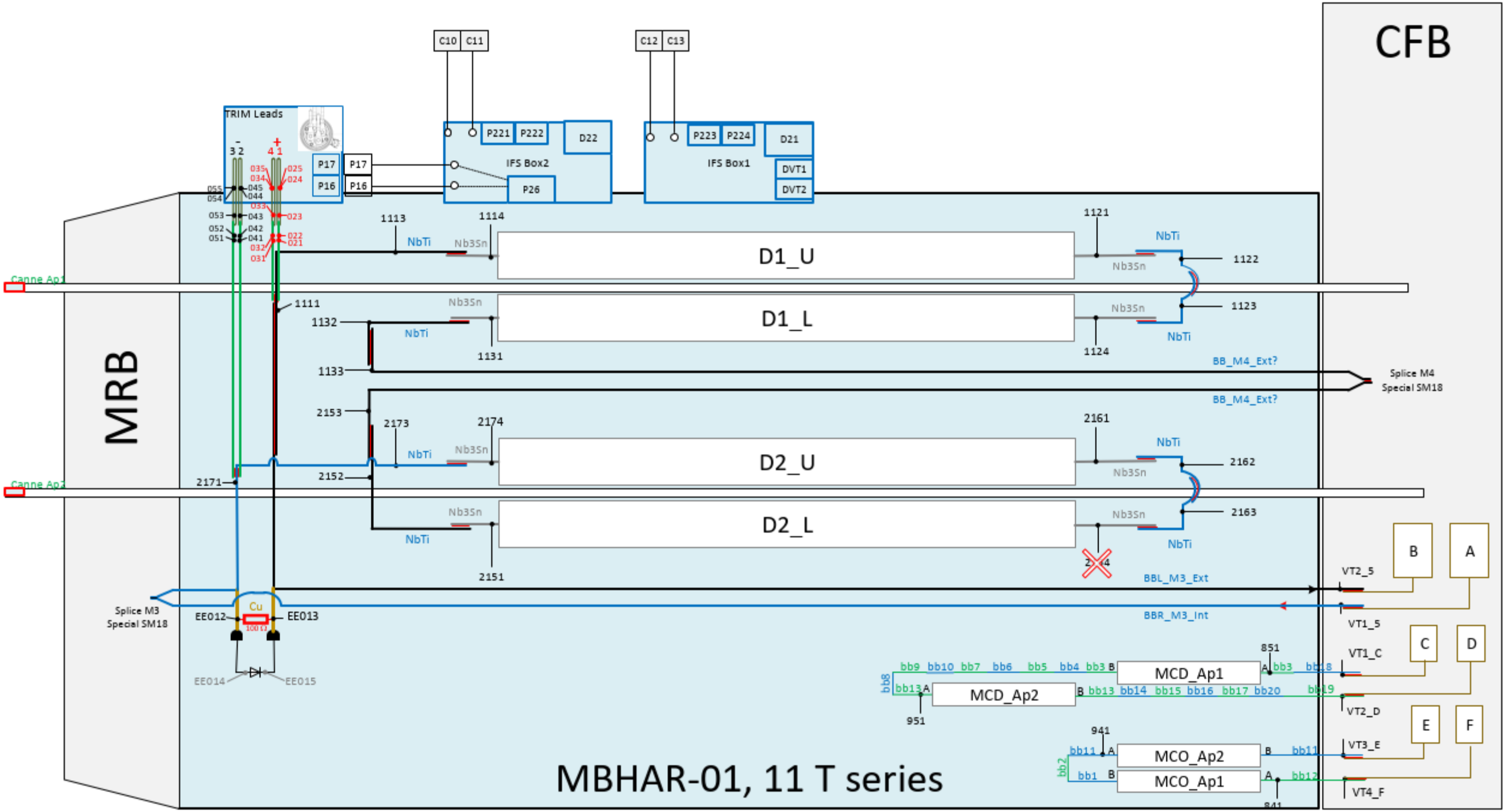
Discharging from Vtap 1121-2161 (the suspected short location)



No low inductance visible.

No strong variation when connecting the full measurement rack.

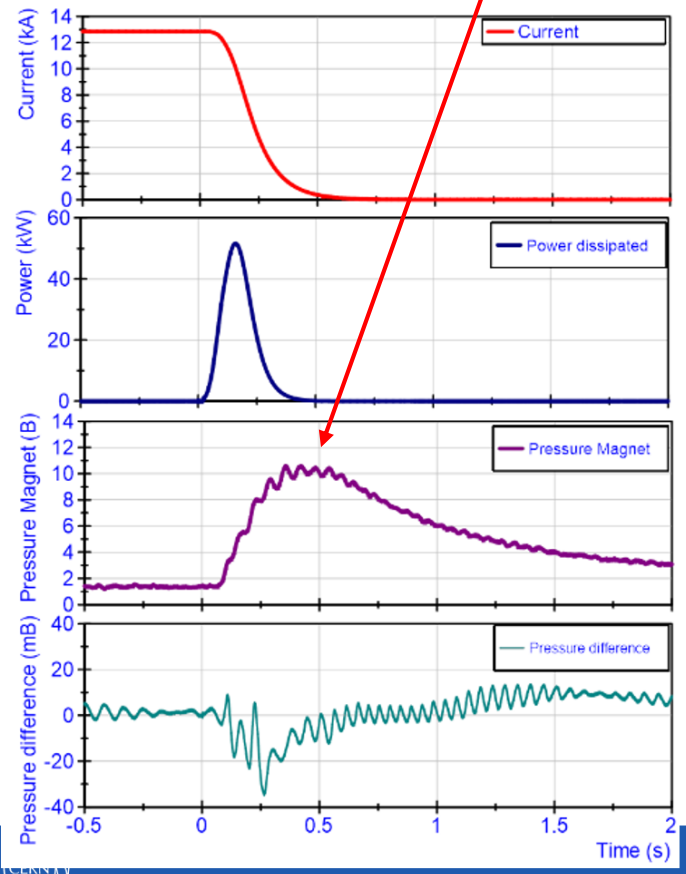
Since the spikes appear above 80 V, the test voltage of 400 V should be sufficient to see any variation.


CFB
MRB
TRIM Leads
C10
C11
C12
C13
P221
P222
D22
IFS Box2
P223
P224
D21
IFS Box1
DVT1
DVT2
P17
P16
P26
D1_U
D1_L
D2_U
D2_L
NbTi
Nb3Sn
1111
1113
1114
1121
1122
1123
1124
1131
1132
1133
2151
2152
2153
2161
2162
2163
2171
2173
2174
BB_M4_Ext?
BBL_M3_Ext
BBR_M3_Int
Splice M4
Special SM18
Splice M3
Special SM18
Canne Ap1
Canne Ap2
EE012
EE013
EE014
EE015
Cu
MCD_Ap1
MCD_Ap2
MCO_Ap2
MCO_Ap1
VT1_5
VT2_5
VT1_C
VT2_D
VT3_E
VT4_F
A
B
C
D
E
F
MBHAR-01, 11 T series

Wild idea: In the capilary there is a compressible gas -> could helium movement move the wires in or close to the ca

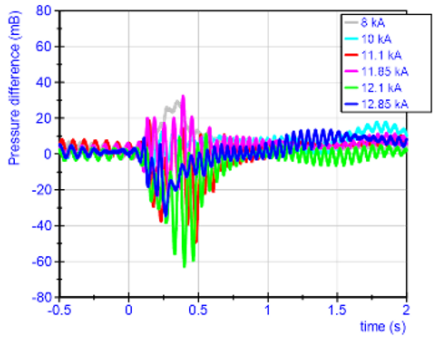
Pressure wave in the magnet during quench, measured for an MB magnet

Test 1: results first pressure peak



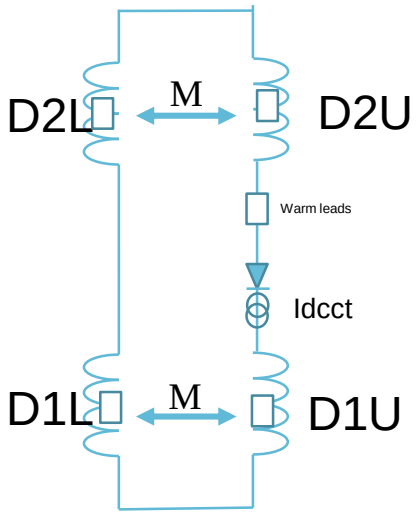
As is visible, the capilaries are prone to oscillations, which are difficult to avoid in 1.5 meter long capilaries between 1.9 K and 300 K.

6 quenches analysed:



Current (kA)	$P_{magnet, max}$ (B)	$\lvert dP \rvert_{max}$ (mB)
8	5.8	29
10	8.0	12
11.1	9.1	49
11.85	9.7	32
12.1	10.0	62
12.85	10.7	34

Pressure difference is highest at the 12.1 kA quench: Never exceeding 60 mB.



Note that at this stage the coils have a resistance, but not all the same.