Test results of the 2 m model magnet of D1 with increased coil pre-stress (MBXFS01b)

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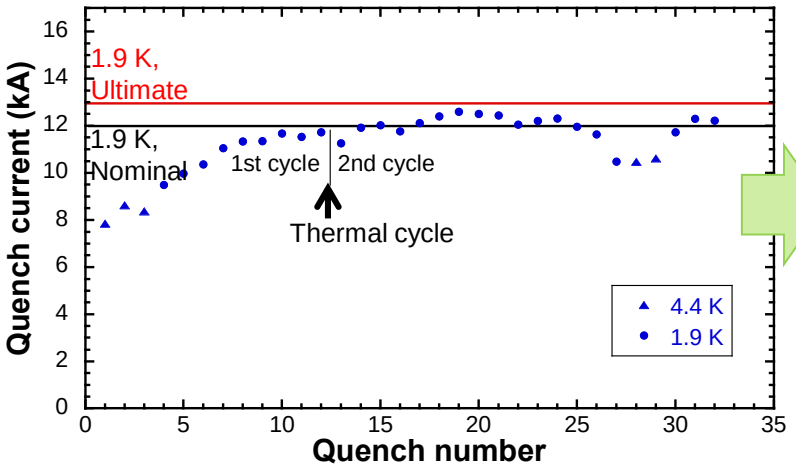
WP3 meeting, 24 May 2017

Outline

- In the first 2 m model magnet after re-assembly with enhanced azimuthal coil pre-stress (MBXFS01b), improvement of training performance was confirmed in the first test cycle.

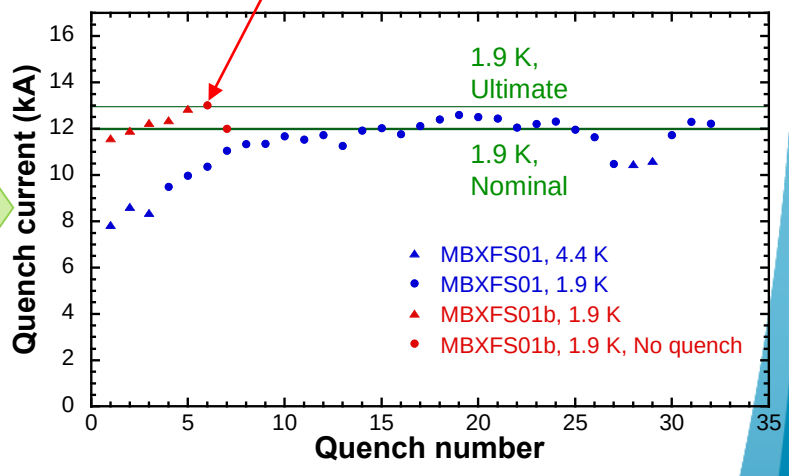
→ Sugano, WP3 meeting on 22th Feb, 2017

MBXFS01 (Before reassembly)



MBXFS01 (After reassembly)

Ultimate current was achieved !



- Report on test results in the second test cycle of MBXFS01b

Test program

- 1st test cycle (12th – 24th Feb)
  - Training quench at 1.9 K

    → Reported at WP3 meeting on 22nd Feb, 2017
  - Magnetic field measurement
    - DC loop at coil center and Z-scan w long rotating coils up to 12 kA

      → Reported at WP3 meeting on 22nd Mar, 2017

- 2nd test cycle (19th Mar – 9th Apr, 17th-19th Apr)
  - Training quench
    - Quench memory
    - Ramp rate dependence
    - Temperature dependence
  - Magnetic field measurement
    - Z-scan w short rotating coils
  - Heater test (Spot heater, QPH, Full energy dump)

This presentation

Training performance of MBXFS01b

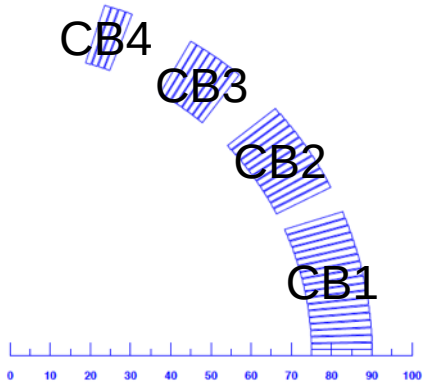
Conditions of training quench

- Energy extraction
  - Dump resistor :73 mΩ (1st cycle), 50 mΩ (2nd cycle-2)
- Voltage threshold: 0.1 V
- Time threshold: 10 ms
- Temperature: 1.9 K, 2.1 K and 4.4 K
- Ramp rate
  - Typically 10 A/s
  - 50–200 A/s for fast ramp test

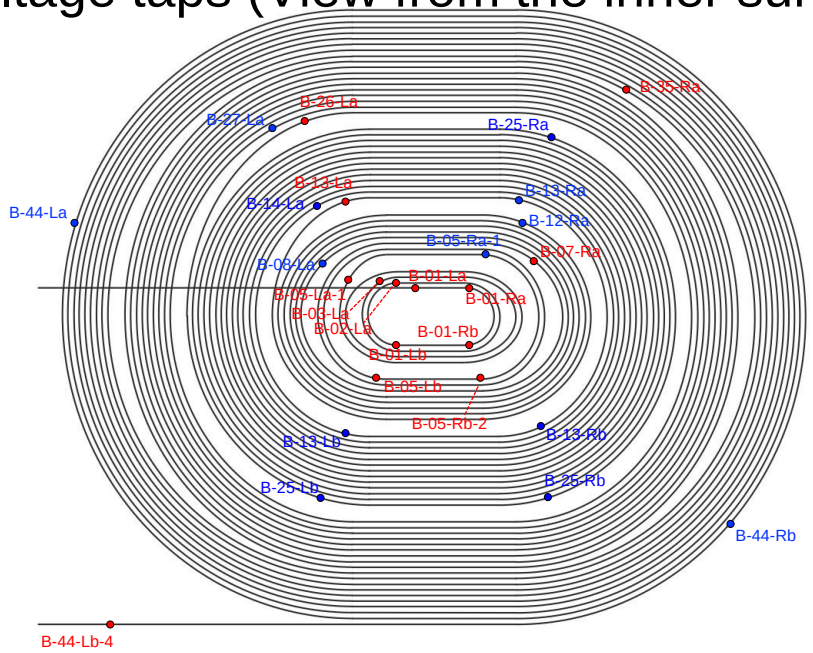
- Quench origin and propagation: voltage taps, quench antennas
- Stress/strain measurements: collar (coil pre-stress), yoke, shell and bullet

Identification of quench start location

Notation of coil blocks



Voltage taps (View from the inner surface)

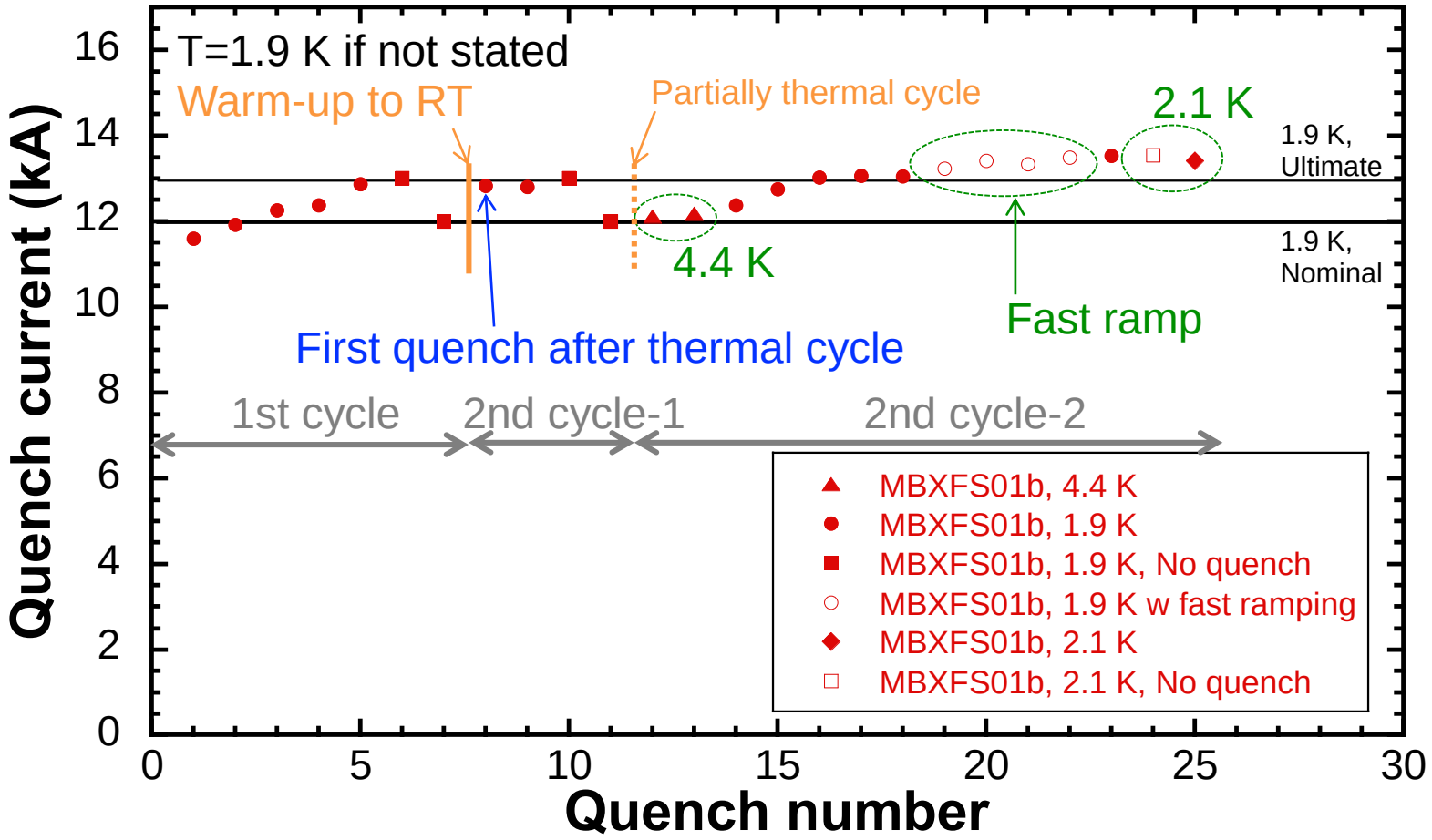


Quench antennas

- Voltage taps: 42 in total per coil, data acquired for 27 taps during training
- Quench antenna: 6 longitudinal positions

  Detecting 6N, 6S, 8N, 8S components at each position

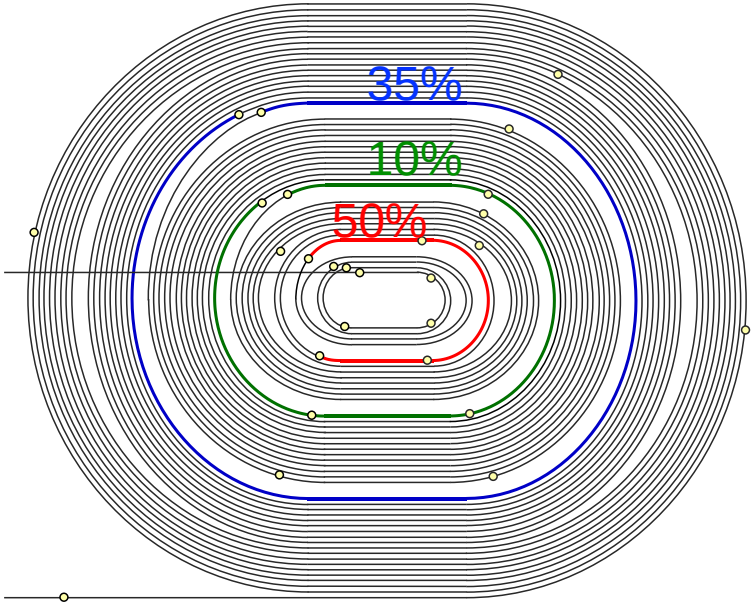
Training plot



- 1 st cycle / 2nd cycle-1
  - I_q at the first quench after complete thermal cycle = 107% of I_{nom}
    → Good quench memory
- 2nd cycle-1
  - Two quenches to the ultimate current

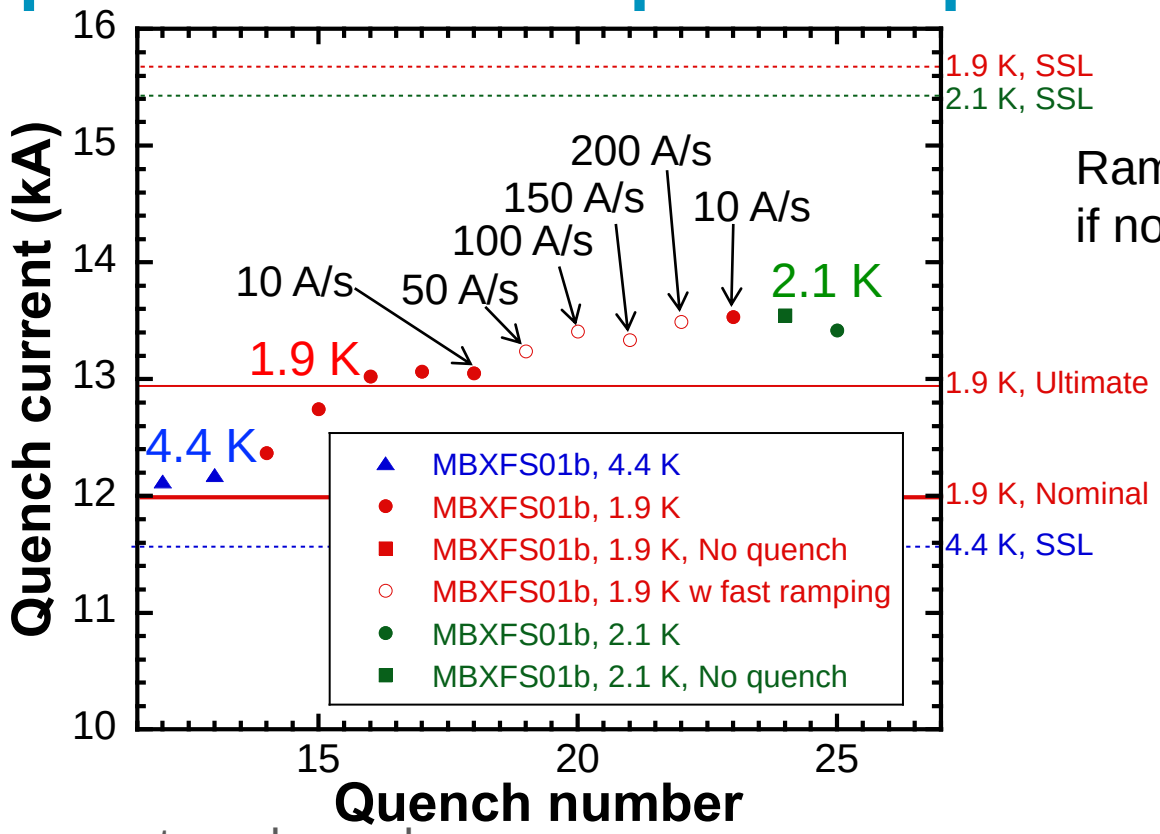
Quench start location

Run	Quench start location			
	Coil	CB No.	Turn No.	Voltage tap
1st cycle				
01b.QA008	T	3	5th	SS, RE side
01b.QA009	T	1	26-27th	?
01b.QA010	T	3	5th	?
01b.QA011	Failure in data acquisition			
01b.QA013	B	3	5th	SS/RE coil end
2nd cycle-1				
01b.QA032	B	2, 3	12-13th	SS/LE coil end
01b.QA033	B	3	5th	RE coil end
2nd cycle -2				
01b.QA138	B	3	5th	?
01b.QA139	T	3	5th	?
01b.QA140	B	1	26-27th	?
01b.QA141	T	1	26-27th	?
01b.QA142	T	1	26-27th	?
01b.QA145	T	3	5th	?
01b.QA146	B	1	26-27th	?
01b.QA147	B	3	5th	RE coil end
01b.QA148	T	3	5th	SS/ RE coil end
01b.QA149	B	2	13th	SS/LE coil end
01b.QA150	T	1	26-27th	?
01b.QA151	B	3	5th	RE coil end
01b.QA154	T	1	26-27th	?



- 50% at the 5th turn (peak field)
- In part of quenches, a quench position could be determined from the voltage tap signals.
- For the rest of quenches, analysis of quench antenna signals to identify the quench start location is ongoing.

Temperature and ramp rate dependence

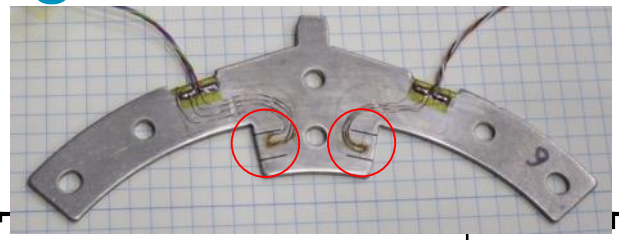


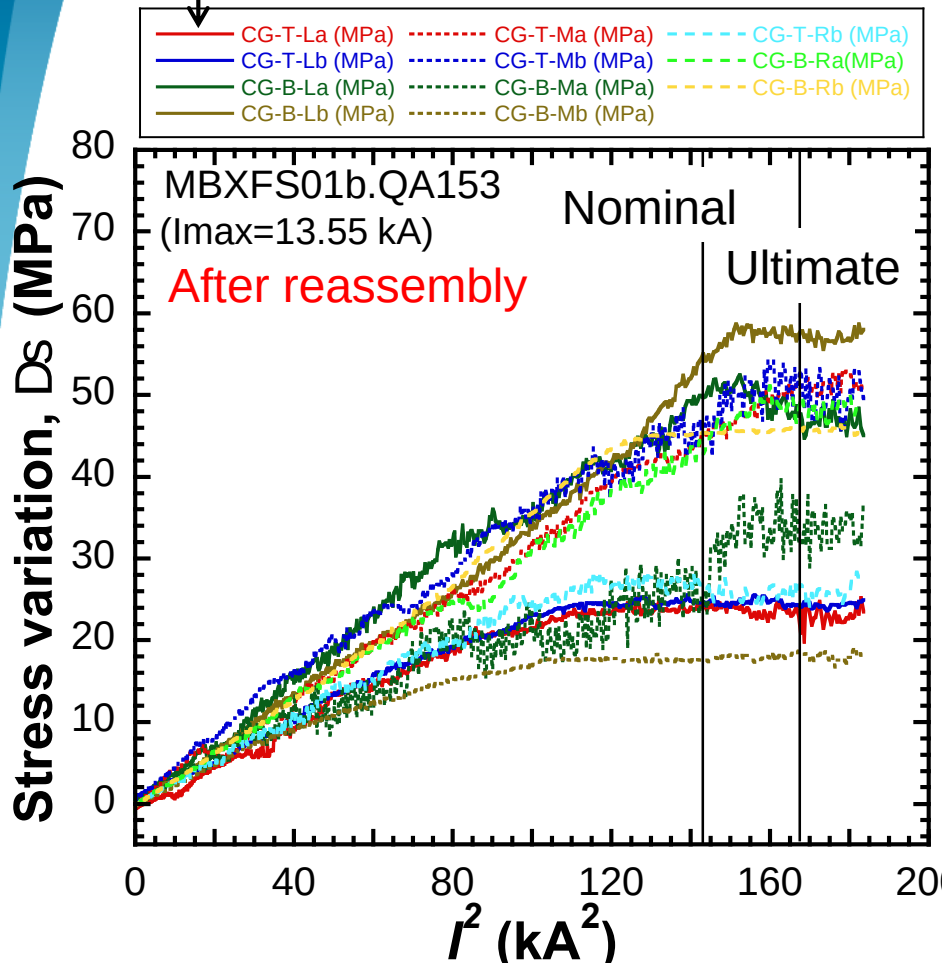
Ramp rate is 10 A/s if not stated.

- Temperature dependence
  - I_q at 4.4 K ~ 100% of SSL
  - I_q at 2.1 K is comparable to Iq at 1.9 K
    → I_q is limited by mechanical support.
  - I_{max} through the tests = 13.55 kA (88% of SSL at 2.1 K)
- Ramp rate dependence
  - I_q increases despite of increasing ramp rate.
    → The magnet was still under training.

Coil pre-stress in the straight section

Different measured positions in SS (See P27)

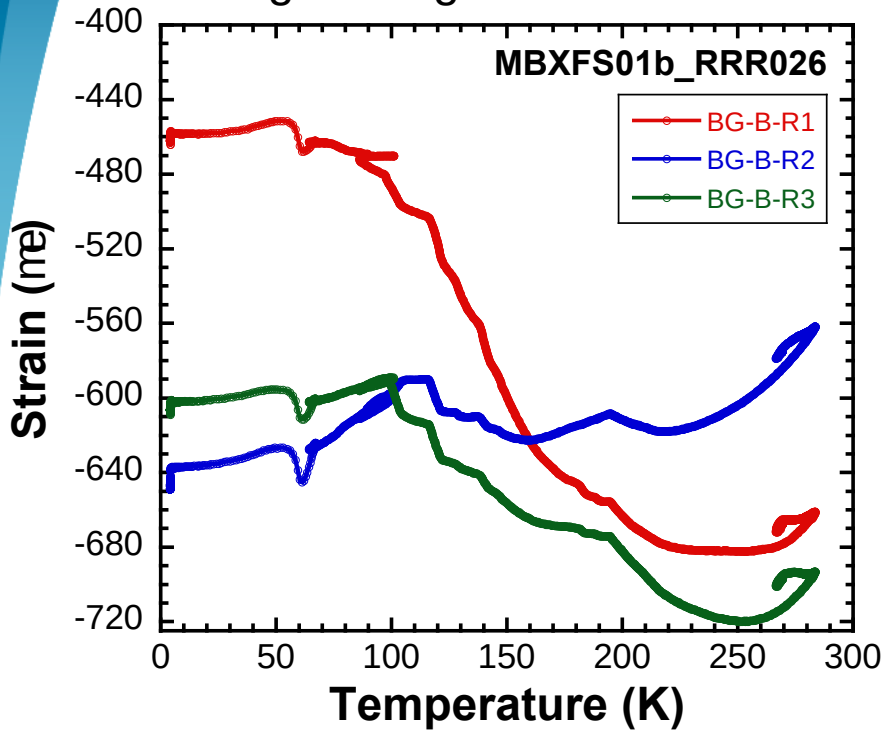




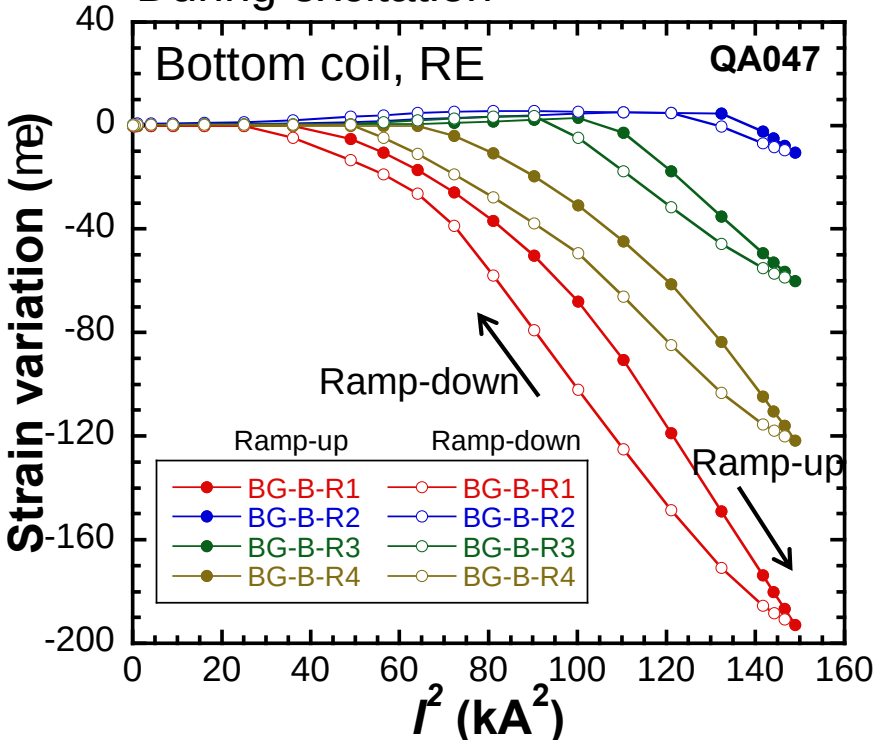
- In half of the measured points, coil pre-stress still increases at the nominal current in the 01b, which is much better than the 01.
- The plateau was observed for all strain gauges at the ultimate current.
- 10-15 MPa more pre-stress would be necessary, but damage of cable insulations should be also taken into consideration.

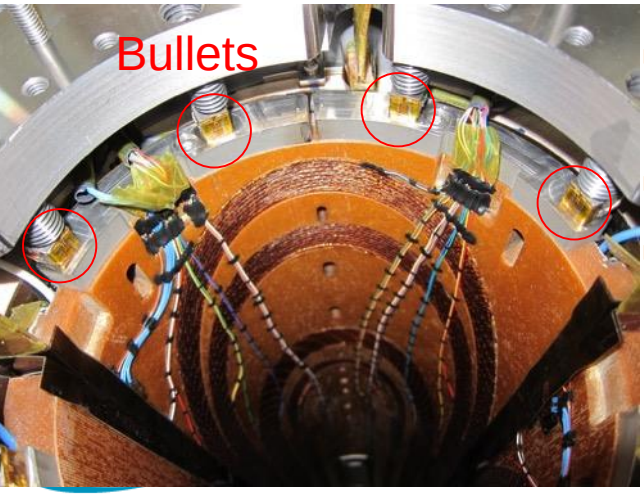
Strain at the bullets

During cooling-down



During excitation



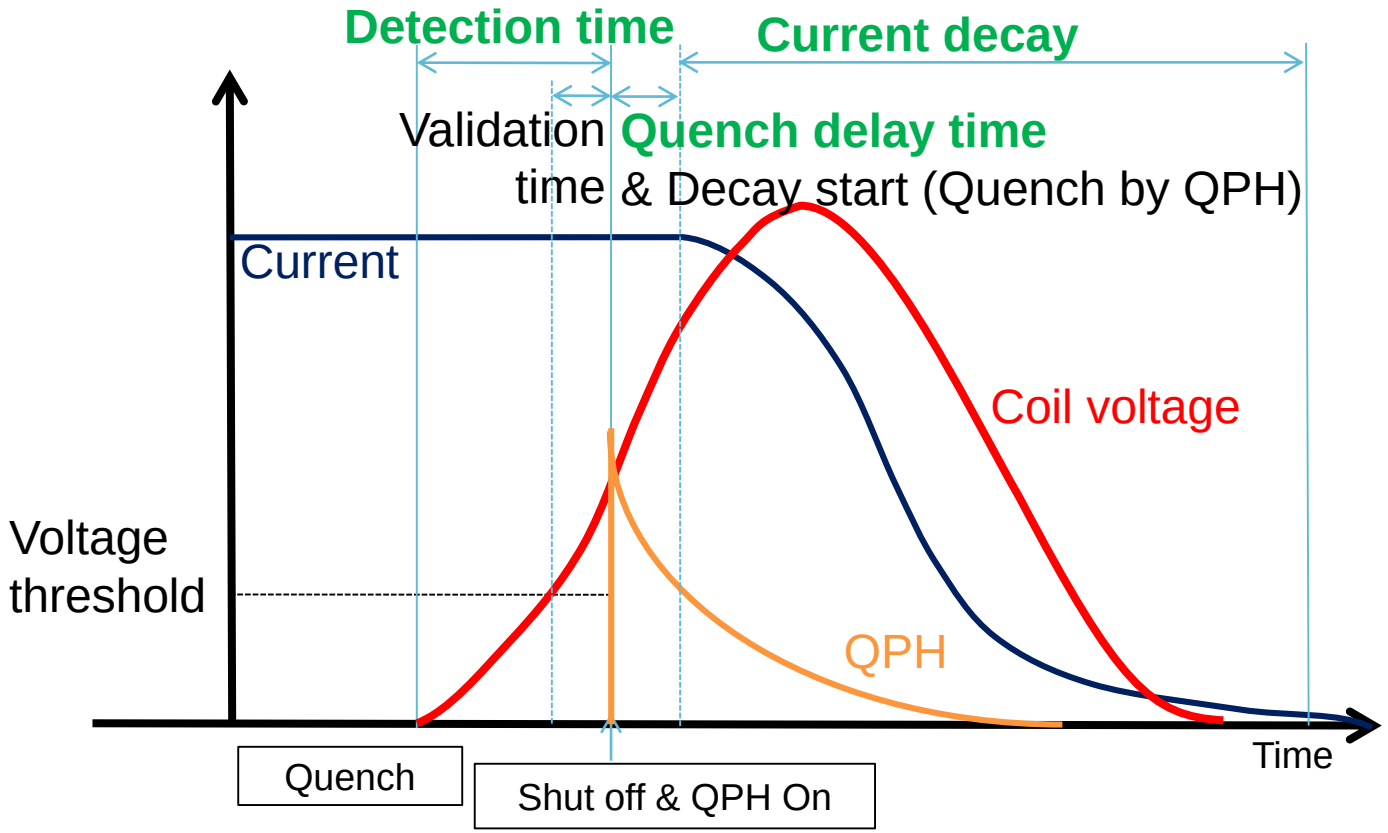


- The coils are longitudinally supported by the bullets.
- No sign of detaching the bullets from the coil during cooling-down
- Strain at the bullets starts to increase at 5–6 kA.
- Load calculated from the strain variation

  = 0.6 – 0.7 tonf/coil
  - Axial pre-load applied at RT: 5.2 tonf/coil
  - Axial Lorentz force: 19 tonf/coil (ROXIE calc.)

Heater test

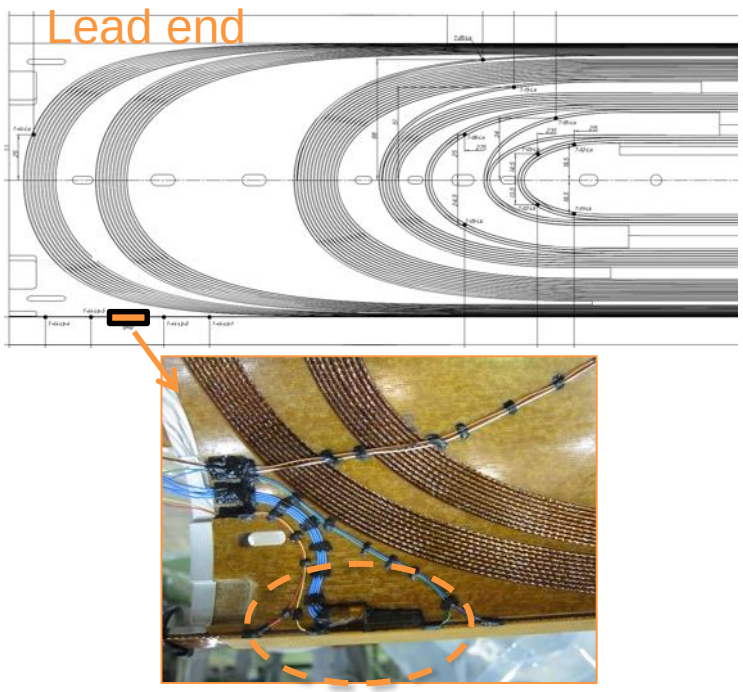
Parameters for quench simulation



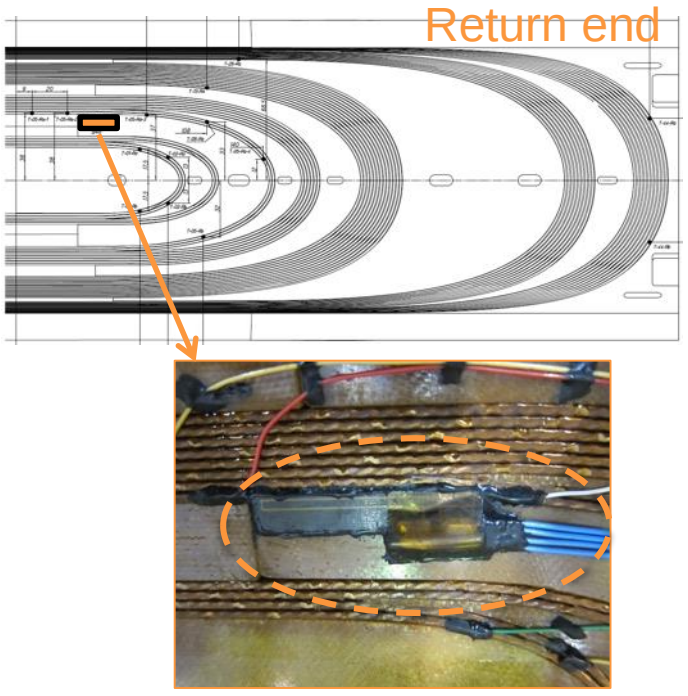
- Spot heater test → Detection time
- QPH test → Delay time
- Full energy dump test → Current decay

Spot heater test

- Two spot heaters for each coil (high field, low field regions)
- At each magnet current, amplitude and duration of pulsed current to a SPH were adjusted until quench occurred.
- Maximum current to the magnet: 12.2 kA
- Detection time was evaluated from balanced voltage rise.



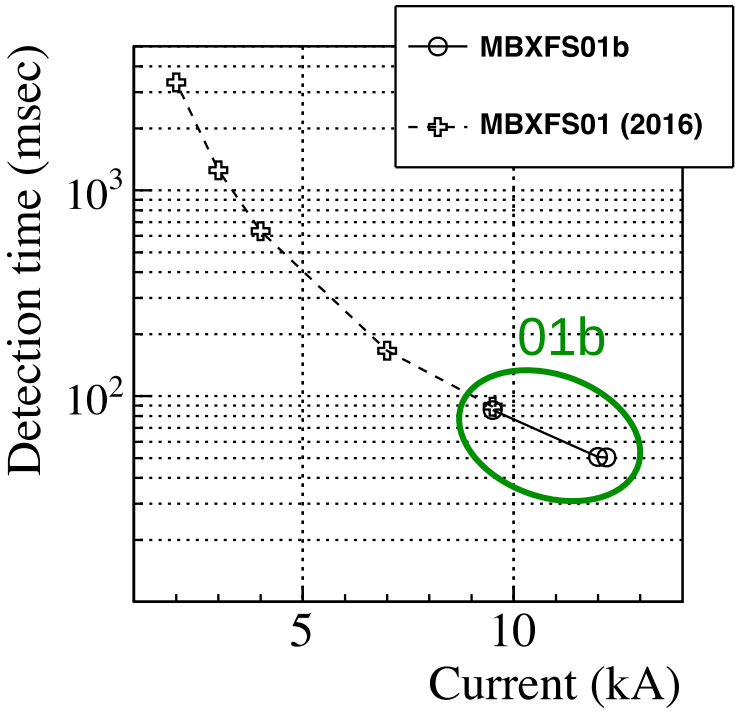
Spot heater at low field region



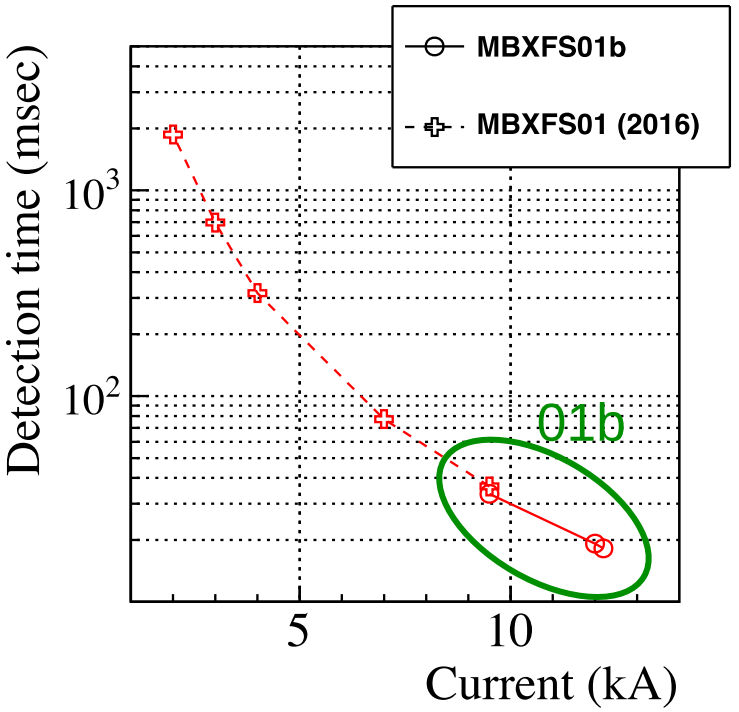
Spot heater at high field region

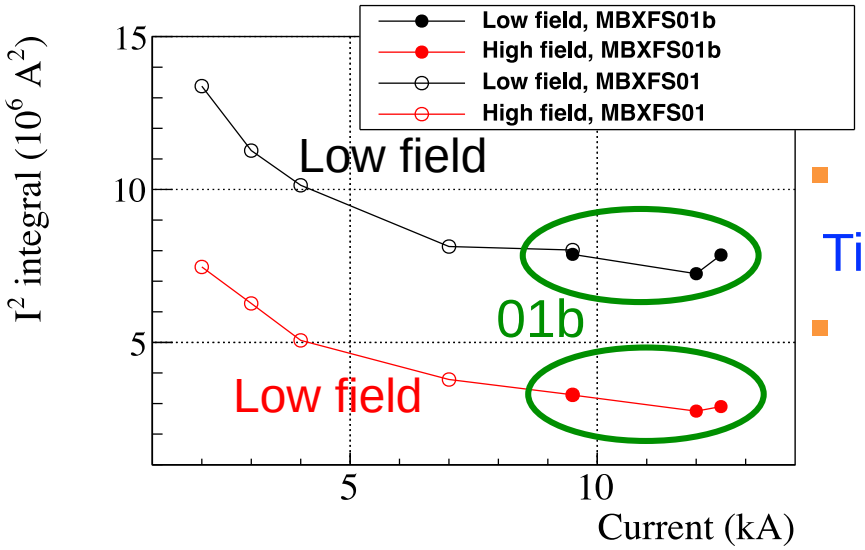
Detection time

Low field



High field





- Definition of detection time:

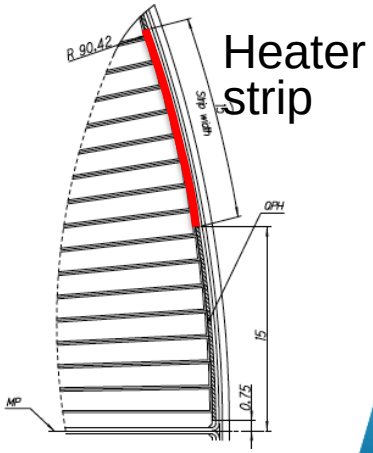
Time to V_{bal}=0.1 V + validation time (10 ms)

- Detection time up to 12.2 kA could be successfully evaluated.

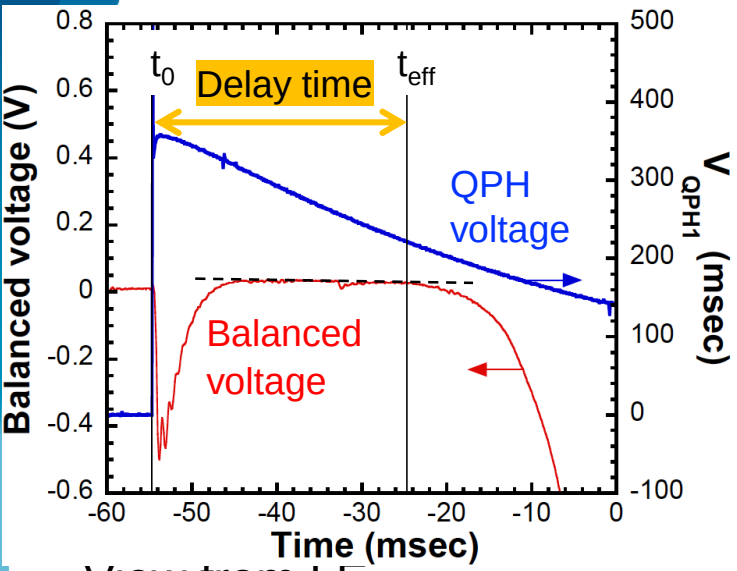
QPH test

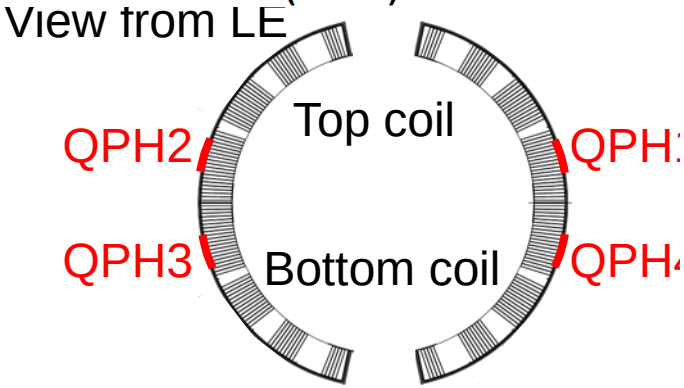
- Energy deposition test at different charged energy of a PS
- PSs from CERN with C=7.05 mF and maximum charged voltage of 800 V were utilized to fire QPHs.
- Only one QPH was connected with a 3 Ω dummy resistor in series for each test to evaluate delay time.
- Maximum current: 12.5 kA
- A SUS strip in a QPH with t25 μm x w15 mm x l2 m without Cu ilands covers 9 turns in CB1 (low field)

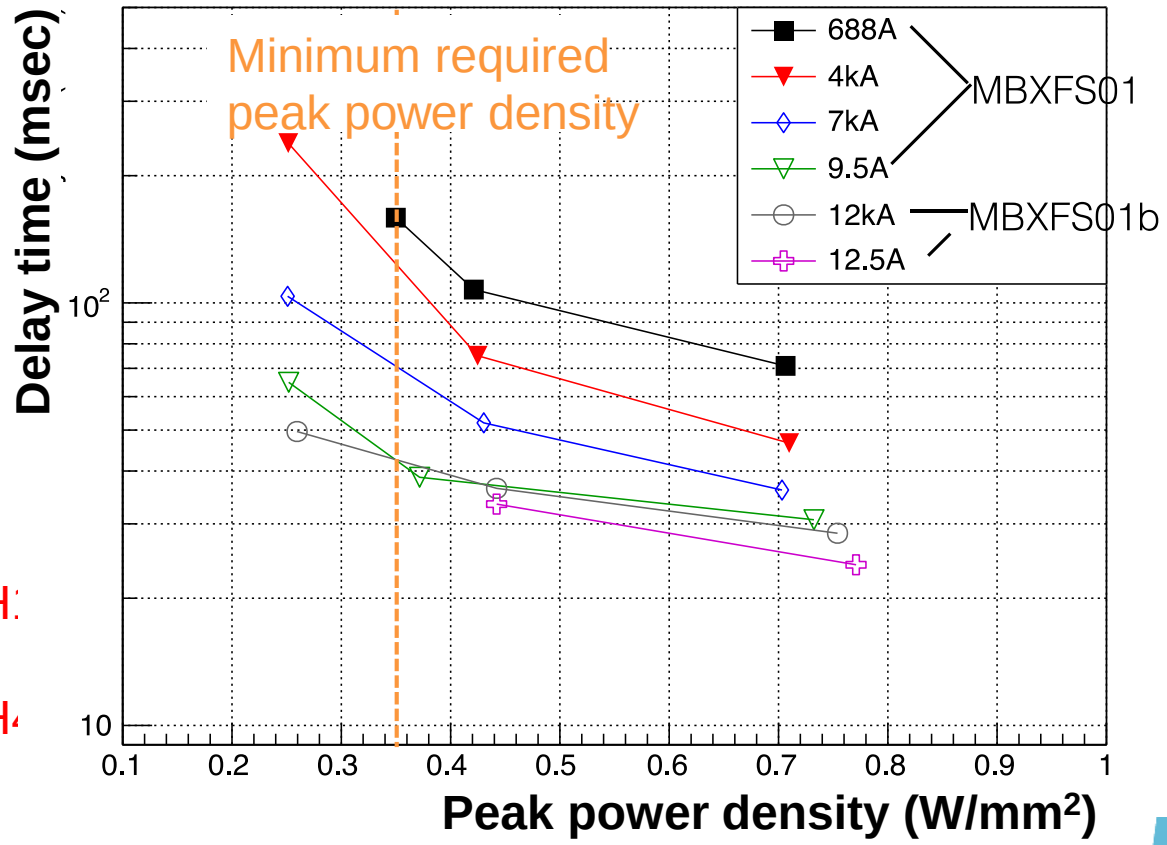
Since quench protection with a dump resistor was a baseline, we did NOT design the QPH used in MBXFS01 and 01b. The purpose of this QPH test was to obtain the experimental data necessary for quench simulation and QPH design for the second model.



Delay time



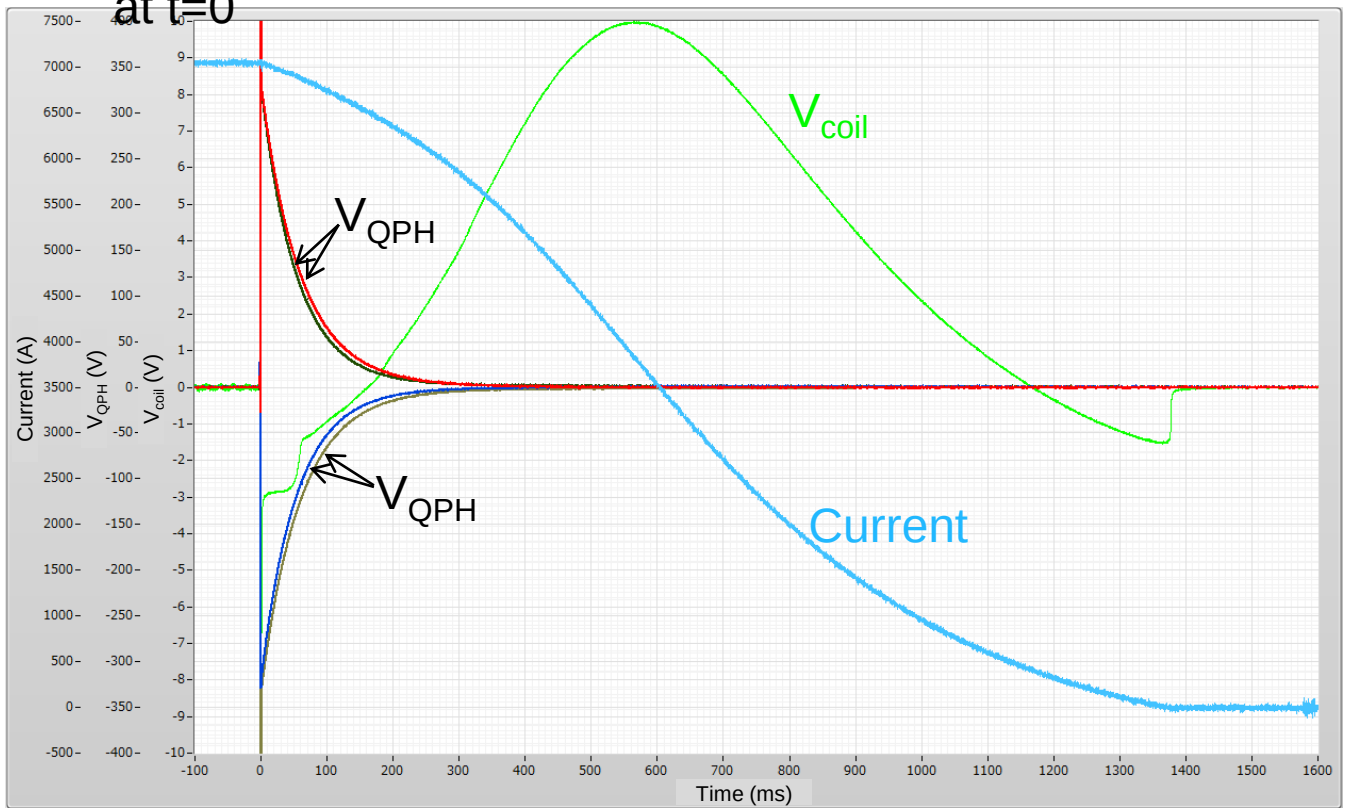




- Definition of delay time:
  Time difference between QPH firing and the onset of V_{bal}
- Delay time up to 12.5 kA could be successfully evaluated.
- Minimum required peak power density to induce quench at 688 A (I_{inj}) =0.35 W/mm^2

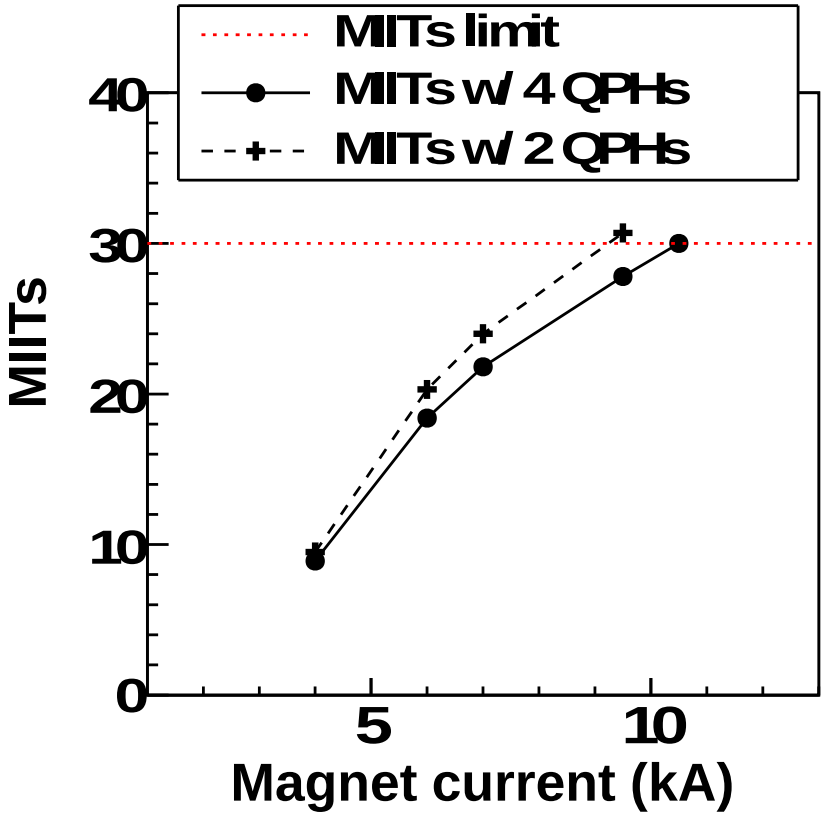
Full energy dump

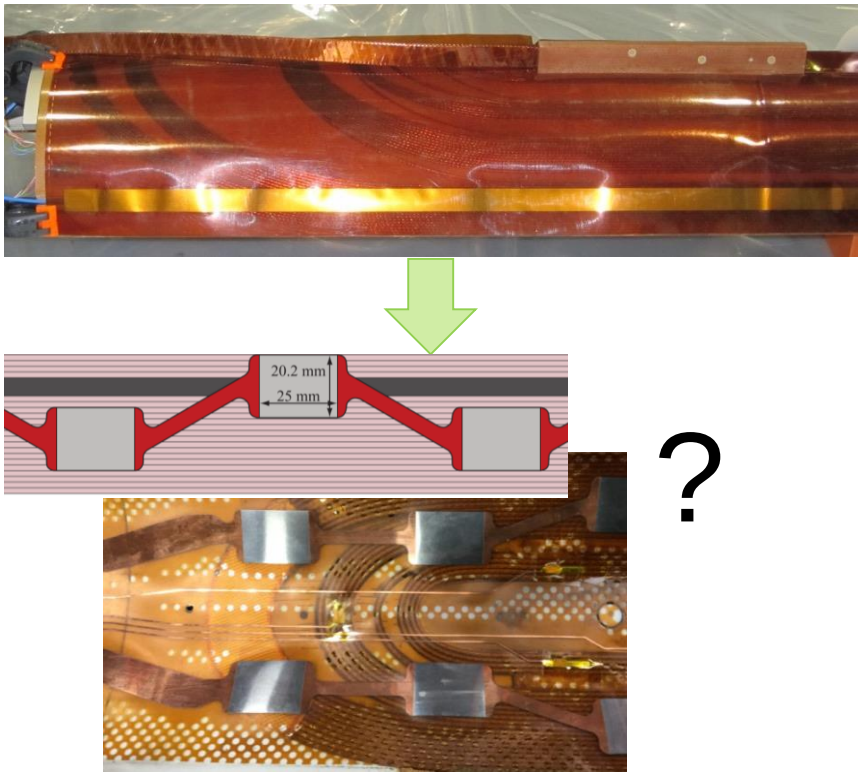
QPH firing at t=0



- Dump resistor was removed from the circuit.
- Tests with either four QPHs (all) or two QPHs (One of the QPH circuits was only activated.)
- Magnet current at 0.688 – 10.5 kA (The maximum current was limited by the MIITs.)
- Evaluation of MIITs

MIITs and dissipated energy





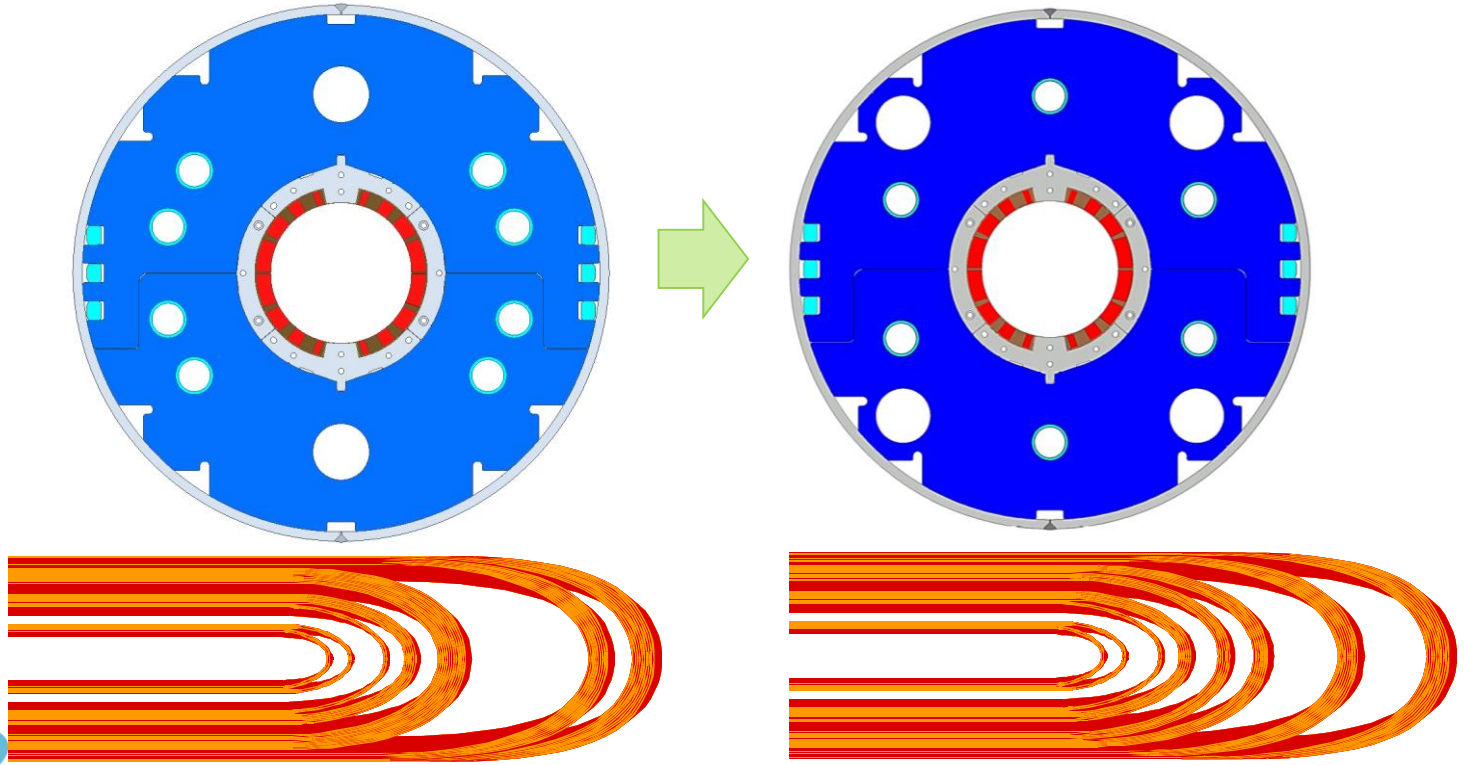
Ambrosio et al, Circuit Review, Mar 2016

- Allowable MIITs at 6 T = 30 (Design report)
- At 10.5 kA with all (four) QPHs, the MIITs reaches around 30.
- For faster current decay, heater strip should cover more turns.
- For designing QPHs, we will start quench simulation using the parameters which were experimentally determined in these tests.

Further plans

Tasks for the second 2 m model (MBXFS02)

- Magnetic design with modified iron yoke
- Quench simulation for designing QPH
- R&D
  - 10 stack measurement with Hi-pot test at higher stress
  - Stress measurement at coil end
  - Impregnation of coil end



MBXFS01 MBXFS02

Schedule of MBXFS02

	2017								2018		
	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Design study											
Coil end design											
Quench simulation											
Procurement											
Wedge											
End spacer											
QPH											
Collar											
Yoke											
Fabrication											
Coil winding											
Collaring											
Yoking											
Shell welding											
End ring welding											
Splice work											
Magnet test											
Preparation											
Magnet test											

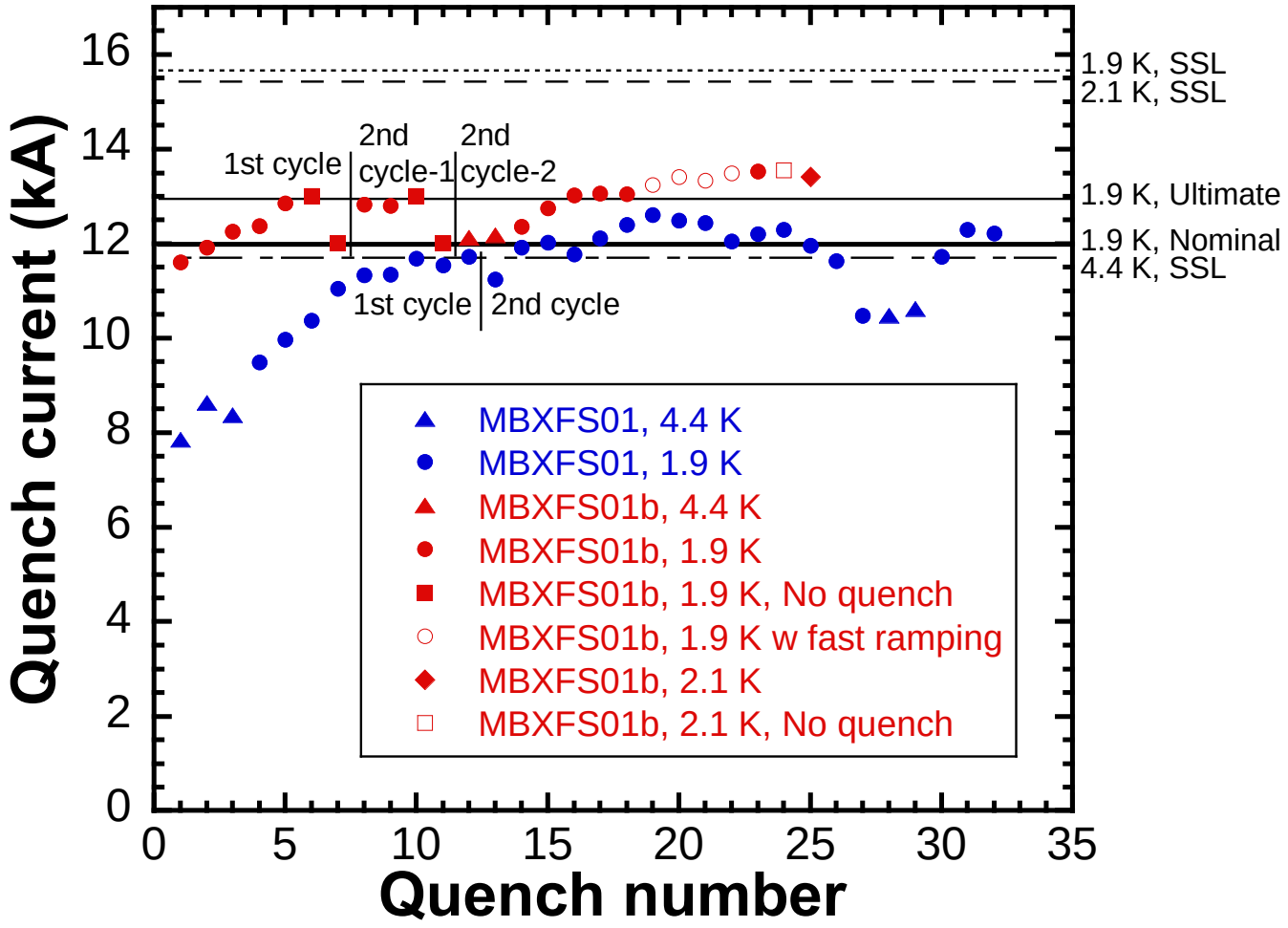
- Three coils including one spare will be wound.

Summary

- Magnet test of the MBXFS01b was completed.
  - Training performance was improved significantly by increasing azimuthal coil pre-stress.
  - The parameters necessary for quench simulation were successfully evaluated by heater test. QPH should be designed so that the heater strip cover more turns.

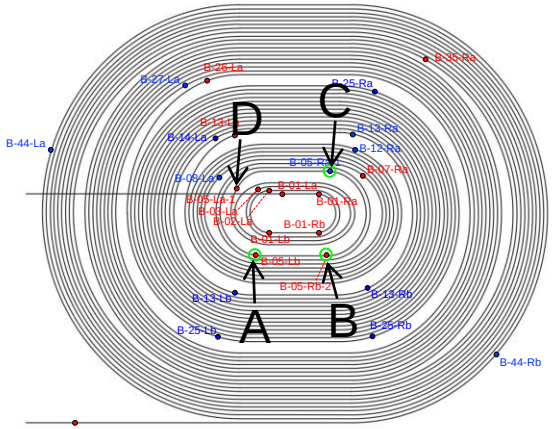
- Coil winding for the second 2 m model (MBXFS02) will be started in September 2017 and magnet test will be performed in March 2018.

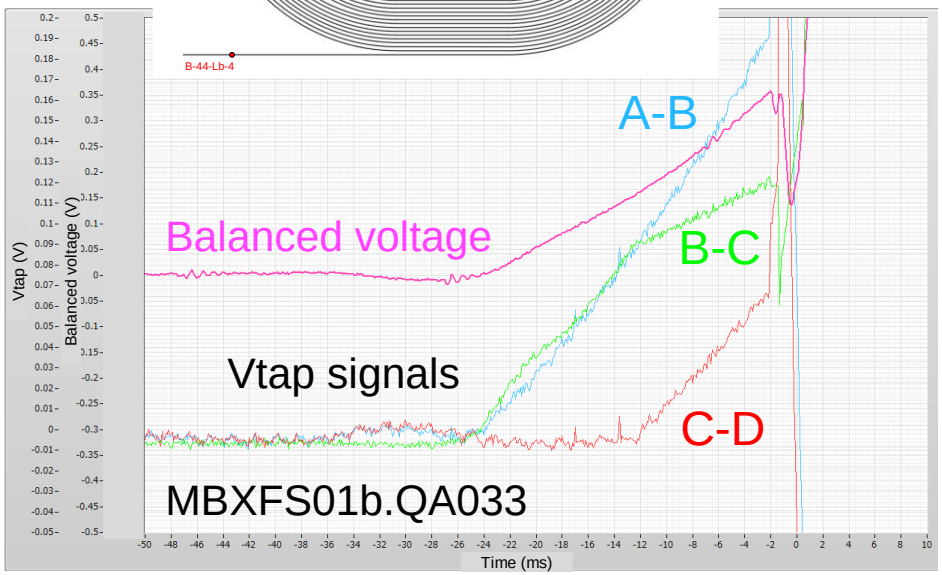
Training plot (comparison btw 01 and 01b)

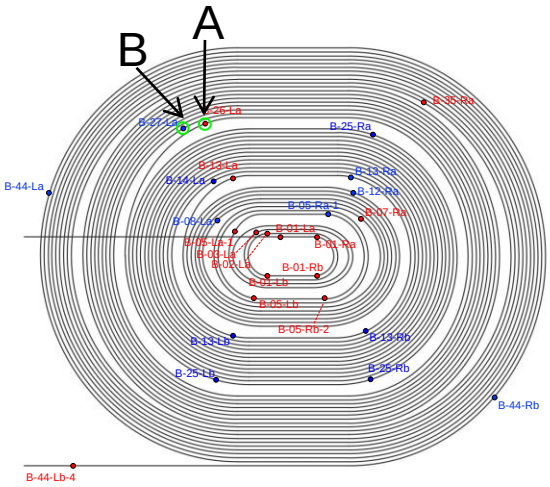


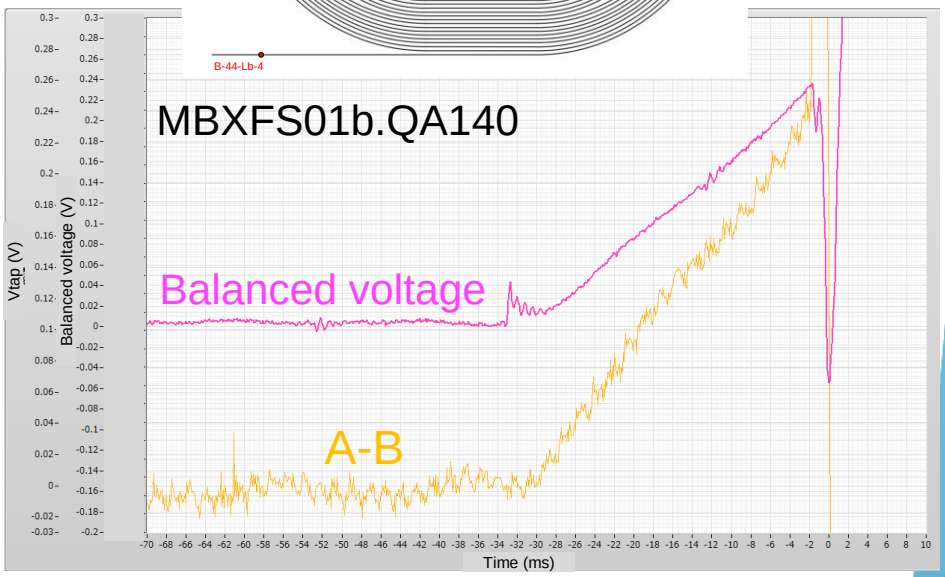
- Better training performance in the 01b than the 01

Typical voltage tap signals









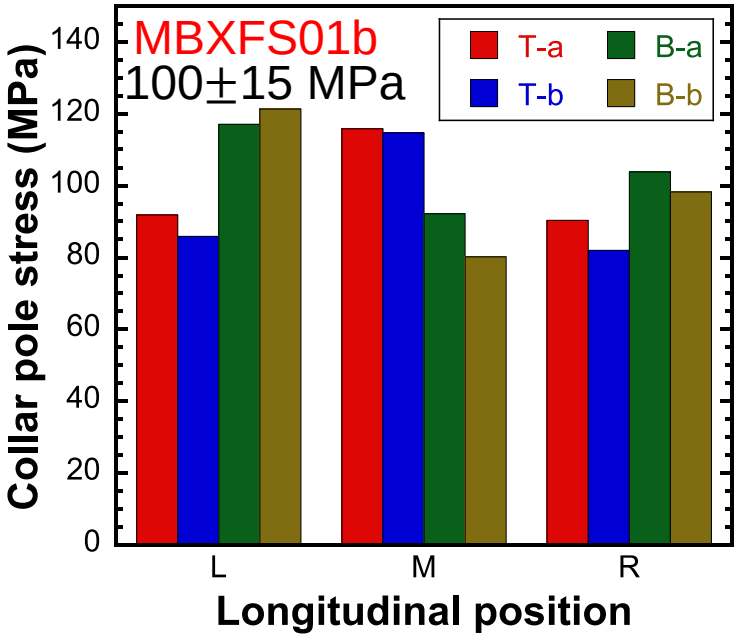
- Voltage generated at A-B and B-C almost simultaneously

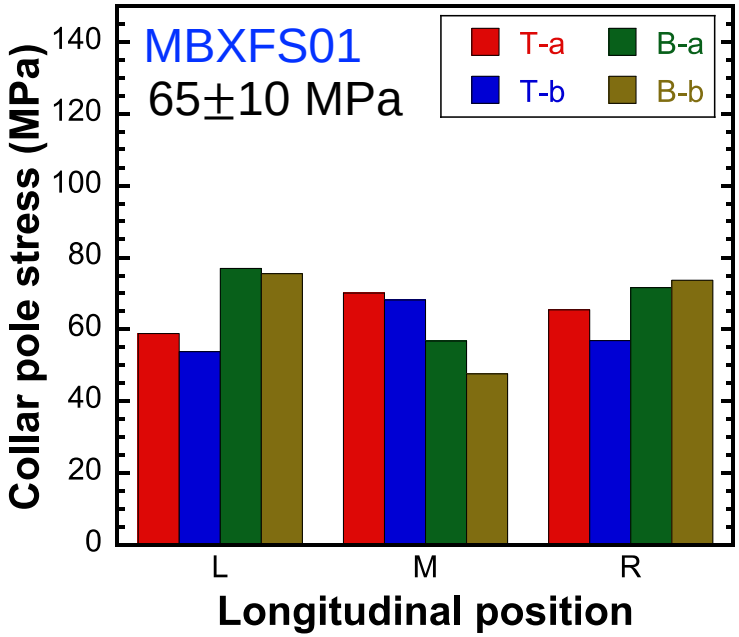
  → Quench start location is close to B.

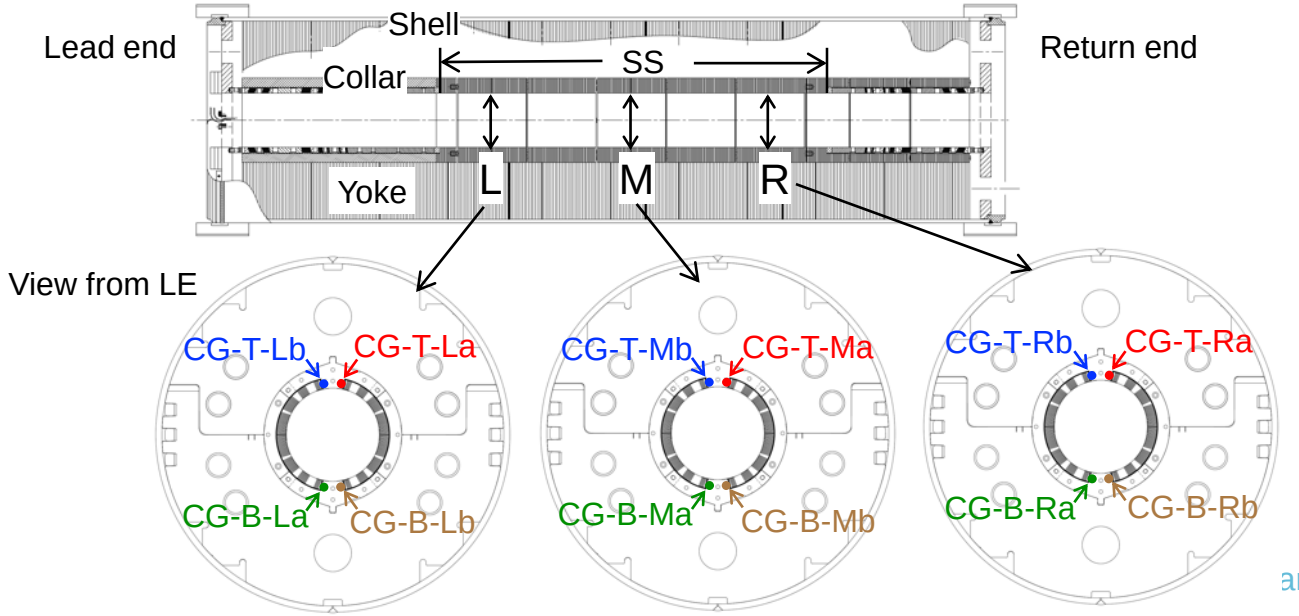
- Quench start location can only be determined as somewhere in one turn.

  → Analysis of quench antenna signals is essential.

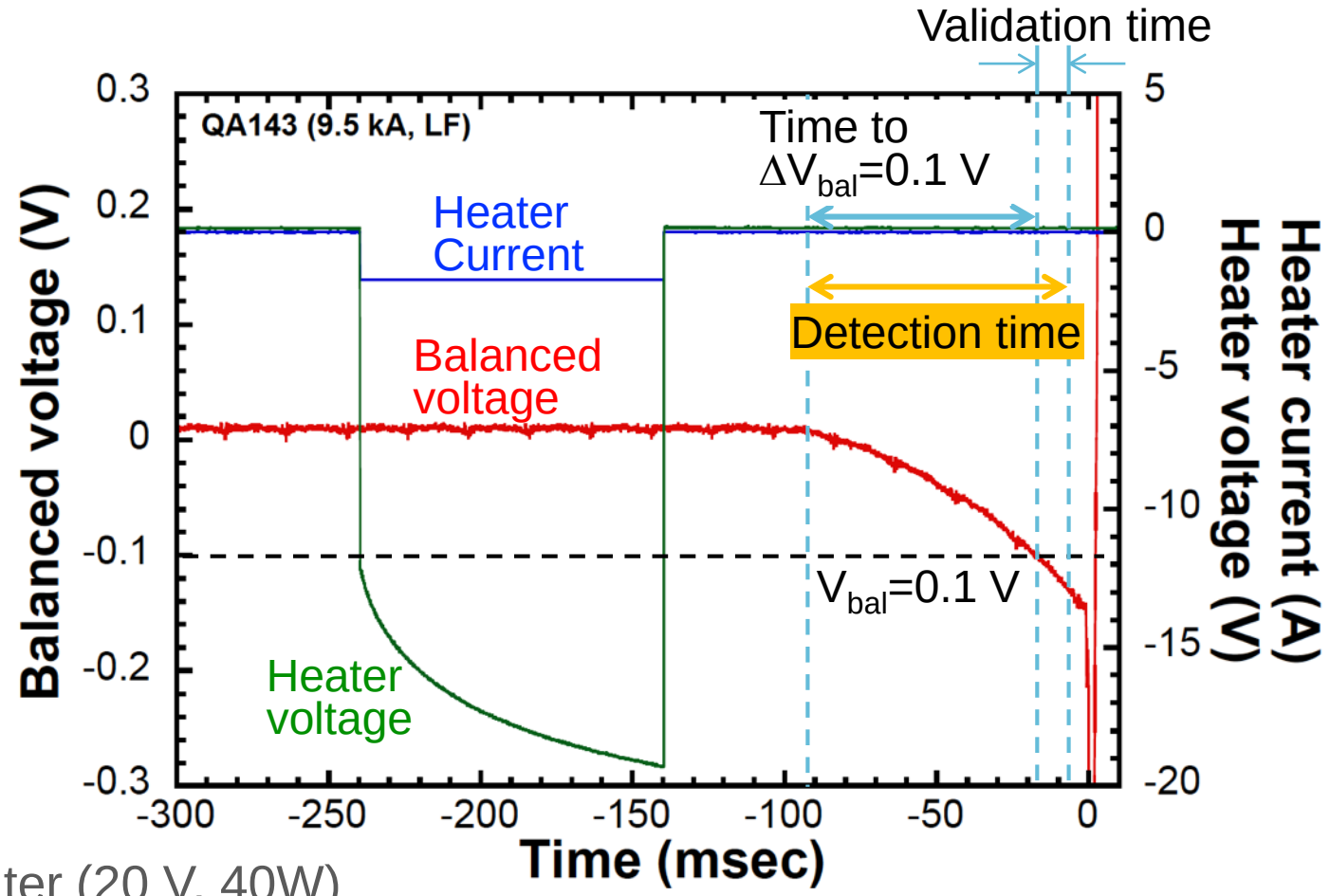
Coil pre-stress after yoking







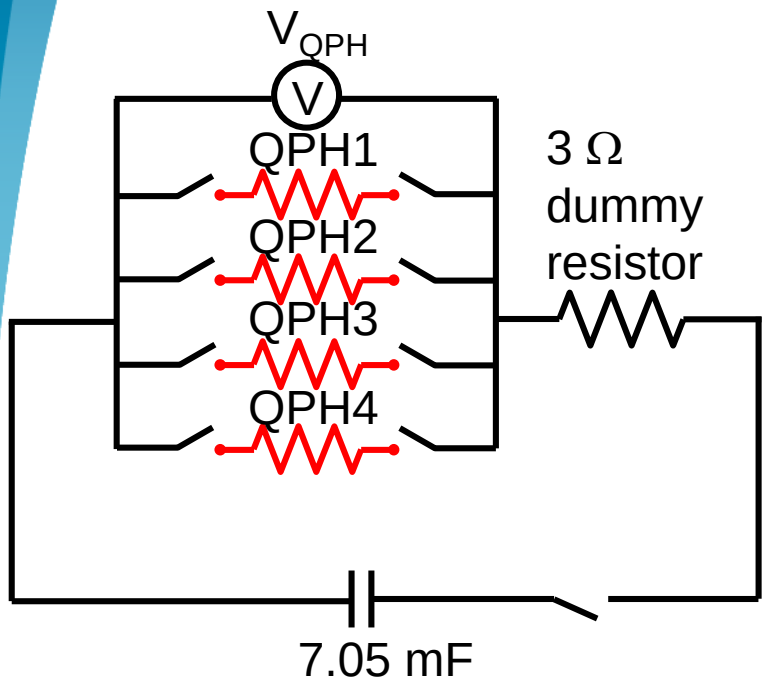
Evaluation of detection time

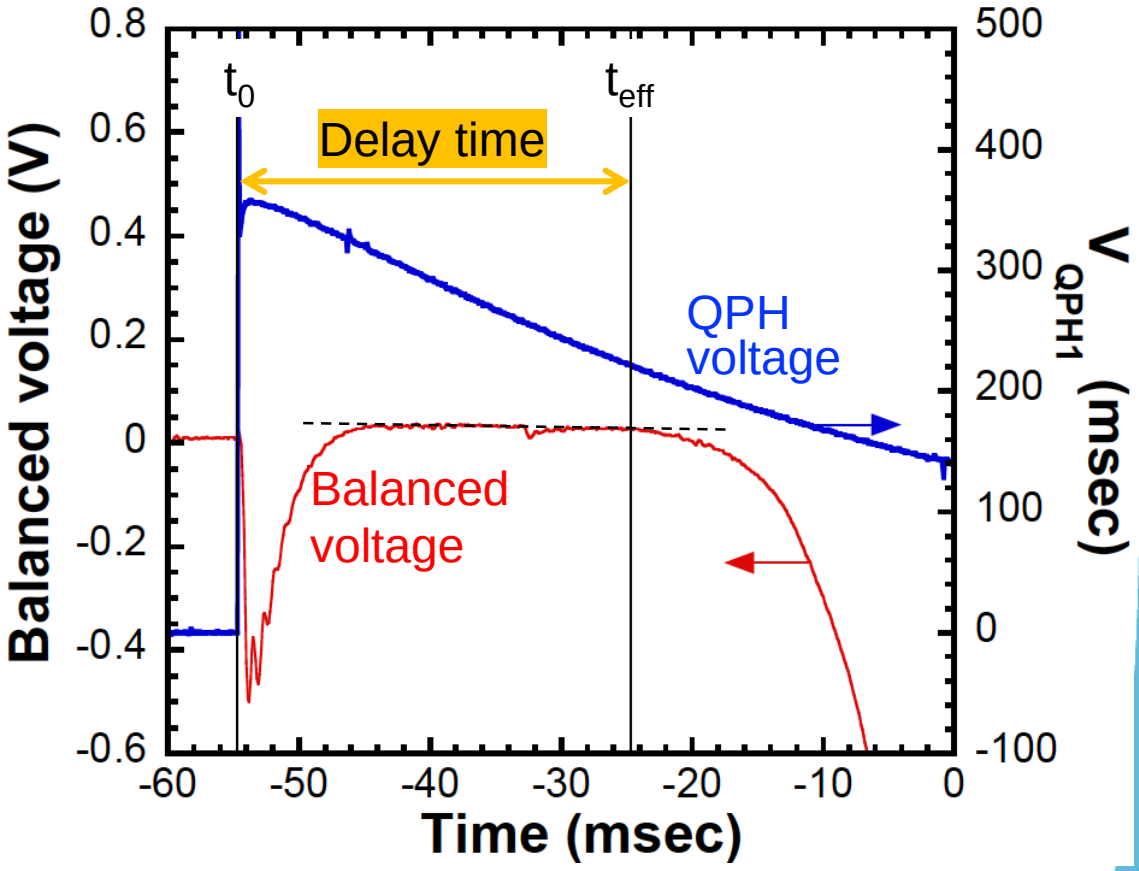


- Spot heater (20 V, 40W)
- Current: 2 – 9.5 kA (MBXFS01), 9.5 – 12.2 kA (MBXFS01b)
- Voltage threshold: 0.1 V
- Validation time: 10 msec

Detection time =
Time to ΔV_{bal}=0.1 V + Validation time

Evaluation of delay time





- Current: 688 A (Injection) – 9.5 kA (MBXFS01), 9.5 – 12.5 kA (MBXFS01b)
- QPH was fired at 100%, 50%, 25% (37.5%) of stored energy of a PS
- Delay time was evaluated as a function of

  P_{peak}: Peak power density ($=V_{QPH,max}^2/R_{QPH}/S$, S=Area of QPH)

Delay time: Time difference between QPH firing and the onset of balanced voltage