Status and Plans for the Second Prototype (MQXFAP2)

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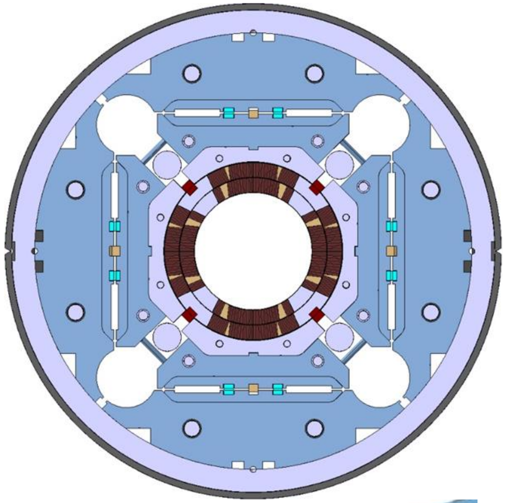
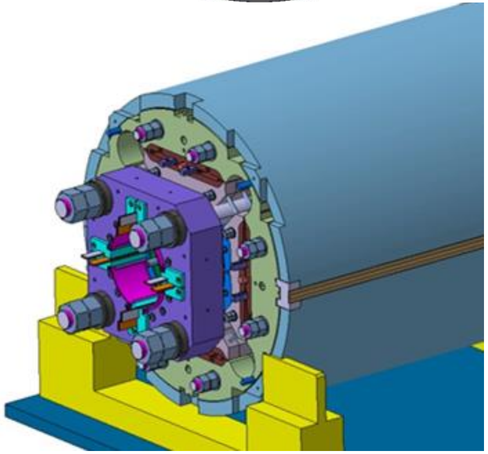
MQXF meeting – May 10, 2018

Design Parameters

Parameter	Unit	MQXFA/B
Coil aperture	mm	150
Magnetic length	m	4.2/7.15
N. of layers		2
N. of turns Inner-Outer layer		22-28
Operation temperature	K	1.9
Nominal gradient	T/m	132.6
Nominal current	kA	16.5
Peak field at nom. current	T	11.4
Stored energy at nom. curr.	MJ/m	1.2
Diff. inductance	mH/m	8.2
Strand diameter	mm	0.85
Strand number		40
Cable width	mm	18.15
Cable mid thickness	mm	1.525
Keystone angle		0.4





G. Ambrosio, P. Ferracin et al.

Prototype Features and Goals

From MQXFAP1 to MQXFAP2:

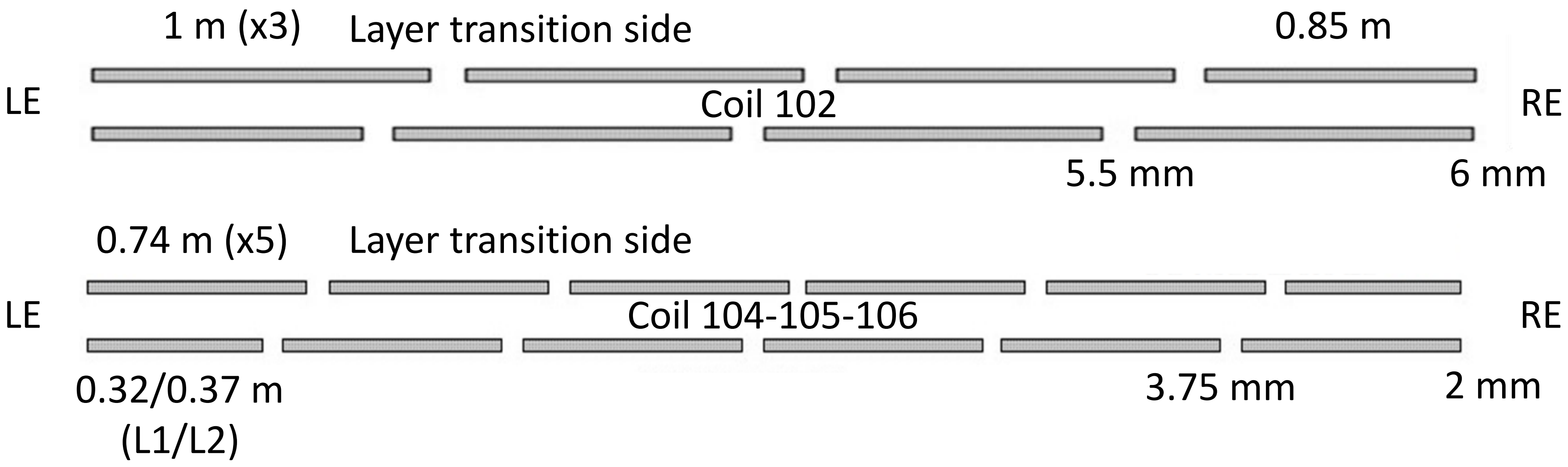
- Coil length according to final specification (4.2 m magnetic length)
- All coils made with strand meeting AUP specification
- Optimized pre-load based on MQXFAP1 and short model feedback
- Field harmonics during assembly and cold test
- Magnetic axis vs. longitudinal position relative to external fiducials (warm)
- Relative change in the field orientation vs. longitudinal position (warm)
- Electrical QA and protection scheme according to HL-LHC requirements

Additional features to be implemented in MQXFA03

- All coil and structure materials conform to HL-LHC approved list
- Fabrication and assembly according to approved MIPS
- Coils wound at both BNL and FNAL; no inner layer heaters/traces
- Full implementation of cooling channels in Ti poles (vs ~85%)
- Compatibility with cold bore assembly (coil bumpers, strain gauges/wiring)

Coil Fabrication

- Four coils selected: MQXA102,104, 105, 106
- Number of wedges was increased from 4 in coils 102 to 6 in coils 104-106, changing the wedge length and the gap distribution in coils.

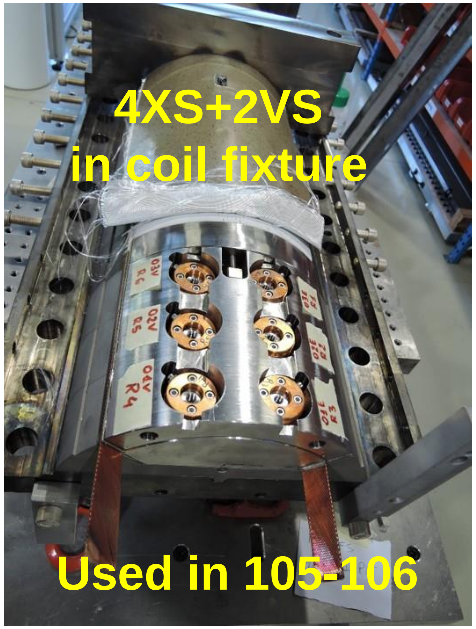


- Axon (CERN recommended vendor) wires utilized for protection heaters and voltage taps in coils 104, 105 and 106.

Strand Characterization

Coil ID	Cable ID	I_{ss} [kA]	B_{ss} [T]	I_{op}/I_{ss} [%]	RRR (XS)
QXFA102	P43OL1073	21.75	14.8	75.9	318-367
QXFA104	P43OL1081	21.74	14.8	75.9	126-135
QXFA105	P43OL1082	21.9	14.9	75.3	211-238
QXFA106	P43OL1084	21.0	14.3	78.6	139-157

- Coil 106 witness samples quenched before (but close to) reaching the 10 μV/m criterion
- I_c was estimated by V-I extrapolation and is lower than in other coils, but above specs
- No issues found with virgin strands or cabling
- May be related to new reaction fixture for witness samples: cross-check of old (retort) and new system in next coil reaction
- Additional extracted wires samples from cable P43OL1084 are also being reacted



L. Cooley, I. Pong, C. Sanabria, D. Turrioni et al.

Coil Electrical QA

Coil ID	QXFA102	QXFA104	QXFA105	QXFA106
HiPot (<1μA)				
Coil to Pole (V)	500/500	500/500	500/500	500/500
Coil to Heater (V)	3200/3200	3200/3200	3200/3200	3200/3200
Coil to end shoe (V)	1000/1000	1000/1000	1000/1000	1000/1000
Heater to end shoe (V)	2500/2500	2500/2500	2500/2500	2500/2500
IL to OL end shoe (V)	1000/1000	1000/1000	1000/1000	1000/1000
Impulse test (V)	2500/2500	2500/2500	2500/2500	2500/2500

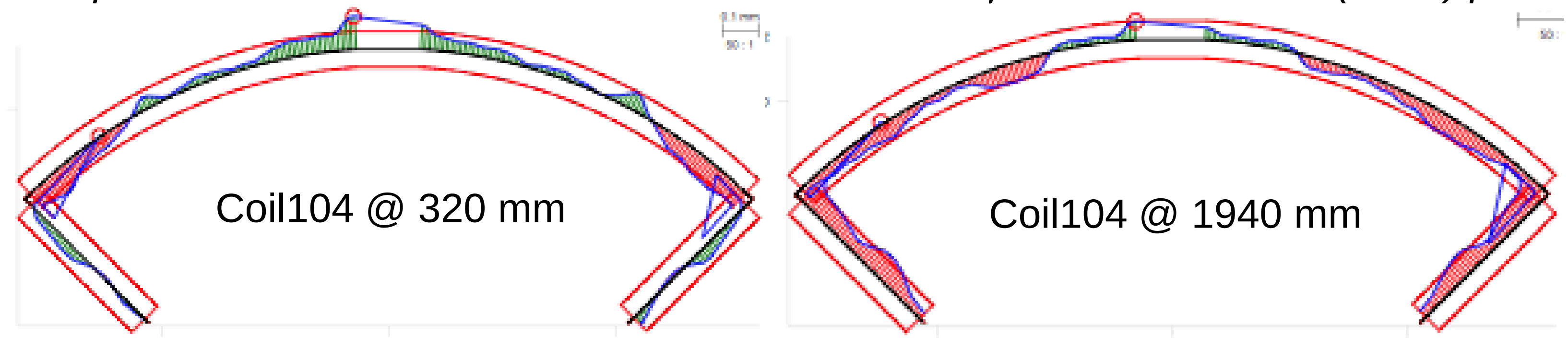
Notes:

- Consistent results before and after shipping to LBNL
- Coil to heater voltage may be have to be increased based on latest electrical criteria (3400 V or 4300 V proposed, under discussion)
- Coil QXFA101was set aside as it failed hi-pot for coil to outer layer return end shoe, and outer layer to inner layer return end shoe

Mechanical Assembly Status and Plans

- MQXFAP2 coil sizes are more uniform than MQXFAP1: no mid-plane shims or asymmetric radial shims required
- Total radial size deviation is -0.025 mm, similar to MQXFAP1, therefore same radial shim package (total 0.5 mm) was selected as a starting point
- Current status: coil pack assembled with Fuji paper
- If results from Fuji paper test are satisfactory, will proceed to final coil pack assembly and loading
- Schedule includes magnetic measurements and alignment survey
- Target shipping date is beginning of July

Examples of CMM results: red contours indicate +/- 50 μm from reference (black) profile

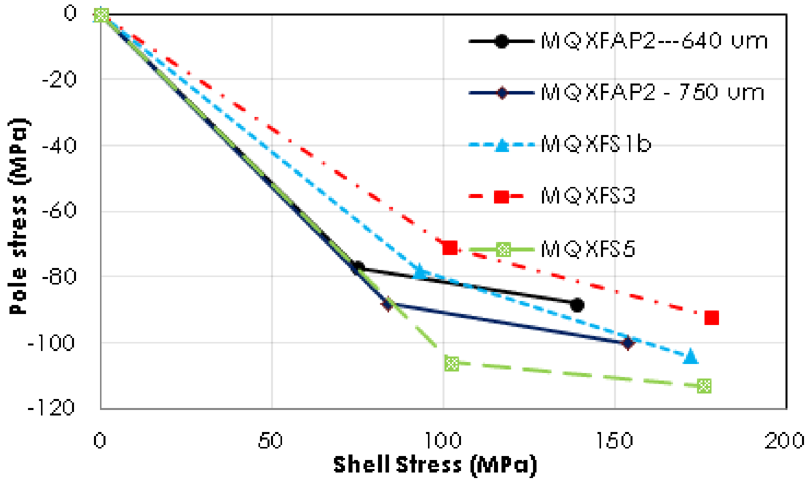


D. Cheng et al.

Pre-load targets: two options proposed

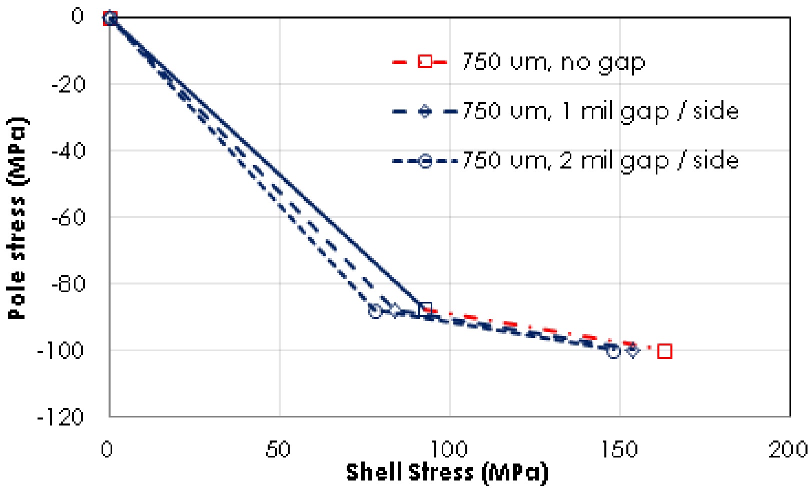
From H. Pan presentation, 3/15/2018, https://indico.fnal.gov/event/16587/

Magnet preload [Mpa]		MQXFS		MQXFAP2	
		1a	1b	640 μm	750 μm
RT	Coil	-61	**-77**	**-77**	**-88**
	Shell	72	95	73	84
CD	Coil	-81	-101	-88	-100
	Shell	140	173	143	154



Initial gap between the pole-key and collar stack

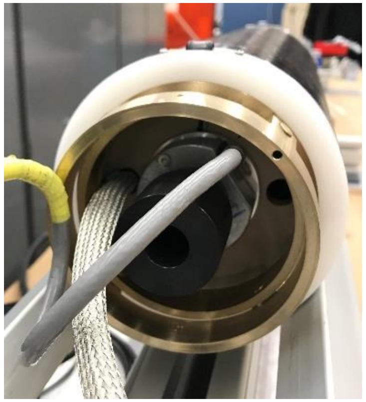
- Reduce the intercepted force but still engage the pole-key at cold.
- Maintain same pole stress with smaller shell stress.
- Gap should be smaller than 5 mil. A gap larger than 5 mil per side will NOT be closed after preload at R.T..



D. Cheng, H. Pan et al.

Warm Magnetic Measurements

- The assembly schedule includes a longitudinal of the field harmonics before loading, and a full set of measurements after loading:
  - Field harmonics as a function of longitudinal position
  - Magnetic axis vs. longitudinal position relative to external fiducials
  - Relative change in the field orientation vs. longitudinal position
- A dedicated (larger diameter) PCB probe was designed and built by FNAL
  - Radius 59.5 mm (vs. 50.5 for cold measurements) and length of 110 mm & 220 mm
- Preliminary measurements were taken on the first MQXFA2 coil pack
- Longitudinal displacement actuator is being commissioned



J. Di Marco, X. Wang et al.

Electrical QA

Will be based on new electrical criteria documents (EDMS 1963398, US-HiLumi-Doc-826)

Maximum expected coil voltage at quench (V) [2]	To ground	670
	To quench heater	900
Minimum design withstand coil voltage at nominal operating conditions (V)	To ground	1840
	To quench heater	2300
Minimum design withstand coil voltage at warm* (V)	To ground	3680
	To quench heater	4600
Test voltage to ground for installed systems at nominal operating conditions (V)		804
Test voltage to ground for installed systems at warm (V)		368
Test voltage to heater for installed systems at nominal operating conditions (V)		1080
Test voltage to heater for installed systems at warm (V)		460
Maximum leakage current (μA) – not including leakage of the test station		10
Test voltage duration (s)		30

* T = 20±3 °C and humidity lower than 60%

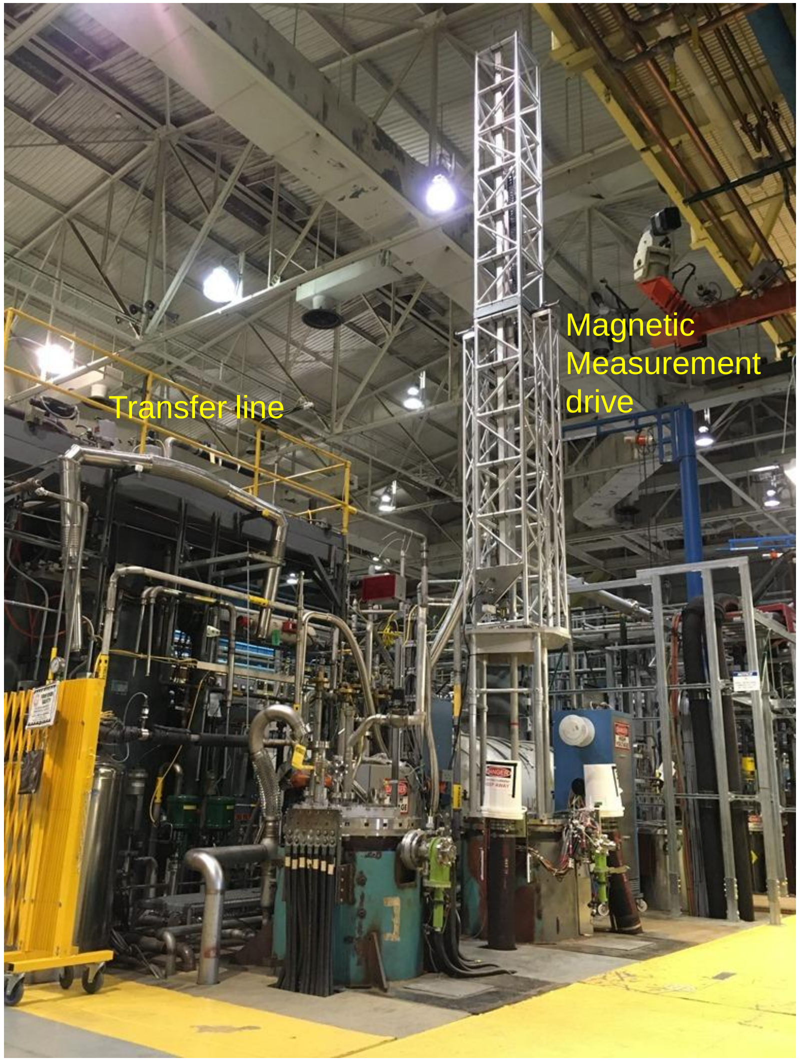
Proposed, under discussion (based on 600V maximum expected coil-heater voltage)

Component	V_max	V_test @ 1.9 K	V_test @ warm	V_test @ warm after He
Coil-Heater MQXFA	600 V	1700 V	3400 V	340 V

Coil QA performed at 3200 V

BNL Test Facility Upgrades for MQXFAP2

- Use of Test Cryostat 3 as a cold buffer tank to improve quench recovery and minimize He loss
- Magnetic measurement system under commissioning



J. Muratore, M. Anerella, P. Joshi, A Marone, S. Hong et al.

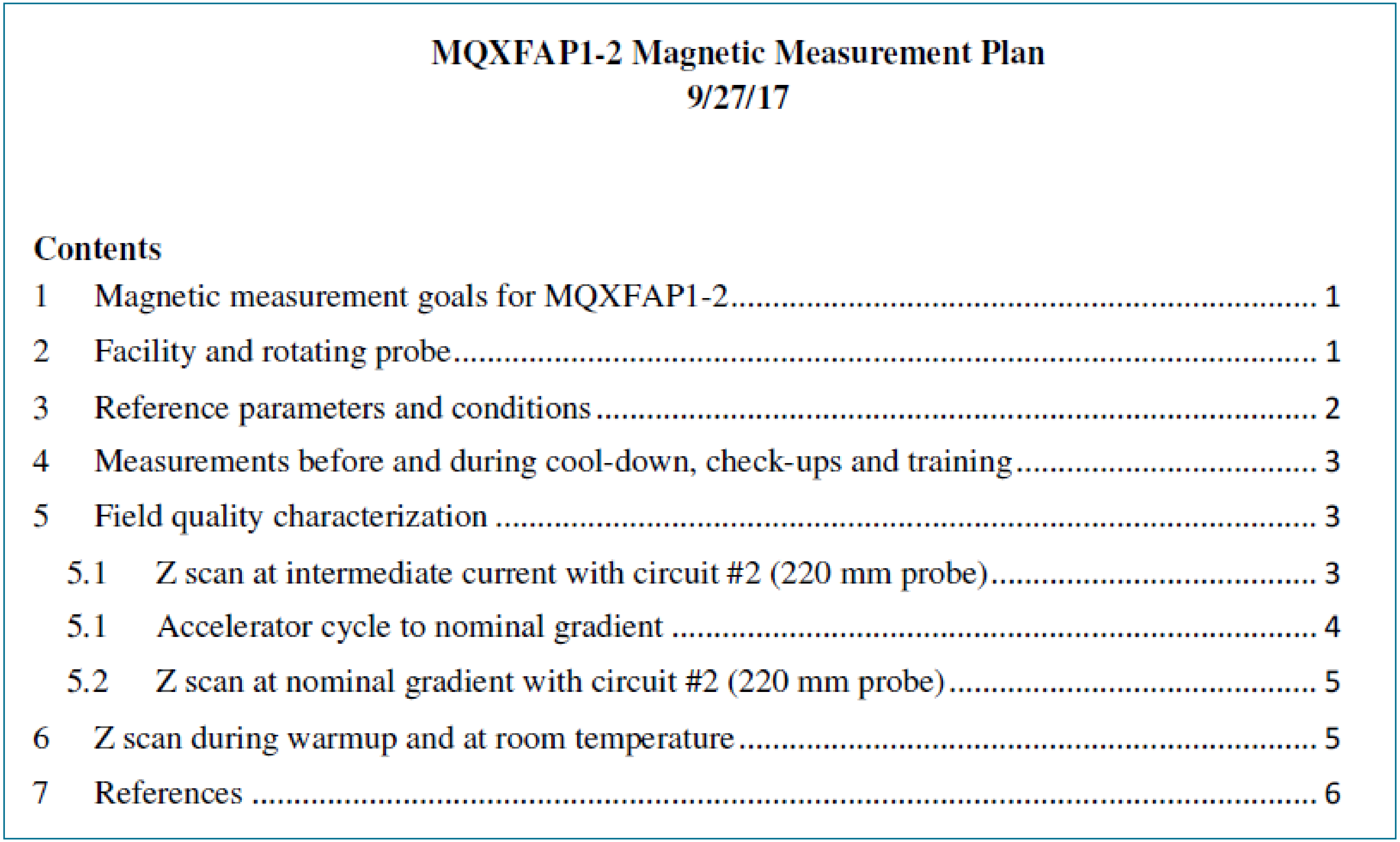
Test Plan Updates and Questions

- Guidance from CERN is consistent with previous tests and current plans, a few points will be noted for further discussion
- Quench protection scheme for training: need to privilege efficiency of recovery with a goal of 2-3 quenches/day
  - Use of CLIQ (lower MIITs, faster training, more redundancy but also potentially less energy extracted)
  - Choice of the dump resistor (more extraction but higher voltage)
- Quench protection studies:
  - Include quenches with the nominal protection scheme after training (no extraction) to ensure that performance is not affected
    - Before or after thermal cycle?
  - No high Miits quenches before thermal cycle
  - No training above ultimate

Test Plan Updates and Questions

- Robustness of maximum quench level achieved:
  - Proposing to demonstrate through power cycling test and magnetic measurement ramps
- Cycling test:
  - How many cycles?
  - Minimum current? 50% was used in TQ
  - Maximum current? (nominal or ultimate)
  - Use higher ramp rate for part or all the cycle?
- Magnetic measurement plan
  - A test plan was prepared for MQXFAP1-2, based on MQXFS1
  - Cycles to ultimate require training to slightly higher current
  - First use of new system: how to validate prior to MQXFAP2 test

Magnetic Measurement Plan


MQXFAP1-2 Magnetic Measurement Plan
9/27/17

Contents

Test Guidance from CERN

TRIPLET

- Test plan to be agreed before test start and stored in EDMS
  - Can be updated according to test results
- Main sequence
    - All test at 1.9 K with the exception of verification at 4.5 K
  - Training to ultimate or until plateau
  - Magnetic measurements and endurance test
  - Ramp rate test
  - Protection test
  - Quenches at 4.5 K
  - Thermal cycle and memory check at ultimate
  - Training above ultimate until a plateau is reached (for short models and possibly for prototypes)

TRIPLET

- Some clarifications on the strategy - 1
  - Virgin training at 1.9 K
  - 4.5 K test and ramp rate are used to work out temperature margin
  - Series magnet will not be powered above ultimate
  - We had the plan of powering short models and (possibly) prototypes above ultimate, but we did not yet
    - This because training is longer than expected, especially above 80% of short sample
  - Once the ultimate is secured, magnetic measurements are done

TRIPLET

- Some clarifications on the strategy – 2
  - Identification of plateau is usually not controversial (few quenches within <50 A) but
    - Sometimes we see relevant detraining, or magnet blocked well below ultimate
    - In these cases ramp rates can overcome
    - But the ramp rate test becomes difficult to interpret since it could include some training
    - In one case a high MIITS test allowed to overcome limitations (11 T short model)
  - So test plan can be jeopardized by non nominal performance

TRIPLET

- Some clarifications on the strategy – 3
  - The most important feature for accelerator operation is the test after thermal cycle
    - Lot of attention is currently put on virgin training, but this is more an "internal affair of magnet group"
  - Nominal current is a must
    - Magnet not reaching nominal has to be rejected

TRIPLET

- Essential elements
  - 4.5 K test to prove temperature margin
    - Until now, all RRP had same performance as 1.9 K, whereas the PIT showed a non negligible loss
  - Ramp rate tests
    - Magnet shall show a flat behaviour until 300 A/s
  - Ability to see coil unloading
  - Ability to measure quench velocity
    - Quench antenna is a must for prototype and series, where we will have less voltage taps
  - Ability to separate mechanical quench from conductor limitation/degradation, or phenomena related to instabilities
    - The toughest problem

TRIPLET

- Three magnet builder nightmares
  - Reversed performance
    - Magnet performing better at 4.5 K than at 1.9 K
    - Magnet performing better at higher ramp rates
    - Magnet performing better after high MIITs
  - Very slow quench velocities
    - Indicates very large local margin, and can jeopardize magnet protection
  - Non reproducible behaviour

US HL-LHC AUP

LARP