**MQXFS Assembly Test Plan**

**Version 2c, 11/11/15**

**Main goals**

* Measure pre-load variation during cool-down and compare with targets
* Confirm the magnet electrical integrity and system readiness for cold test
* Assess any internal coil damage due to coil pack assembly incident
* Confirm design calculations up to the level that can be reached with the available coils
* Provide feedback to select the coil configuration for the next test

**Overview**

* Install magnet on header and perform warm checks
* Cool down, monitoring strain gauges
* Perform system checks up to 6kA
* Ramp to quench at 1.9K
* If progress is limited below nominal level (16.48 kA, 132.6 T/m)
  + Characterize performance limitations, in particular, to help determine which coils should be replaced in the next assembly
  + Warm up and proceed to next assembly
* If magnet achieves the nominal level (132.6 T/m), but progress is limited below ultimate
  + Perform selected field quality, ramp rate, protection studies up to nominal level
  + Characterize performance limitations, in particular, to help determine which coils should be replaced in the next assembly
  + Proceed to next assembly without a thermal cycle
* If magnet exhibits good training performance to ultimate level (17.90 kA, 143.2 T/m)
  + Perform full field quality, ramp rate, temperature dependence, protection studies program
  + Perform a thermal cycle

**Test sequence**

*Note: additional details for magnetic measurements and protection studies are provided in separate documents*

**A. Setup, cool-down, system and magnet checks**

1. Before connection to the header
   * Prepare and mount the top and bottom interface plates
   * Electrical checkout: sequential resistance measurements, heater and strain gauge checkout through the cable “pigtails”, hi-pot test
   * Hi-pot schedule: Coil to ground (with heaters grounded or floating) at 1000 V, PH to ground (with coils grounded or floating) at 1000 V, Spot heater to ground (with coils grounded or floating) at 500 V. Continuity check between coils and end-shoes, as well as between IL and OL end-shoes.
2. Magnet on the 30 kA header
   * Mounting temperature sensors on top and bottom of the magnet shell
   * Electrical checkout through the instrumentation “tree” of the header assembly
3. Magnet in cryostat at 300 K
   * Connect all systems to DAQ
   * RRR measurements at 300 K
   * Warm magnetic measurements to confirm assembly data and verify the coordinate system in the vertical position
4. During cool-down
   * Maintain a 100 K limit on temperature range between the magnet top and bottom.
   * Strain gauge monitoring with 3 min interval between readings
5. System checks (120 m dump resistor; 4.5K or 1.9K). Imax ≤ 6 kA
   * Electrical checkout and quench detection checkout; hi-pot test (see Section 1 for the hi-pot schedule)
   * Manual trip at 1000 A
   * Heater provoked quenches at 3.3 kA (20% nominal current) and 4.94 kA (30% nominal current). Set HFU capacitance at 19.2 mF. Fire all heaters gradually increasing the HFU voltage, starting at 200 V until the quench is induced. Measure delay to quench. Check signals for any signs of insulation failures.
   * Technical ramp at 400 A/s (limited to 6 kA). If no quench is generated, proceed to next step without attempting to increase ramp rate or max current.
6. Preliminary magnetic measurements before training (120 m or 30 m dump resistor; 1.9K; Imax = 6kA).
   * Z scan of the straight section only at 0.96 kA (injection level) and 6 kA
   * Ramp rate study: 100 A to 6kA at 20, 40 , 60 A/s
7. Quench protection studies before training (30 m dump resistor, no delay; 1.9K)
   * Procedure: Fire one heater circuit with gradually increasing voltage. When quench occurs, measure delay from heater firing to quench start, protect with all other heaters and dump resistor
   * Four discharges in total: IL heater at 20 and 30% nominal current, and OL heater at 20 and 30% nominal current, using CERN heater strips (coil 103).

**B. Primary performance assessment**

1. Quench training at 1.9K
   * Setup of protection and DAQ systems for quench training
     1. Initial dump configuration: 30 mΩ (to be confirmed after electrical checks, and re-evaluated during the test depending on achieved current/voltage)
     2. Acquire voltage spike signals for all training and ramp rate quenches
     3. Acquire quench antenna signals (no magnetic measurements during ramps)
   * Ramp to quenchat 1.9 K
     1. Ramp rate: 20 A/s in first ramps, then continue at mixed ramp rates: start at 50 A/s and then continue at 20 A/s
     2. Protection delays plan: set to zero for the first 1-2 quenches, check MIITs. Increase delays up to 10 ms for selected quenches (if a safe margin on MIITs level and maximum temperature can be confirmed) to study propagation.

* Monitor and evaluate progress until a selection can be made to continue the test following one of the options listed below.

**C.1:** **If a decision is made to stop training below nominal:**

1. Performance studies up to maximum stable current, and characterization of performance limits. Main options are listed below. Final selection will be made after additional discussion, and reconfirmed during the test depending on results.
   * (Short) current holding tests below quench level, to find maximum stable current and check coil/locations participating in holding quenches, if any
   * Current holding tests from maximum stable level, while increasing temperature (to check temperature margin, and quench coil/location as temperature is increased)
   * Splice resistance measurements
   * Magnetic measurements to maximum stable current
   * Protection heater studies to maximum stable current
   * Ramp rate dependence study
     1. Ramp up at dI/dt = 10 A/s, 50 A/s, 100 A/s, 200 A/s, 300 A/s, 350 A/s
     2. Additional points depending on results
   * Temperature dependence study (1.9K-4.5K)
     1. Ramp to quench at about 0.5 K intervals (5 points)
   * Down ramps from maximum stable current
   * Fast extraction study
   * Training quenches with increased delays (to determine if quenches appear in more than one coil, to study quench propagation, and to look for signs of local degradation through changes in quench velocity)
2. Operation at 4.5 K
   * Energy loss measurements loops at different ramp rates (lower loop only from 500 A to 6500 A)
3. Warm up to 300K
   * RRR measurements at 10-20 K
   * Magnetic measurements during warm-up

**C.2:** **If training proceeds to nominal level**

1. Perform selected studies at nominal level:
   1. Magnetic measurements at 1.9K
      1. Accelerator cycle, Ramp rate dependence, Stair-Step and Z-scan at selected currents
   2. Protection heater tests (delays as function of current and power, comparisons/consistency between different heaters and coils, up to nominal level)
   3. Splice resistance measurements
   4. Current holding test at nominal level (8 hours)
   5. Current holding tests at nominal while increasing temperature (to check temperature margin, and limiting coil/location at elevated temperature)
   6. Down-ramp at 300 A/s from nominal
      1. If quench, repeat with lower ramp rate and find maximum stable down ramp
   7. Fast extraction study
2. Continue training up to ultimate level
   1. Select between C.2.a and C.2.b cases depending on progress

**C.2.a:** **If a decision is made to stop training below ultimate**

1. Performance studies up to maximum stable current
   * Short holding tests below quench current, to find maximum stable current and check if more than one coil/location is participating in quenches
   * Additional magnetic measurements up to maximum stable current
   * Additional protection heater studies up to maximum stable current
2. Other quench studies and characterization of performance limits
   * Ramp rate dependence
     1. Ramp up at dI/dt = 10 A/s, 50 A/s, 100 A/s, 200 A/s, 300 A/s, 350 A/s
     2. Additional points depending on results
   * Temperature dependence (1.9K-4.5K)
     1. Ramp to quench at about 0.5 K intervals (5 points)
   * Training quenches with increased delays (to determine if quenches appear in more than one coil, to study quench propagation, and to look for signs of local degradation through changes in quench velocity)
3. Operation at 4.5 K
   * Energy loss measurements loops at different ramp rates (lower loop only from 500 A to 6500 A)
4. Warm up to 300K
   * RRR measurements at 10-20 K
   * Magnetic measurements during warm-up

**C.2.b:** **If training proceeds up to ultimate**

1. Performance studies up to ultimate level
   1. Current holding tests at ultimate while increasing temperature (to check temperature margin, and limiting coil/location at elevated temperature)
   2. Down ramp at 300 A/s from ultimate
      1. If quench, repeat with lower ramp rate and find maximum stable down ramp
   3. Complete magnetic measurement plan up to ultimate
   4. Complete protection heater studies up to ultimate
   5. Complete fast extraction study up to ultimate
   * Ramp rate dependence study
     1. Ramp up at dI/dt = 10 A/s, 50 A/s, 100 A/s, 200 A/s, 300 A/s, 350 A/s
     2. Additional points depending on results
   * Temperature dependence study (1.9K-4.5K)
     1. Ramp to quench at about 0.5 K intervals (5 points)
2. Operation at 4.5 K
   * Energy loss measurements loops at different ramp from 500 A to 6500 A and from 6500A to 12500 A)
3. Warm up to 300K
   * RRR measurements at 10-20 K
   * Magnetic measurements during warm-up
4. Full thermal cycle
   * Confirm key findings and investigate open question from first cycle
   * Perform special protection studies with expected Thot > 250 K