Test results of MCBXFBP2a

Salvador Ferradás, Jerome Feuvrier, Jean-Luc Guyon, Franco Mangiarotti, Juan Carlos Pérez, Guillaume Pichon, Gerard Willering

Test plan: EDMS #2414418

WP3 Meeting – 12 November 2020

https://indico.cern.ch/event/973841/

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1. HV Tests
2. Protection scheme
3. Cooldown & Warm-up
4. Cold powering
5. Conclusions

Electrical insulation test (I/III)

@Reception
SM18 Hall
293 K, Air

Circuit	V [kV]	Time [s]	Resistance [GΩ]
Inner – GND	2	60	140
Outer – GND	2	60	104

@Cryostat
Cluster D
293 K, Air
CD1 Before test

Circuit	V [kV]	Time [s]	Resistance [GΩ]
Inner – GND	2	60	19
Outer – GND	2	60	16

@Cryostat
Cluster D
1.9 K, He
CD1 Before test

Circuit	V [kV]	Time [s]	Resistance [GΩ]
Inner – GND	2	60	5.7
Outer – GND	2	60	17

MIT515

- Voltage: 5 kV (+4%, -0%, ±10 V nominal test voltage at 1 GΩ load (0°C to 30°C)

- Current: ±5% ±0.2 nA at all voltages (20 °C) [1].
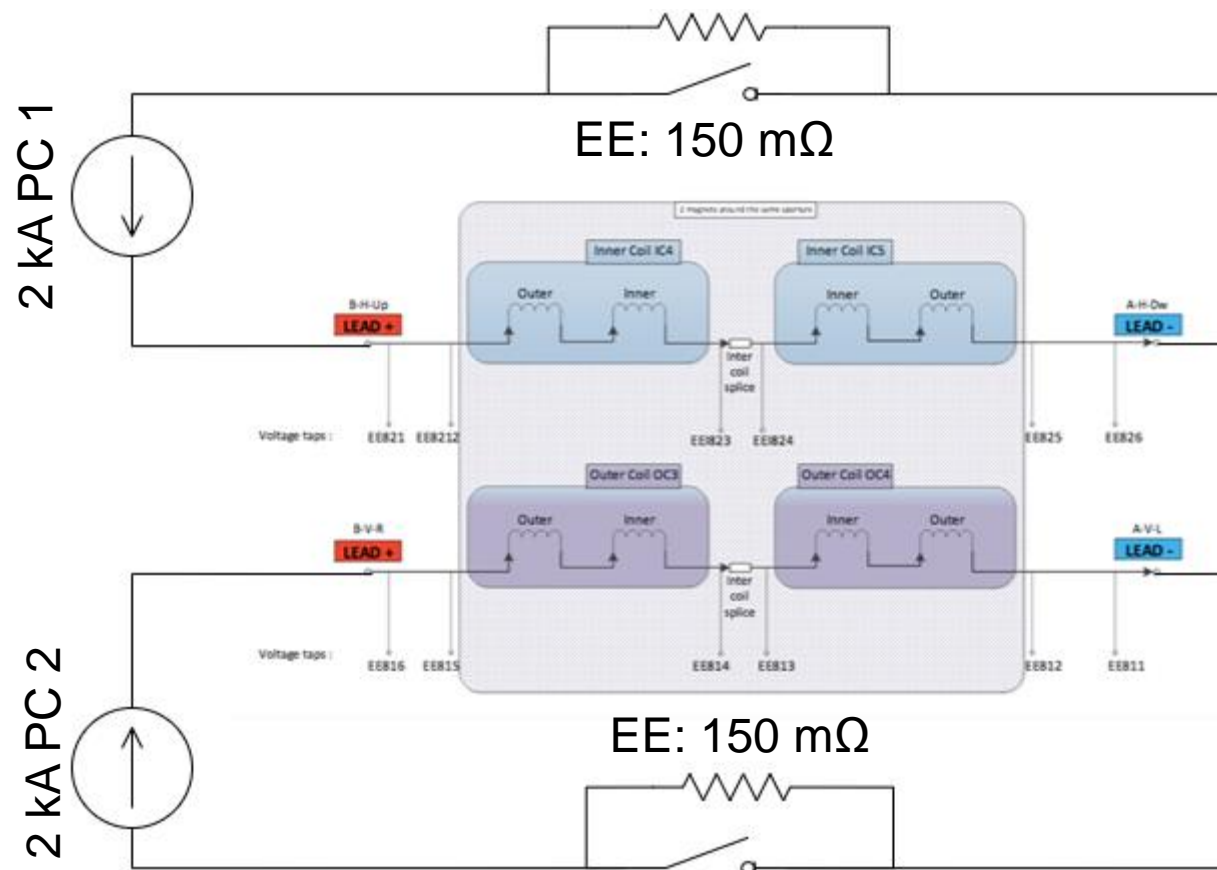

MCBXFBP2a
HCMCBXFB100-E9000001

EDMS : 2413181

[1] MIT515; 5 kV d.c. Insulation Resistance Testers; https://us.megger.com/5-kv-insulation-resistance-tester-mit525#technical
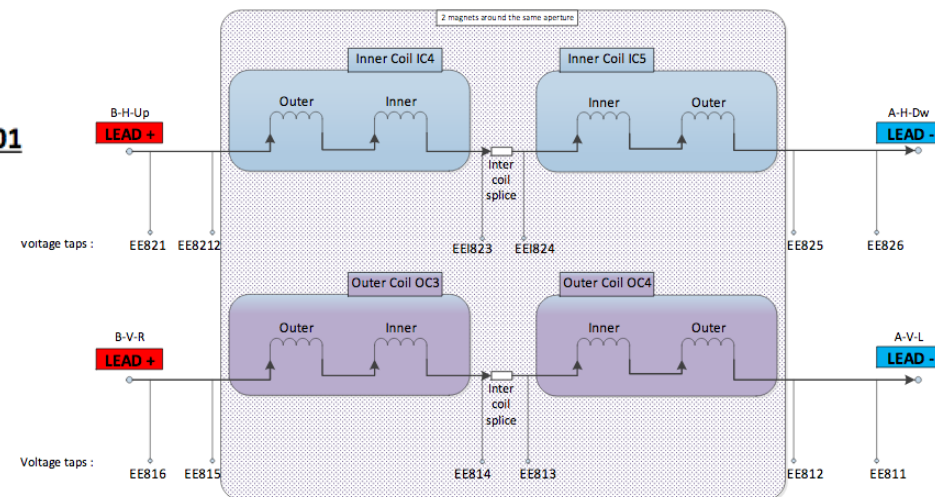
Electrical insulation test (II/III)

@Cryostat
Cluster D
1.9 K, He
CD1 After test

Circuit	V [kV]	Time [s]	Resistance [GΩ]
Inner – GND	2	60	54
Outer – GND	2	60	12

@Cryostat
Cluster D
4.5 K, He
CD2 Before test

Circuit	V [kV]	Time [s]	Resistance [GΩ]
Inner – GND	1	60	31
Outer – GND	1	60	6.9

@Cryostat
Cluster D
4.5 K, He
CD2 After test

Circuit	V [kV]	Time [s]	Resistance [GΩ]
Inner – GND	1	60	29
Outer – GND	1	60	14

MCBXFBP2a
HCMCBXFB100-E9000001

EDMS : 2413181

MIT515

- Voltage: 5 kV (+4%, -0%, ±10 V nominal test voltage at 1 GΩ load (0°C to 30°C)
- Current: ±5% ±0.2 nA at all voltages (20 °C) [1].

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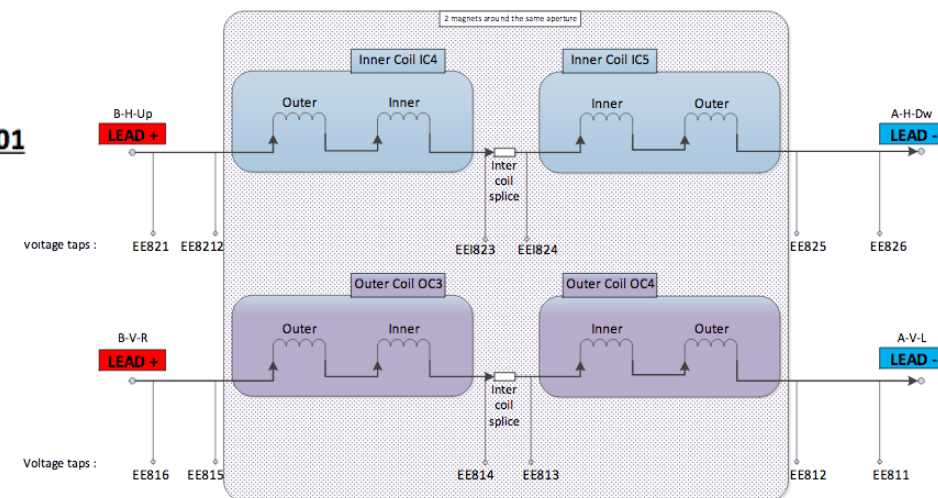
Electrical insulation test (III/III)

@Cryostat
Cluster D
4.5 K, He
CD3 Before test

Circuit	V [kV]	Time [s]	Resistance [GΩ]
Inner – GND	1	60	40
Outer – GND	1	60	11

@Cryostat
Cluster D
4.5 K, He
CD3 After test

Circuit	V [kV]	Time [s]	Resistance [GΩ]
Inner – GND	1	60	25
Outer – GND	1	60	21

MIT515
- Voltage: 5 kV (+4%, -0%, ±10 V nominal test voltage at 1 GΩ load (0°C to 30°C)
- Current: ±5% ±0.2 nA at all voltages (20 °C) [1].

MCBXFBP2a
HCMCBXFB100-E9000001

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[1] MIT515; 5 kV d.c. Insulation Resistance Testers; https://us.megger.com/5-kv-insulation-resistance-tester-mit525#technical
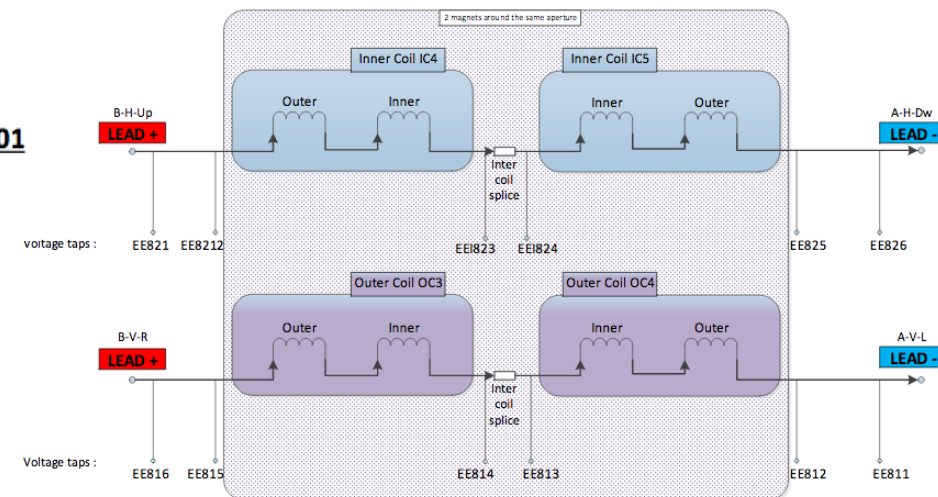
Protection scheme

Baseline protection

EE: 150 mOhm
Both circuits have a bipolar IGBT EE switch
QH: - none

Detection setup	Name	Vtaps (+, -, mid)	Settings
Magnet	Diff_Inner_coil (PotAim)	EE821,EE826,EE823	10 ms @ 100 mV
	Diff_Outer_coil (PotAim)	EE816,EE811,EE814	10 ms @ 100 mV
	Sum_In_Ind (uQDS, inductive compensation)	EE821,EE826 & Idcct	10 ms @ 200 mV
	Sum_Out_Ind (uQDS, inductive compensation)	EE816,EE811 & Idcct	10 ms @ 200 mV
Splices	Splices_inter_coil_ID		8 ms@ 10 mV
	Splice_inter_coil_OD		8 ms@ 10 mV
Leads and insert	Sc Cable		8 ms @ 10 mV
	Cu Cable		80 ms @ 500 mV

2 kA PC 1

EE: 150 mΩ

2 kA PC 2

EE: 150 mΩ

MCBXFBP2a
HCMCBXFB100-E9000001

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Cooldown 1

Warmup 1

Max allowed ∆T = 100 K
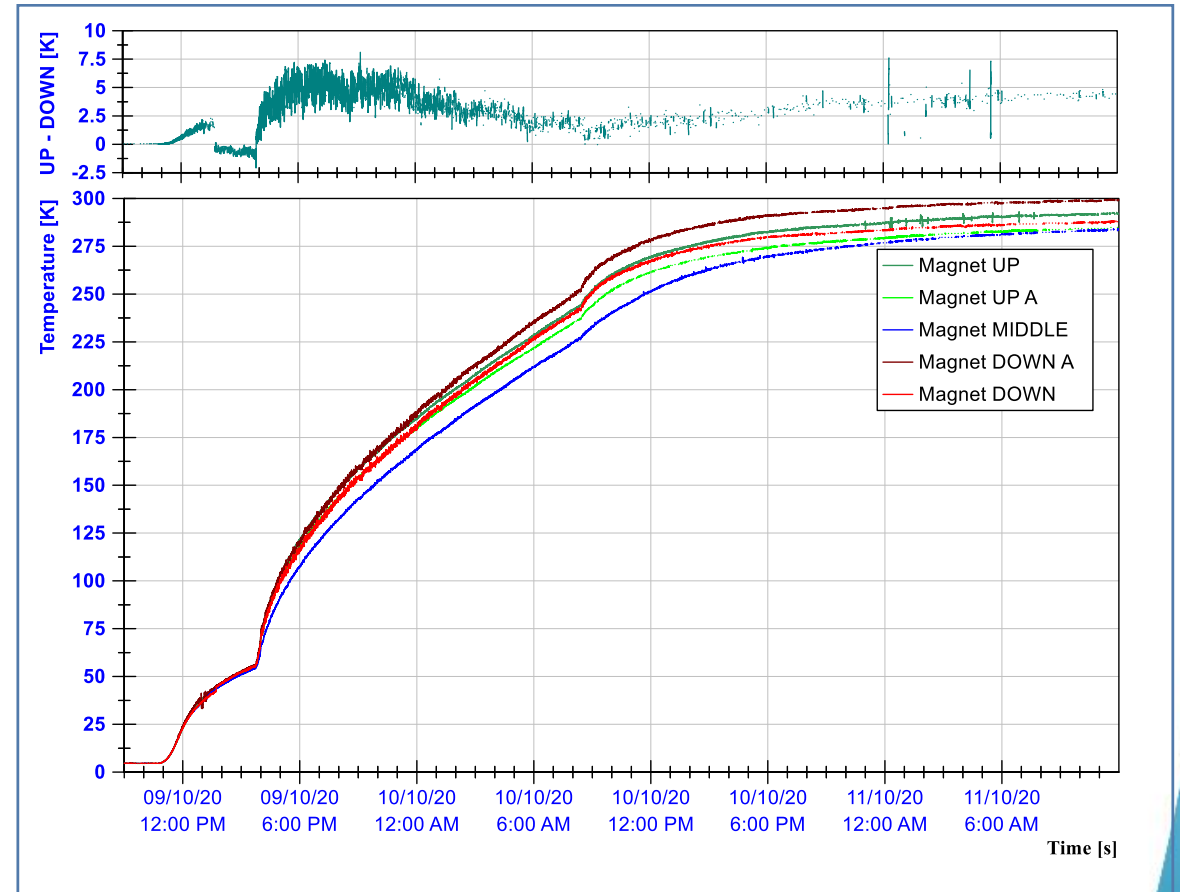
Max allowed ∆T = 100 K
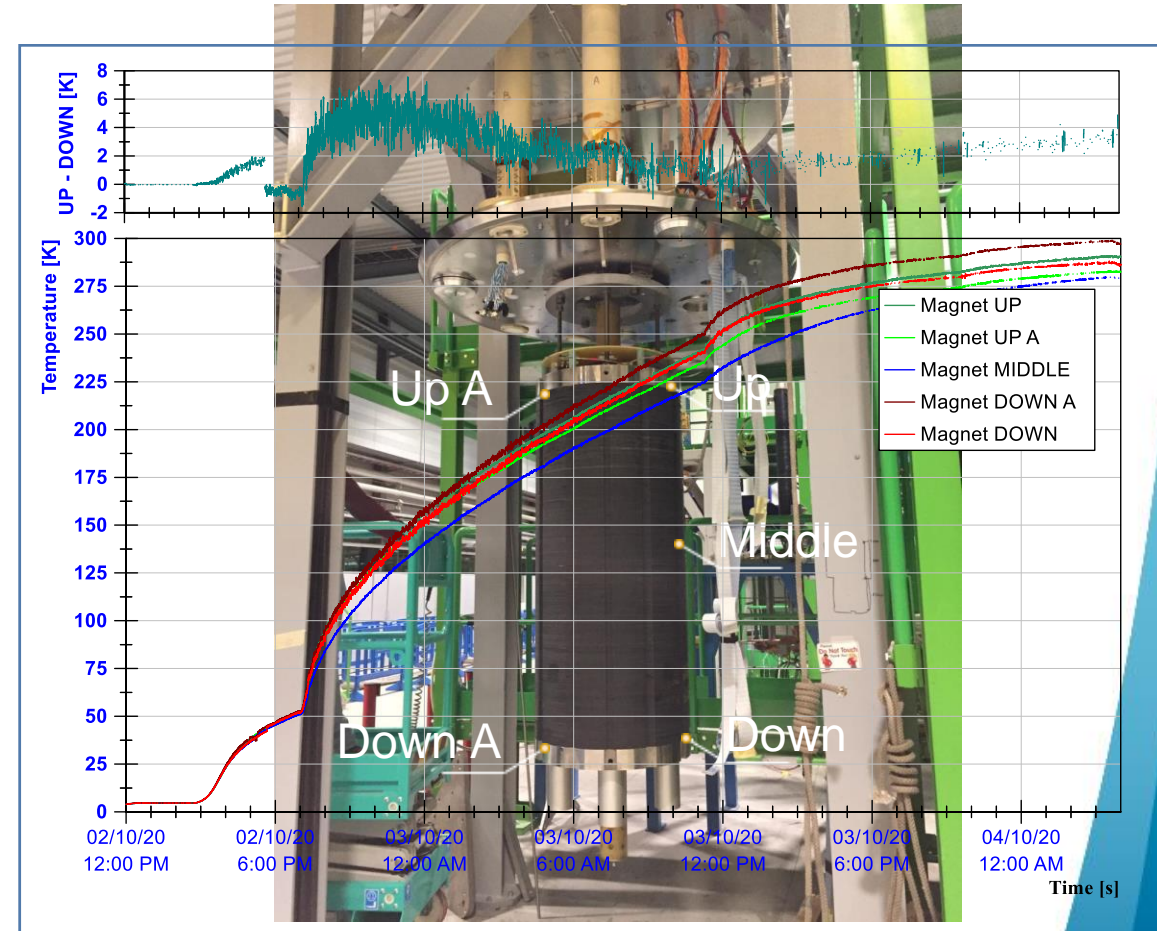
! Anomalous behavior of the sensors in the valve distribution box

Disclaimer: Approximate sensor positioning

Cooldown 2
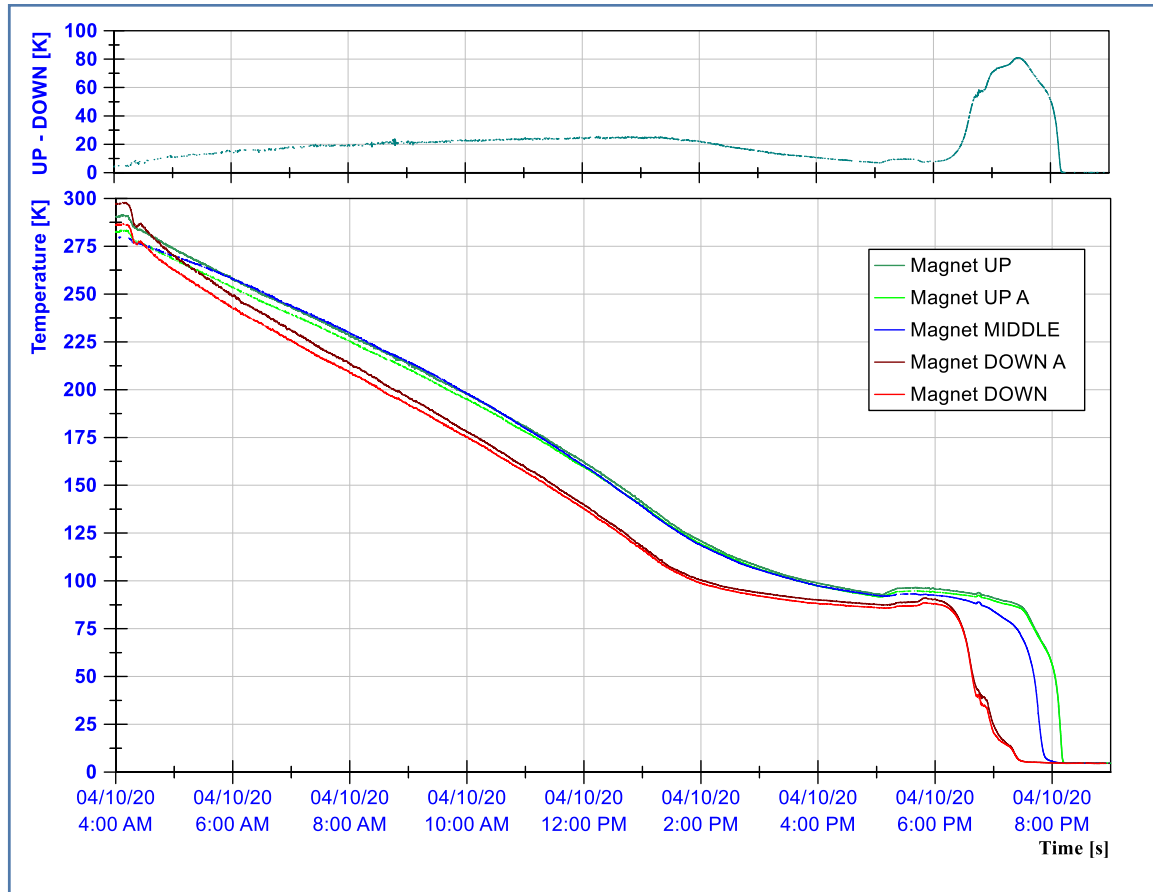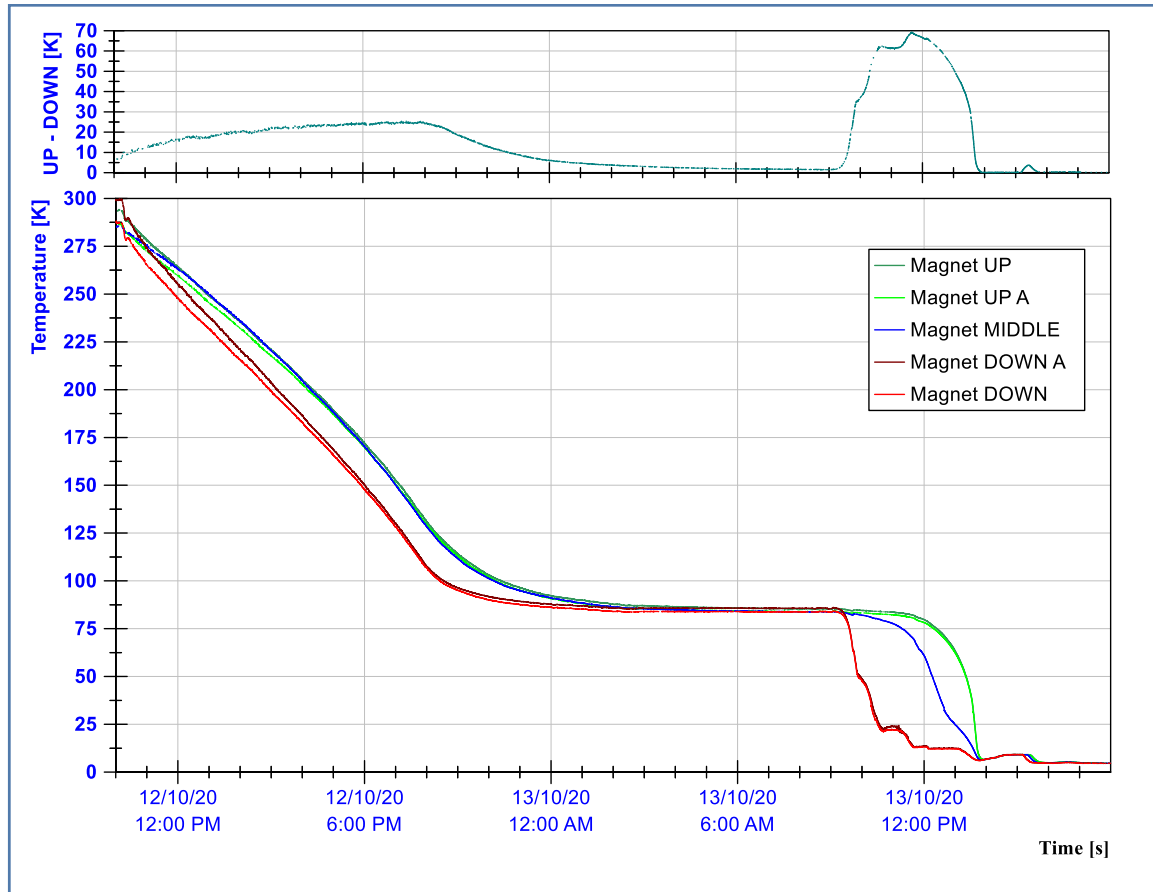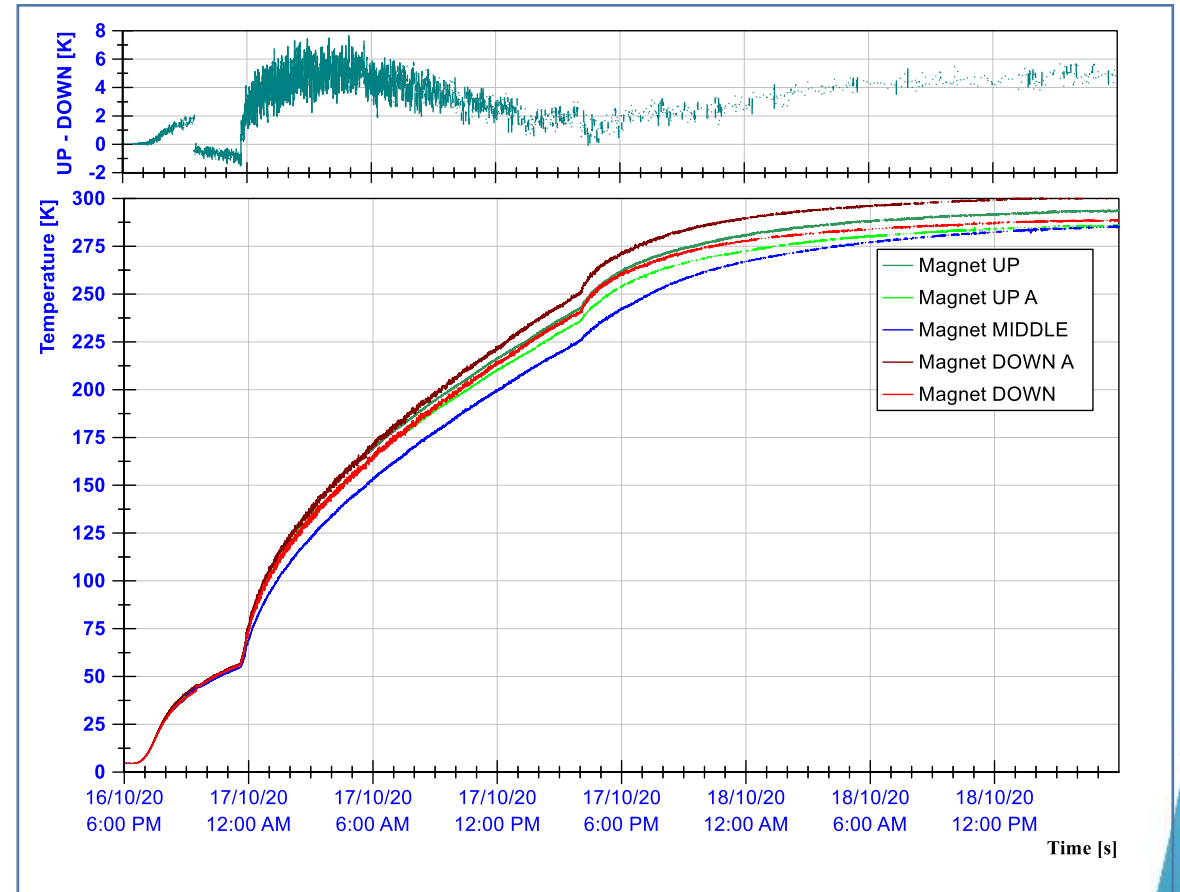
Warmup 2

Cooldown 3
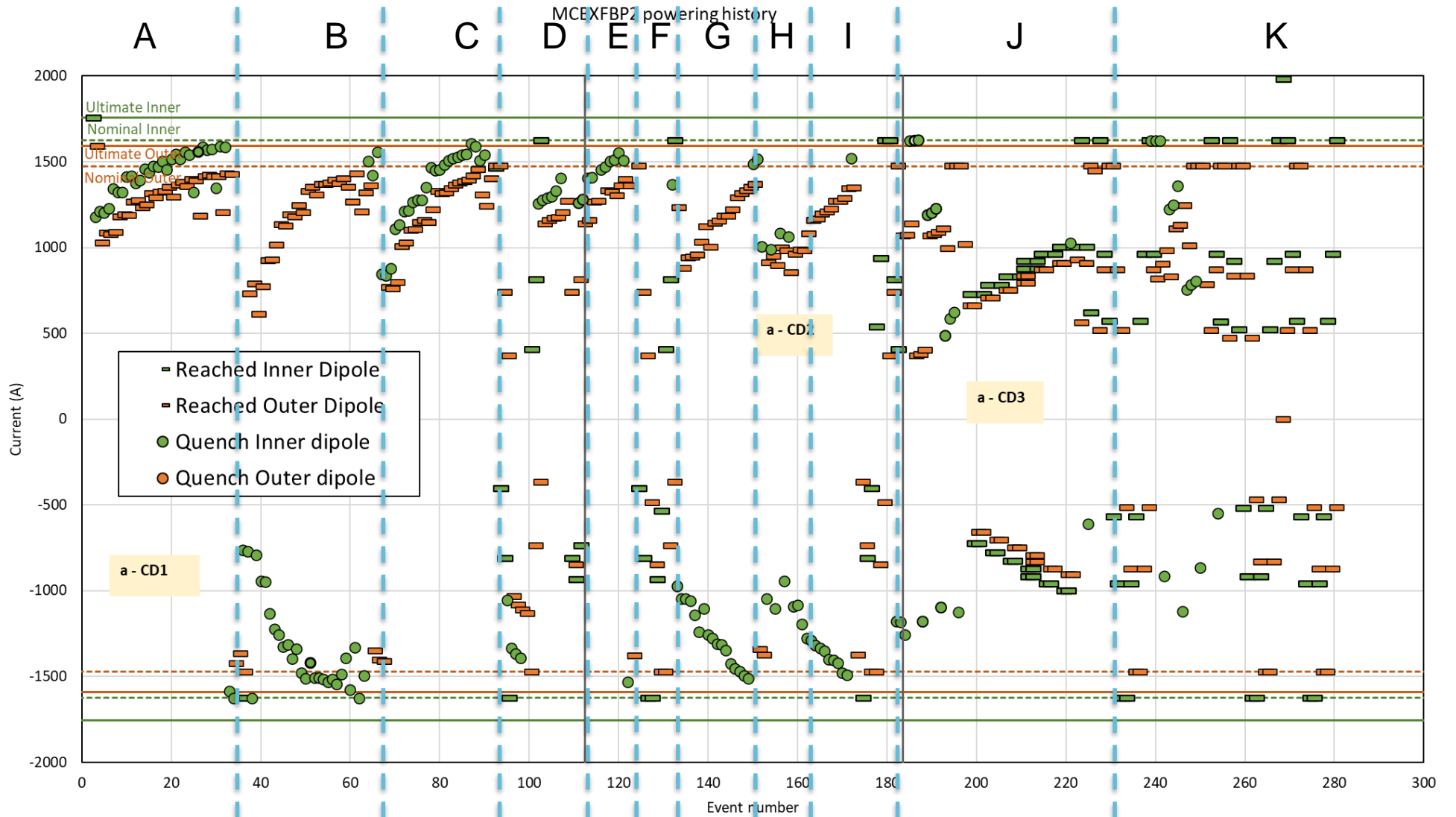
Warmup 3

Summary of events, for completeness

MCBXFBP2 powering history

MCBXFBP2a:

- Reached ultimate in both circuits standalone
- Reached 1980 A Inner circuit stand alone

- 280 Events

Training quenches			
	IC4	IC5	OC3
	91	83	4
Total	177		

- Reached nominal + torque
- Reached 97% of - nominal torque

A. Training Q1 (from event 0)

- MCBXFBP2a:
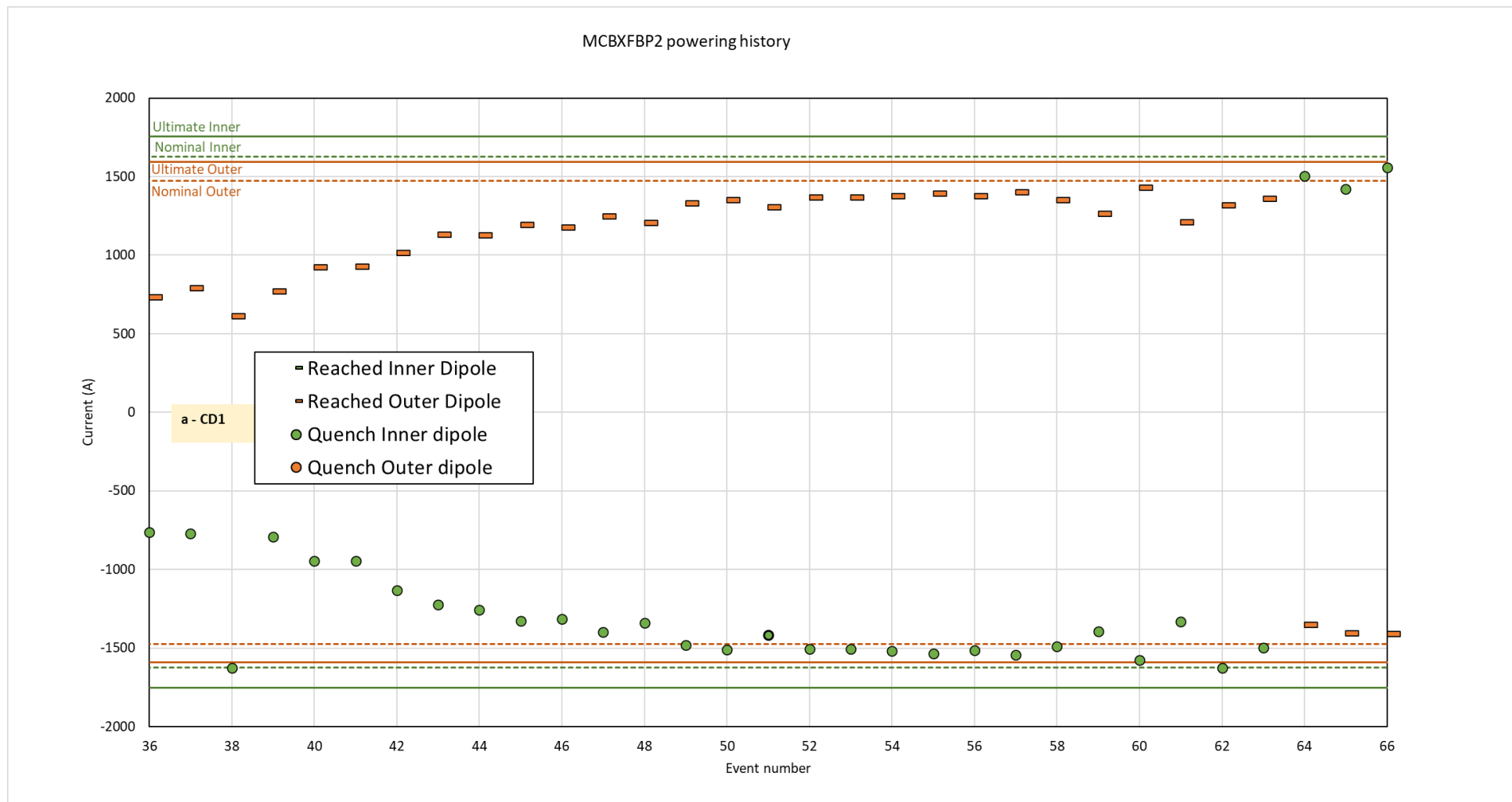
- 32 quenches to nominal

Training quenches		
IC4	IC5	OC3
20	11	1

MCBXFBP2 powering history
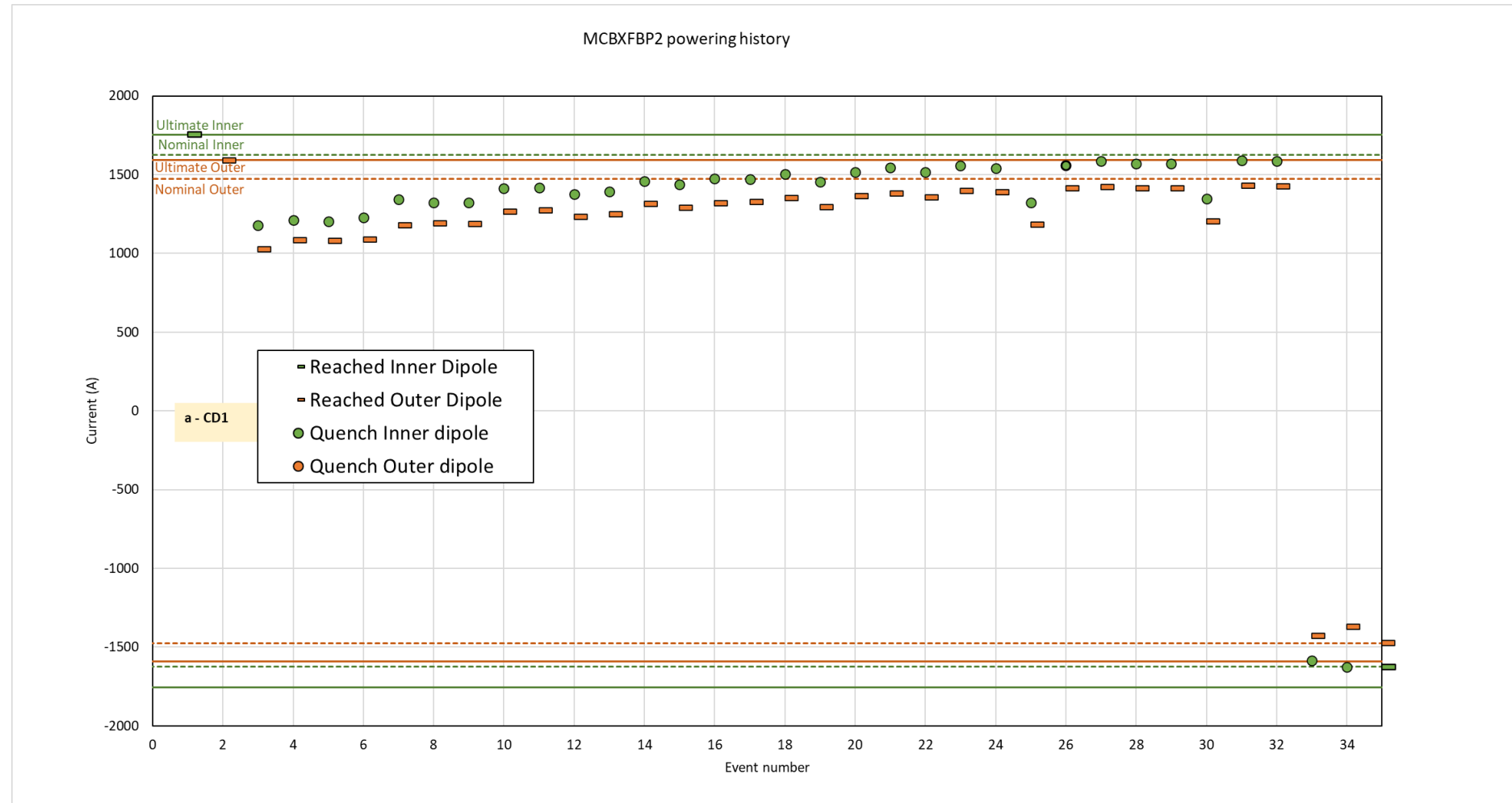
B. Training Q2 right after

- MCBXFBP2a:

- 31 quenches

	Training quenches		
	IC4	IC5	OC3
	11	18	2

- First quench at 23% of nominal torque
- Reached 94% of nominal torque in event #60

MCBXFBP2 powering history

C. Training Q1 again right after

MCBXFBP2a:

22 quenches

	Training quenches		
	IC4	IC5	OC3
	12	10	0

- First quench at 27% of nominal torque
- Reached 97% of nominal torque in event #87


MCBXFBP2 powering history
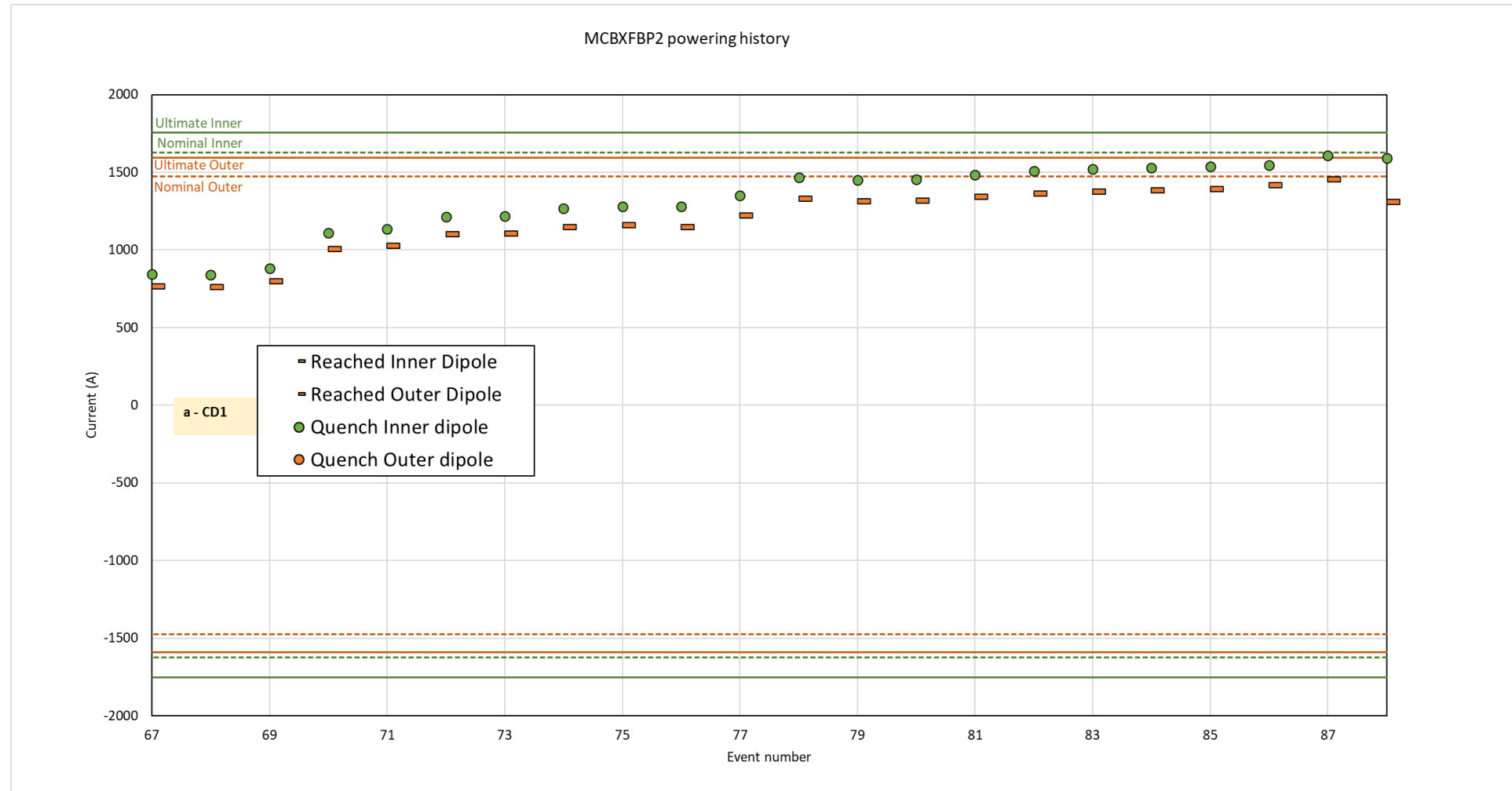
■ MCBXFBP2a:

- Up to 90% of nominal torque in the first and third quadrant
  - The magnet quenched twice before reaching the 90% target in Q1
  - Quenched at 45% in Q3 after inversing the torque in Q2. Three more quenches were performed before moving to Q4. Target was not reached.
  - A last ramp in Q1 (**not shown in the plot bottom right**) was performed after the last ramp in Q4 and the magnet quenched at 60% of nominal torque.
- Up to 25% of nominal torque in the second and fourth quadrant
  - Reached without quench in Q2 and Q3.
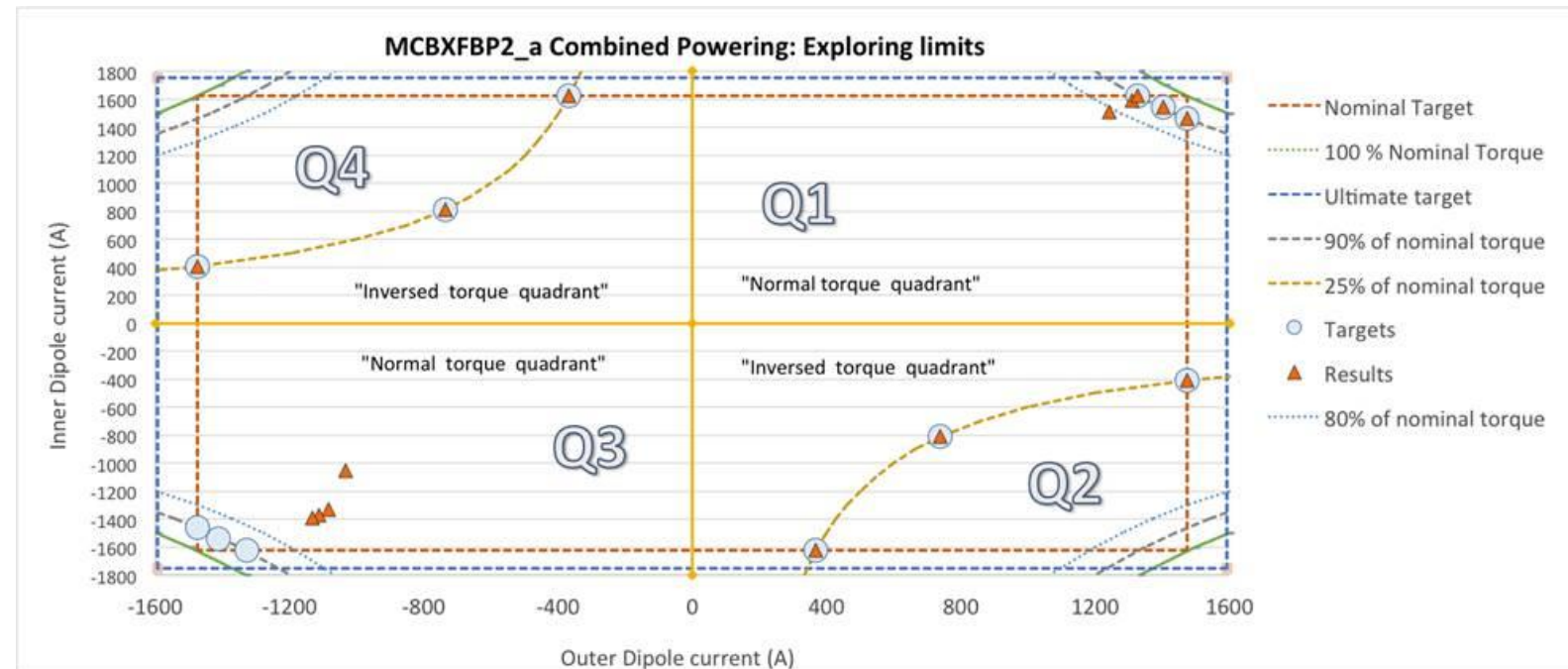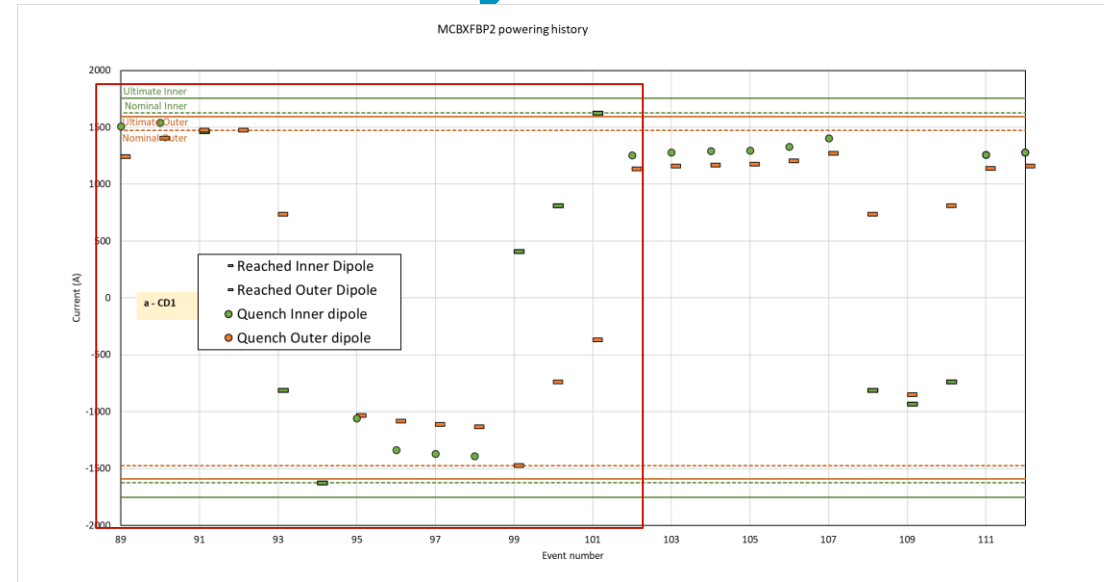
- MCBXFBP2a:

1. The magnet was retrained up to 74% of nominal torque in Q1 (last event was at 60%), it took 5 more quenches
2. Reached 25% of nominal torque in quadrant 2 without quench
3. Reached 33% of nominal torque in quadrant 3 without quench
4. Reached 25% of nominal torque in quadrant 4 without quench
5. Ramp to quench in Q1, reaching 60% of nominal torque (not shown in the plot bottom right)
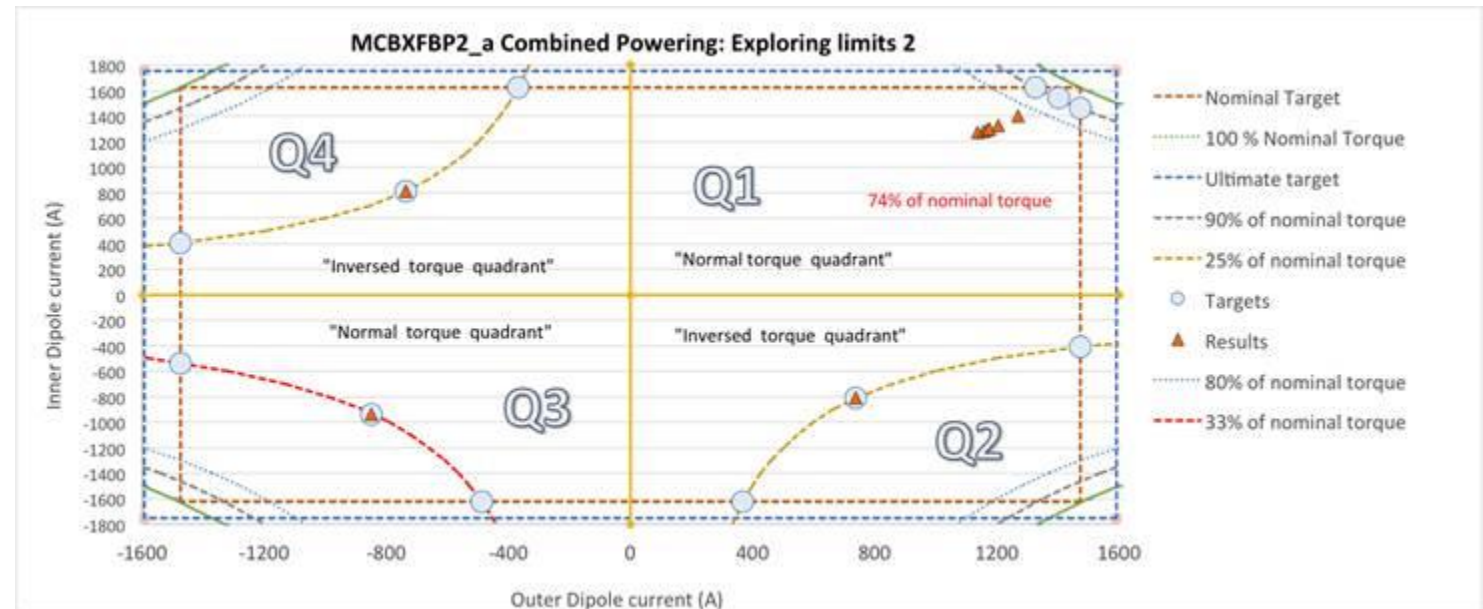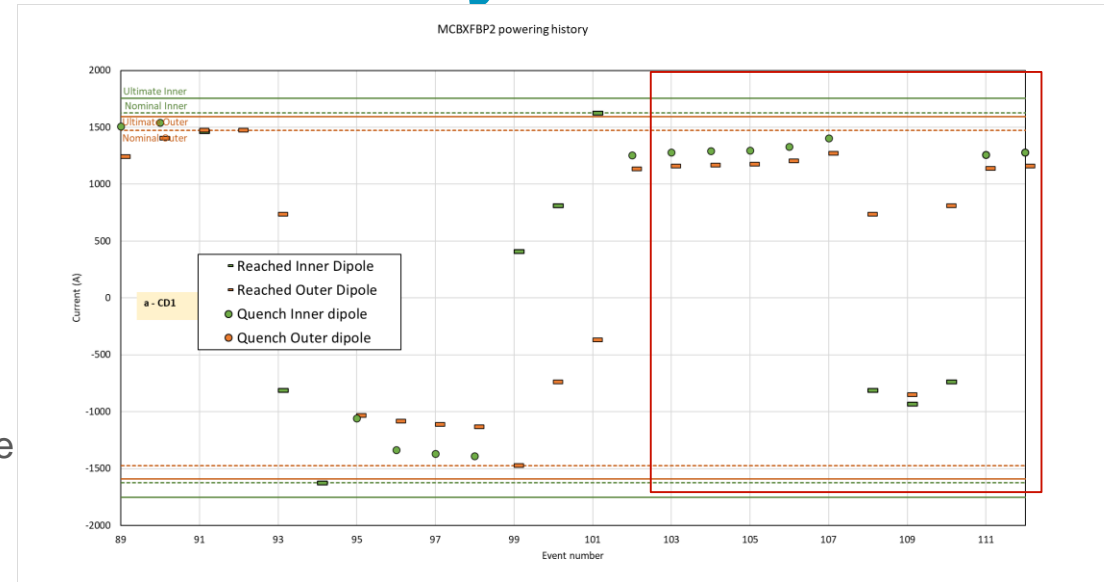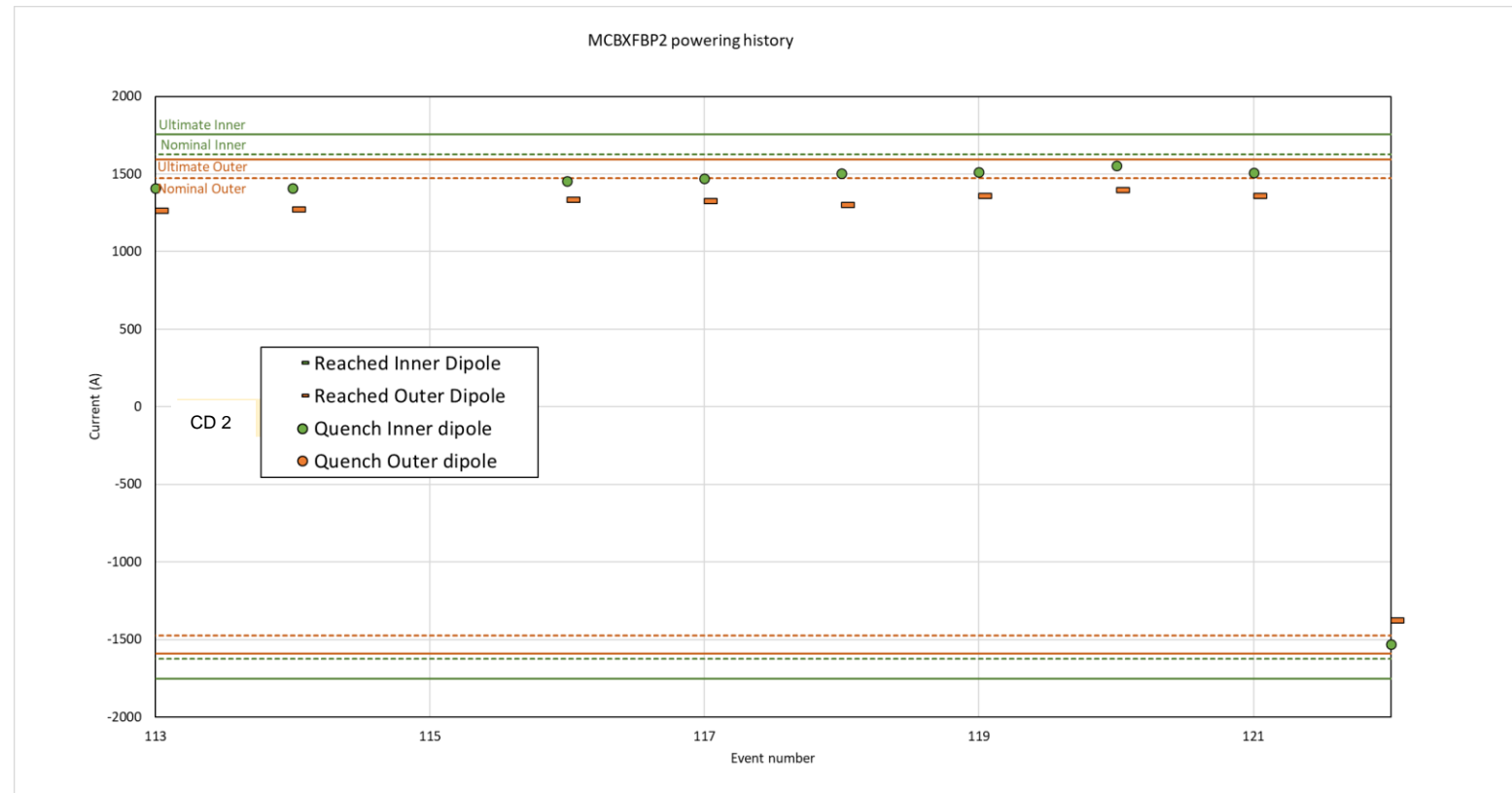
E. Training verification in Q1 after TC

CD 2

MCBXFBP2a:

Last quench in Q1 before TC at 61% of nominal torque

First quench at 75% of nominal torque

7 quenches until 90% of nominal after TC (9 in total in this test due to a bit of detraining in the last two)

Training quenches		
IC4	IC5	OC3
6	3	0

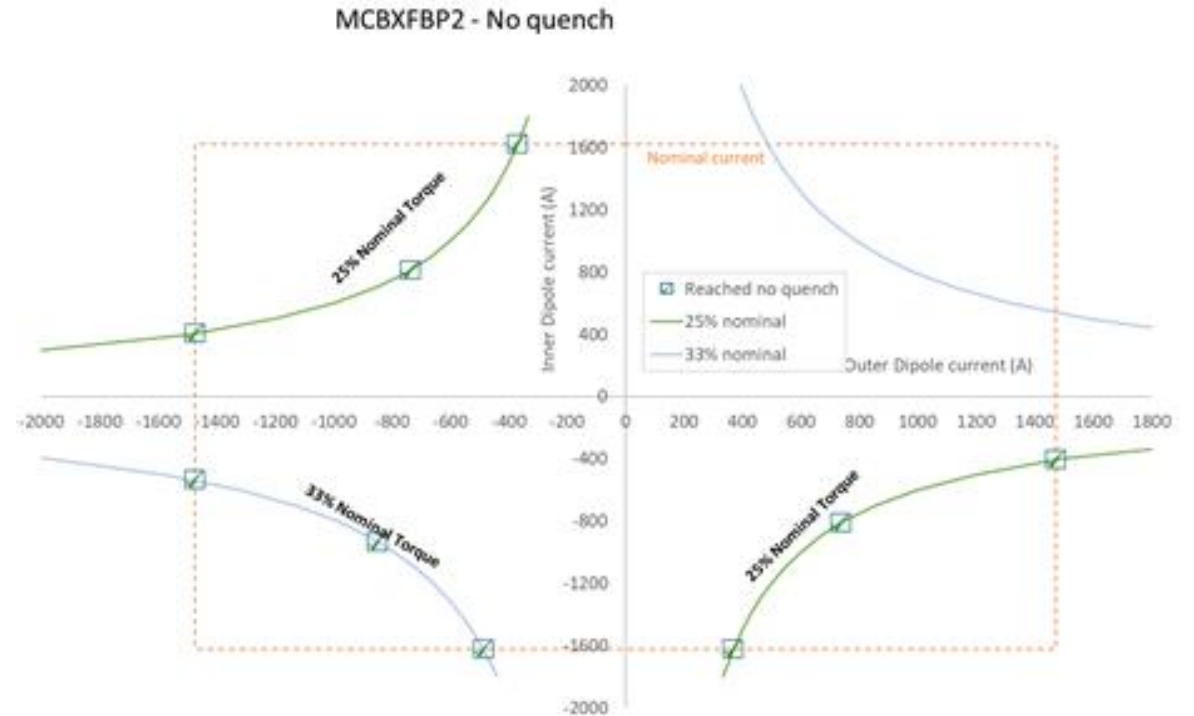Reached 90% of nominal torque in event #120

MCBXFBP2 powering history

F. Quench free cycle after th cycle

- MCBXFBP2a:

1. Verified the quench free region. 3 ramps in quadrant 2, 3 and 4, coming from training in Q1
2. OK 25% inversed torque
3. OK 33% direct torque
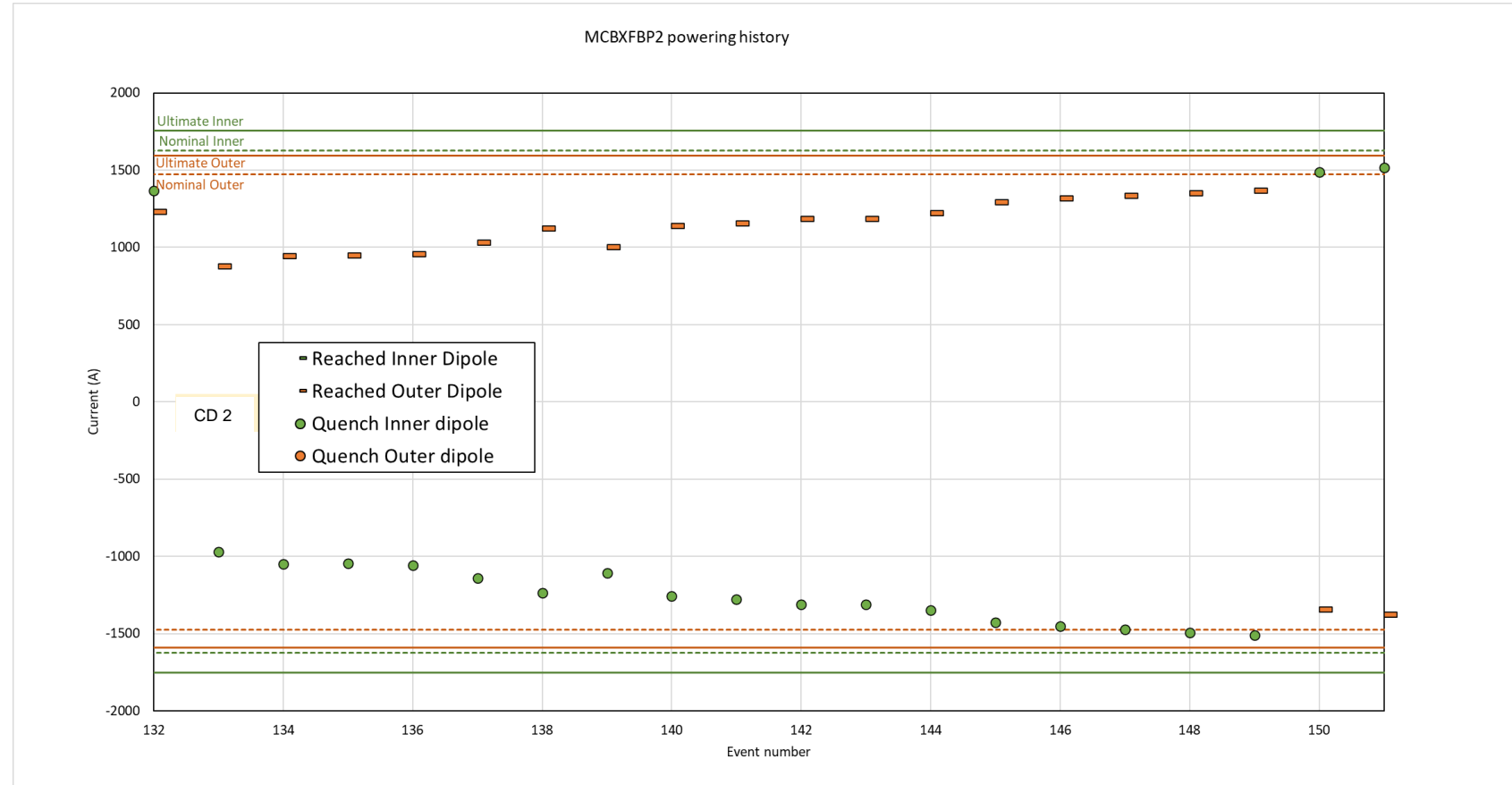
CD 2

G. Training Q2 after TC

CD 2

MCBXFBP2a:

Quench in Q1 right after the quench free cycle
First quench at 35%
19 quenches until 87% of

Training quenches		
IC4	IC5	OC3
8	11	0

Reached 87% of nominal torque in event #151

MCBXFBP2 powering history
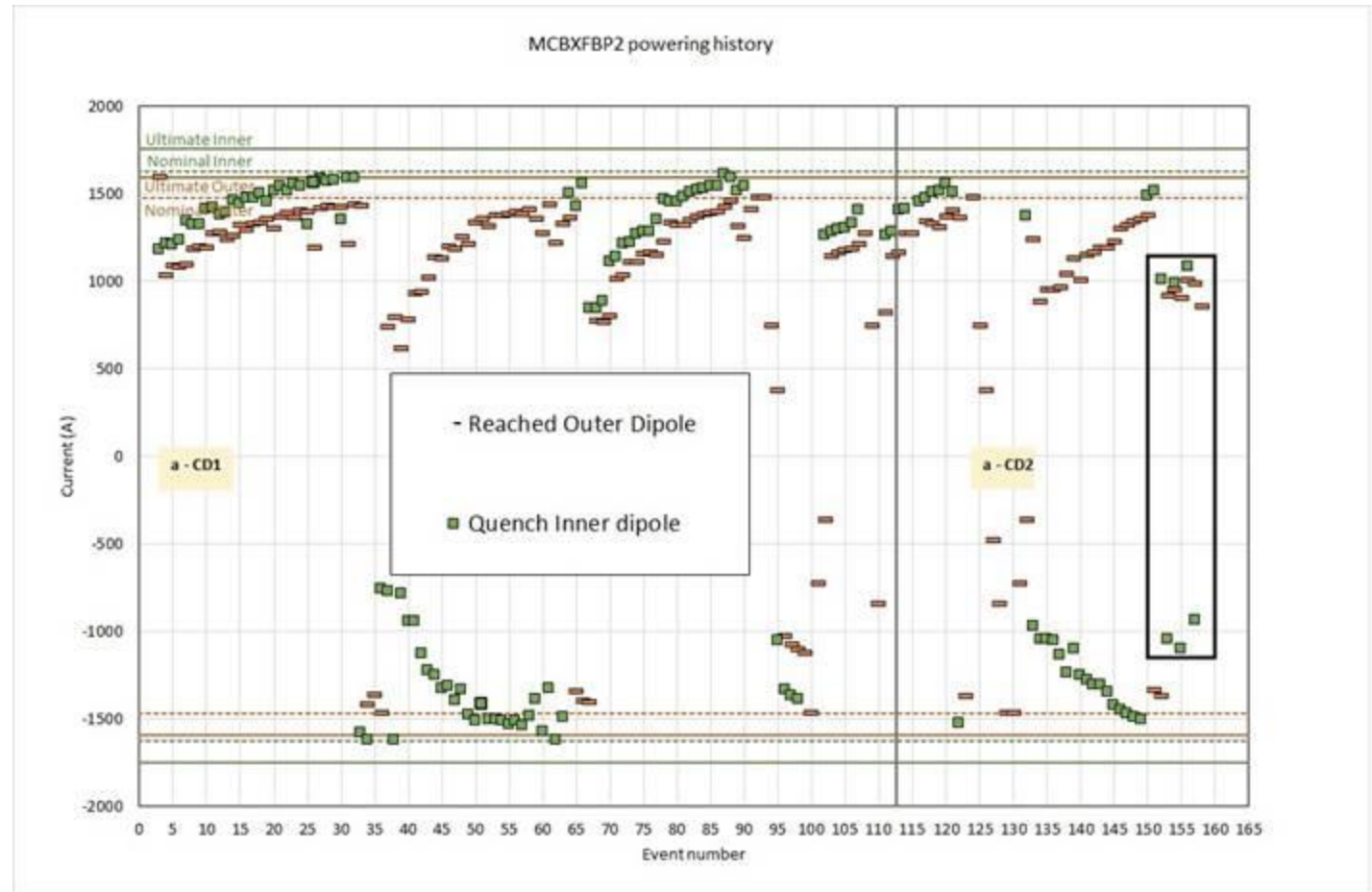
H. Alternating torque sense

CD 2

- MCBXFBP2a:

- 8 quenches
- Those quenches happened between:
- • 33% and 45% of nominal torque, average 41%
- • 58% and 68% of nominal field, average 64%
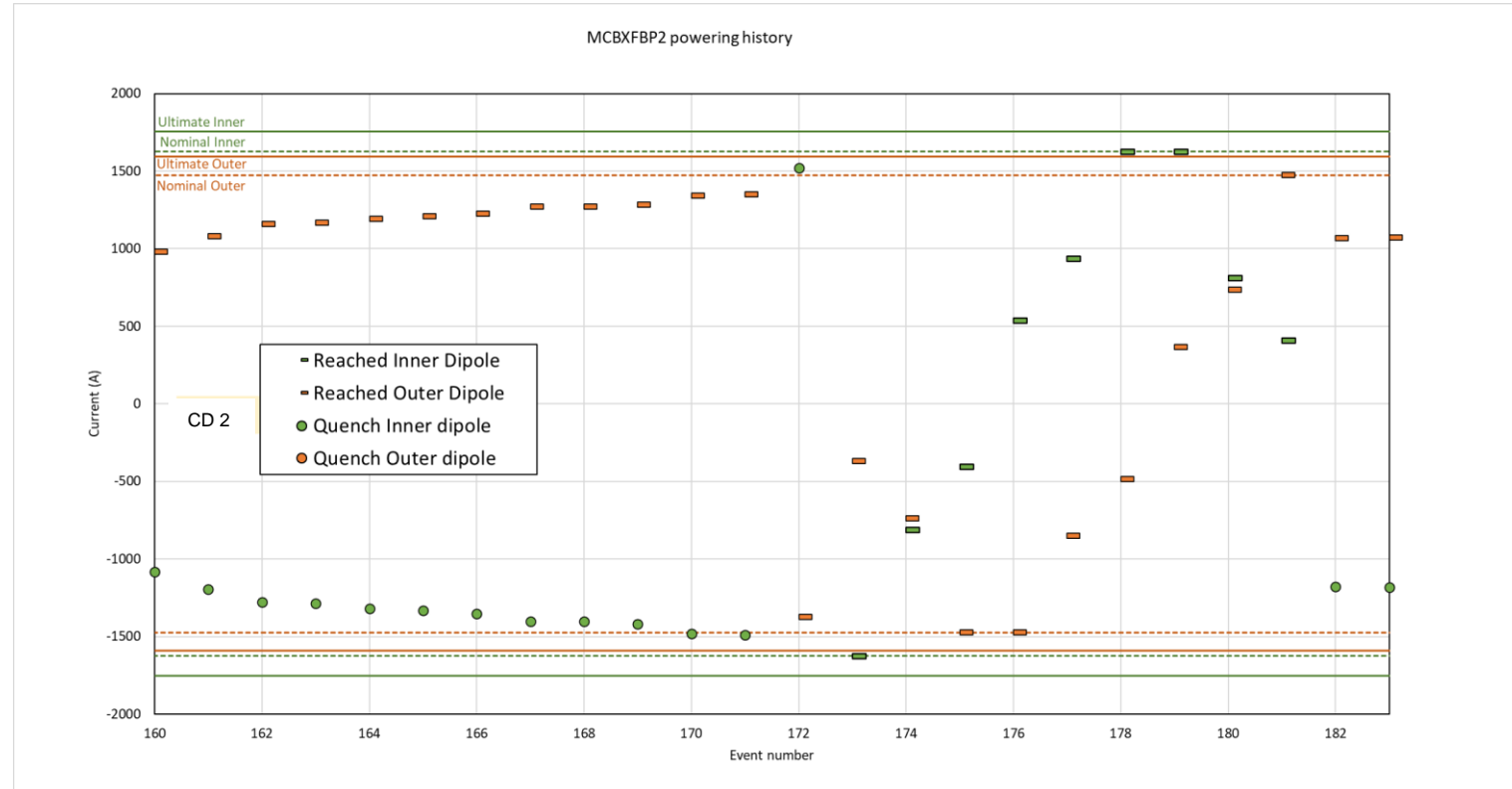

MCBXFBP2 powering history

I. Re-train in Q2, quench free at 33% and circular cycle (I/II)

CD 2

MCBXFBP2a:

Coming from a quench in Q1

Re trained Q2 in 13 quenches from 44% to 85% of nominal torque and then verified in Q4

CD 2

- MCBXFBP2a:

- Coming from a quench in Q1
- Re trained Q2 in 13 quenches from 44% to 85% of nominal torque and then verified in Q4

- The circular cycle is not shown in the events plot
- Quench in Q1 to reset after the training (event 172) before the quench free cycle

- Quench free cycle targeting 33% of nominal torque (57% of nominal field) in Q4 and 25% of torque (50% of field) in Q1 and Q3.
- A ramp to quench was performed in the diagonal after the cycle again in Q2 reaching 52% of nominal torque (72% of nominal field).
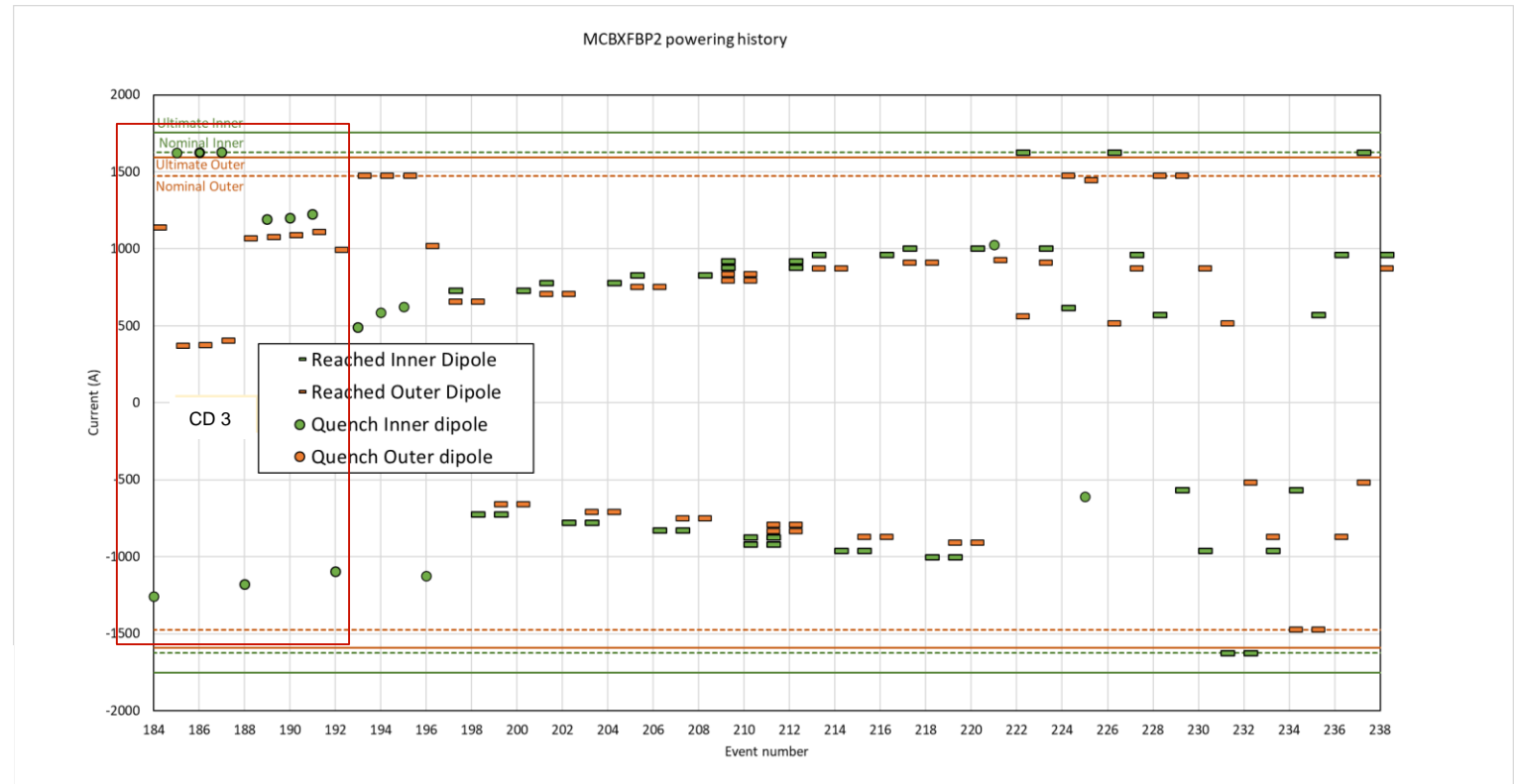

MCBXFBP2 - No quench
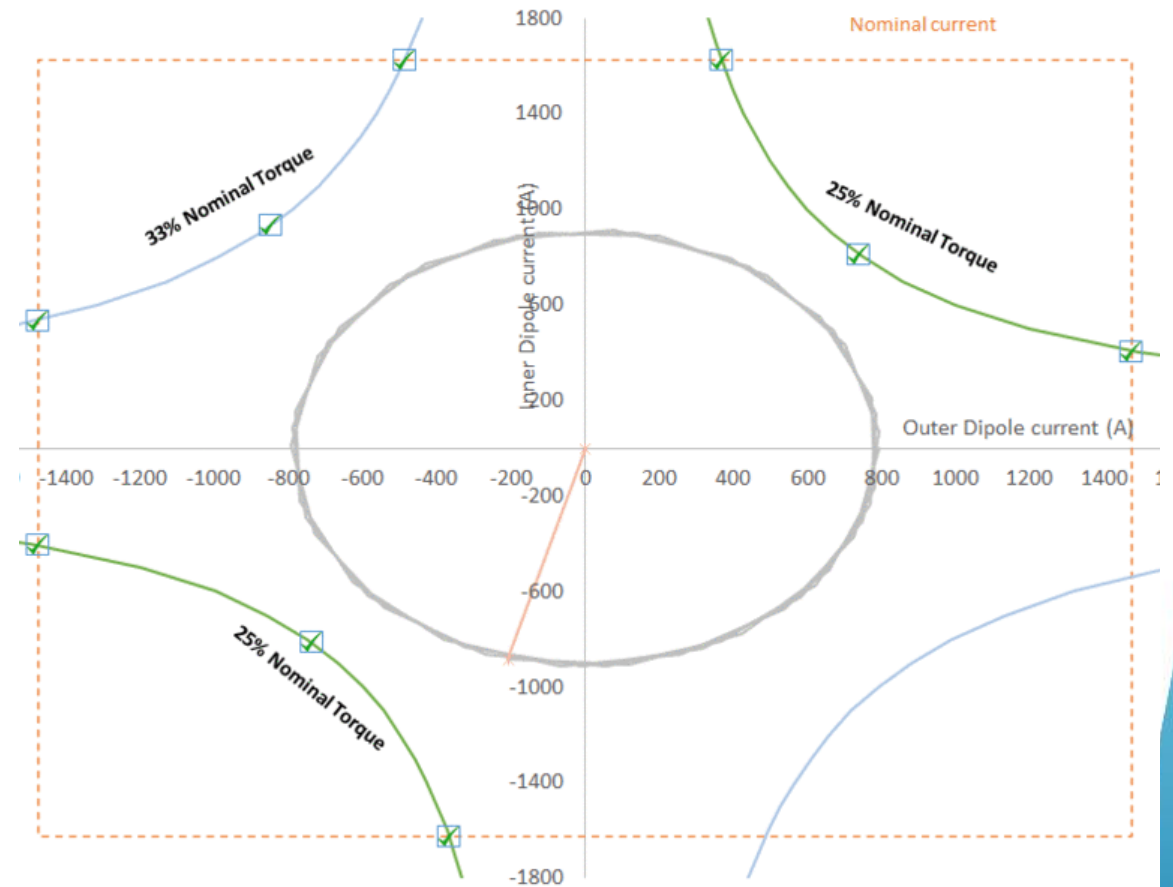
CD 3

- MCBXFBP2a:

- A third cooldown was requested

- The magnet quenched twice in Q2 just before this cycle. This might explain the low quench current of the ramps in Q1

- Ramp to quench in Q2:   60% of nominal torque
- Ramp Inner in Q1 to nominal current and then outer until quench (3 cycles):   25,25,27 % of nominal torque
- Ramp to quench in Q2:   52% of nominal torque
- Ramp both magnets in diagonal until quench in Q1(3 cycles):   54,54,57 % of nominal torque
- Ramp to quench in Q2   45% of nominal torque
- Ramp Outer in Q1 until nominal and the inner until quench (3 cycles)   30, 36, 38 % of nominal torque
- Ramp to quench in Q2   47 % of nominal torque
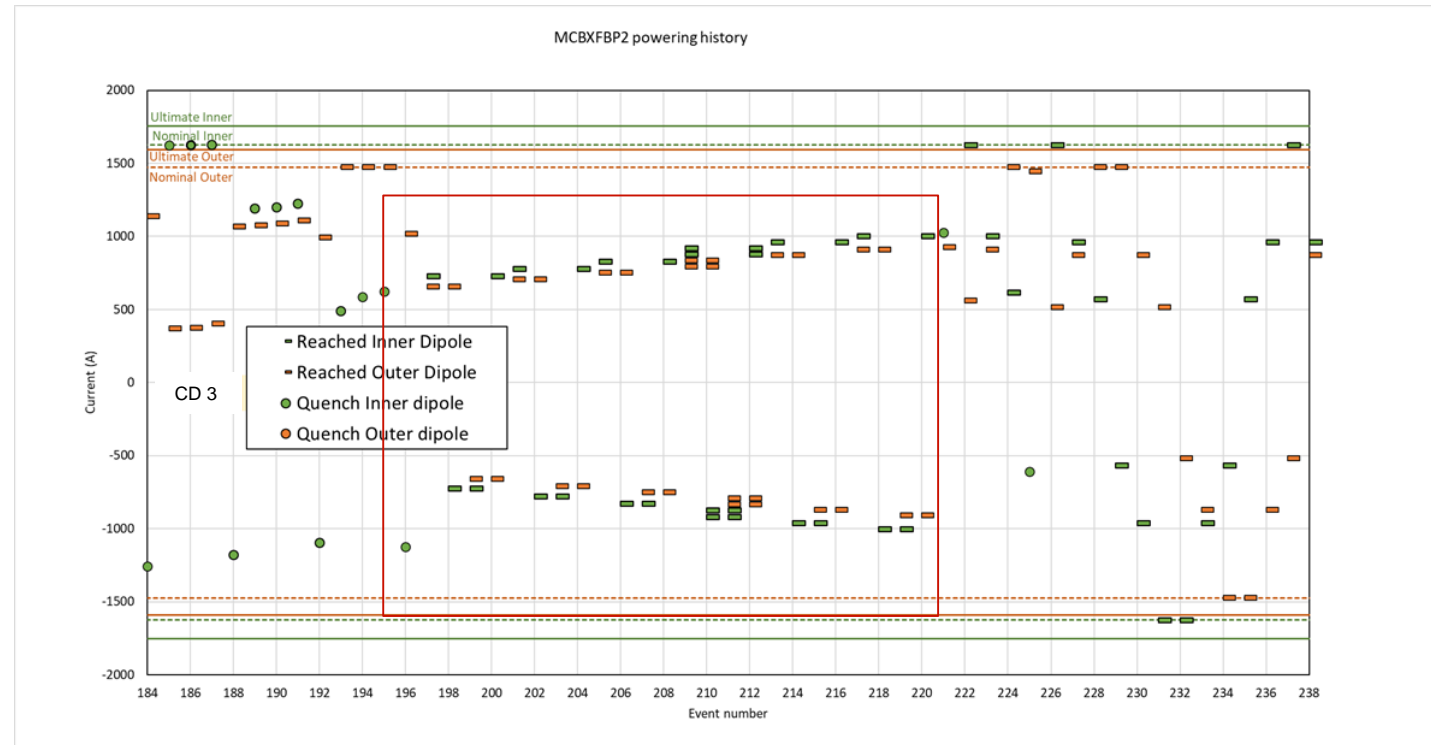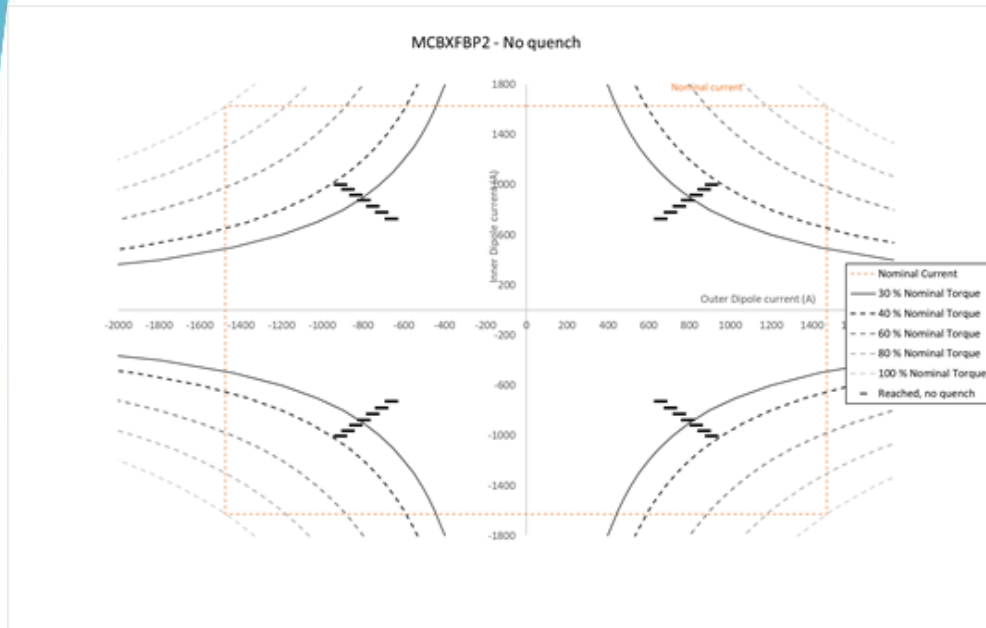

MCBXFBP2 powering history

22

J. Verification of the powering sequence and more quench free cycles (II/III)

CD 3

- MCBXFBP2a:

  a. Quench free cycle of 4 points (diagonals) 20, 23, 26, 29, 32, 35, 38% of nominal torque
  b. Quench when attempting 41%

MCBXFBP2 - No quench
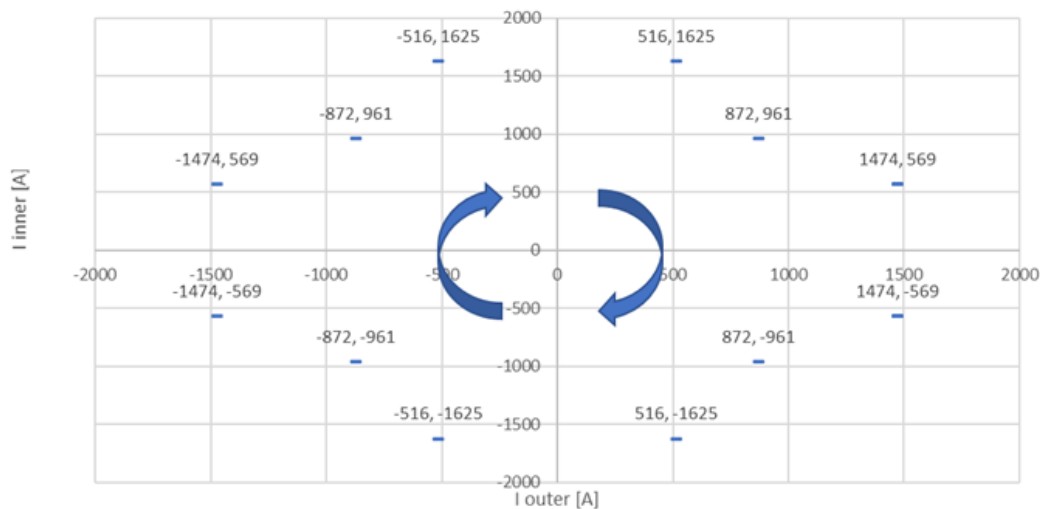

MCBXFBP2 powering history

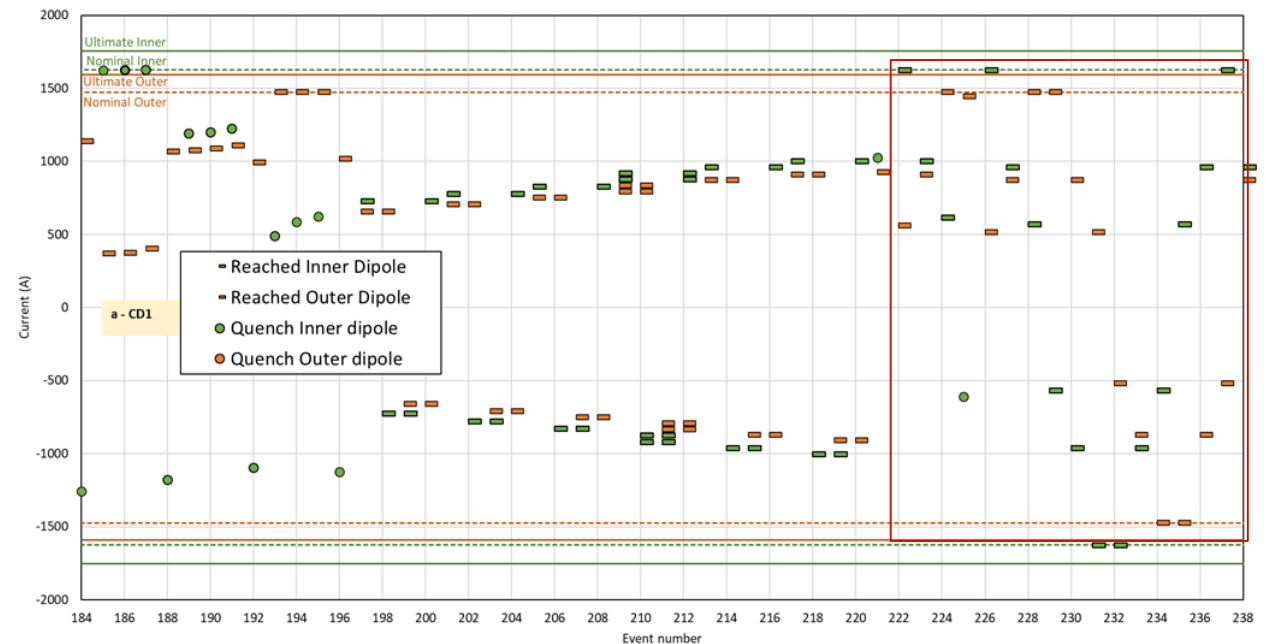# J. Verification of the powering sequence and more quench free cycles (III/III)

CD 3

- MCBXFBP2a:

  a. Quench free cycle of 4 points (diagonals) 20, 23, 26, 29, 32, 35, 38% of nominal torque
  b. Quench when attempting 41%
  c. Quench free cycle attempt of 12 points at 38%, quench.
  d. Quench free cycle of 12 points at 35% OK

CD 3

MCBXFBP2a:

- Ramp to Q1 to 35% of nominal torque (event 238)
- Ramp Inner in Q1 to nominal current and then outer until quench (3 cycles):   55, 61, 66 % of nominal torque
- Ramp to quench in Q2:   31% of nominal torque
- Ramp both magnets in diagonal until quench in Q1(3 cycles):   56, 58, 70 % of nominal torque
- Ramp to quench in Q2   47% of nominal torque
- Ramp Outer in Q1 until nominal and the inner until quench (3 cycles)   46, 48, 49 % of nominal torque
- Ramp to quench in Q2   28 % of nominal torque


MCBXFBP2 powering history
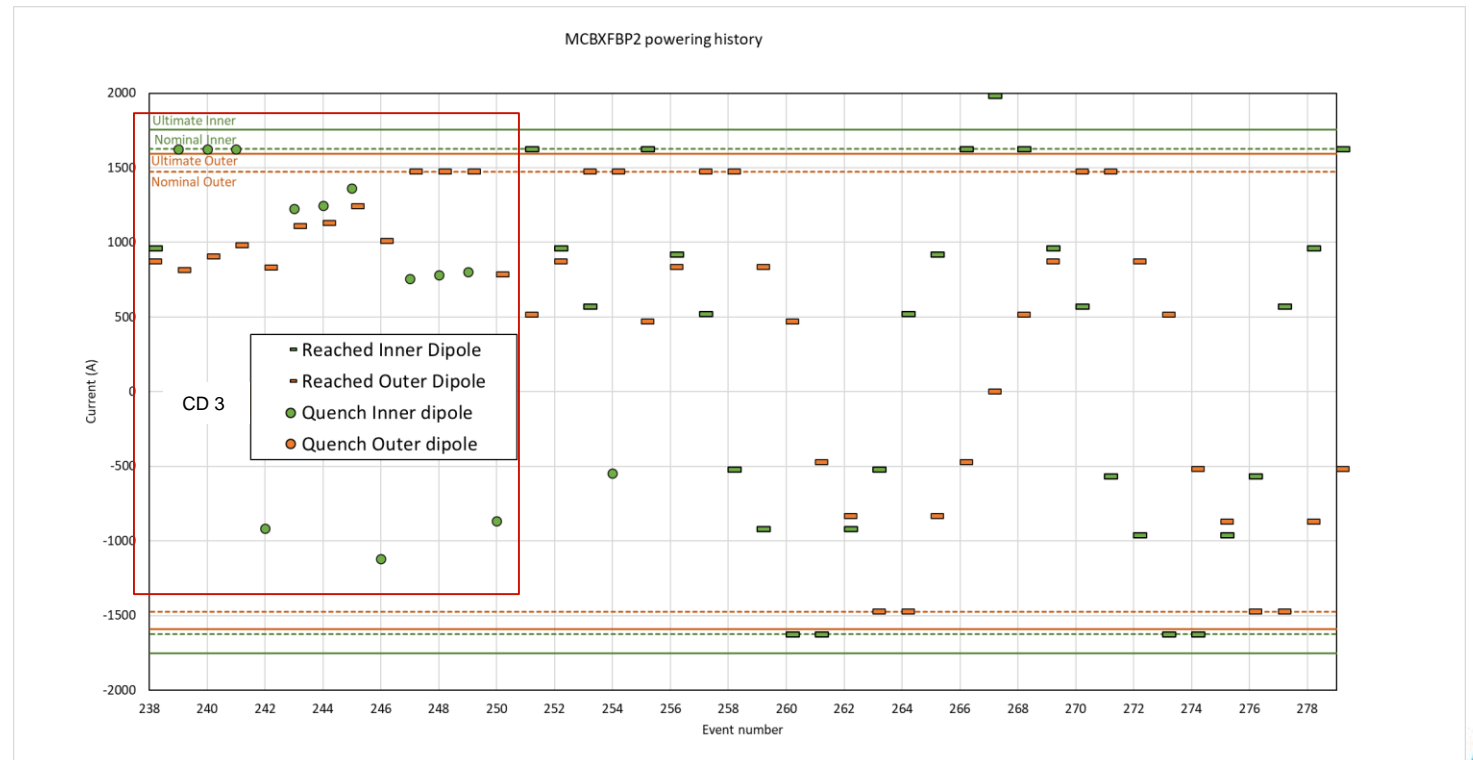
K. Second verification of the powering sequence and more quench free cycles (II/II)

CD 3

- MCBXFBP2a:

- 1.   Attempted the 12 point quench free cycle at 35% of nominal torque (quench, event 254)
- 2.   Successfully performed a 12 point quench free cycle at 32 % of nominal torque
- 3.   Ramped Inner circuit alone to test stability at high current (event 267)
- 4.   Successfully performed a 12 point quench free cycle at 35 % of nominal torque

MCBXFBP2 powering history
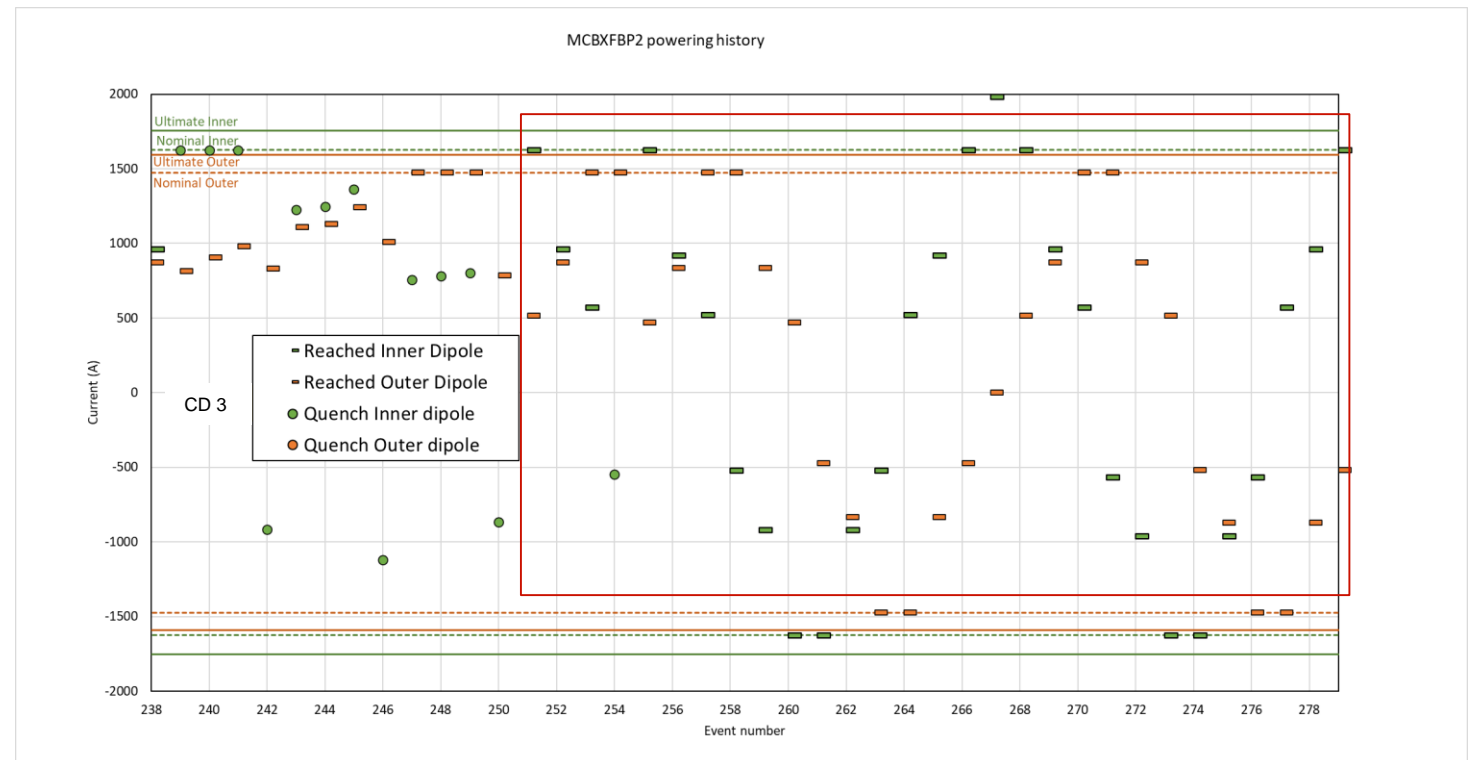
Conclusions

- MCBXFBP2a:

- Good margin in standalone configuration
  - No quench inner nor outer
  - Reached 1980 A in the inner circuit
- 33 quenches from *new* to nominal
- ~ 20 quenches from ~ nominal in one torque sense to ~ nominal in the other, when the magnet was already trained
- Perfect memory after thermal cycle
- Quench free region:

  - Q1/Q3: ~35% of nominal torque   Q2/Q4: ~35% of nominal torque

- Ongoing: vibration analysis of the voltage signals