Test plan for SPL short cryomodule

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Objective of test

- **Validation of RF power test setup** with 1 MW klystron/modulator on sc cavity in pulsed mode
- **Validation of cavity performance inside cryo-module and of assembling procedure**: conditioning with 1 klystron of pair of cavities up to 25 MV/m
  - main coupler conditioning
  - calorimetric Q-measurement
  - X-ray generation of cryo-module
  - long run test @ max field
  - crosstalk between cavities by RF or dark currents, ...
- **Validation of LLRF system**
- **Validation of cryo-module design**
  - static losses
  - critical heat flow in super-fluid helium
  - microphonics, ...

Test object [1]

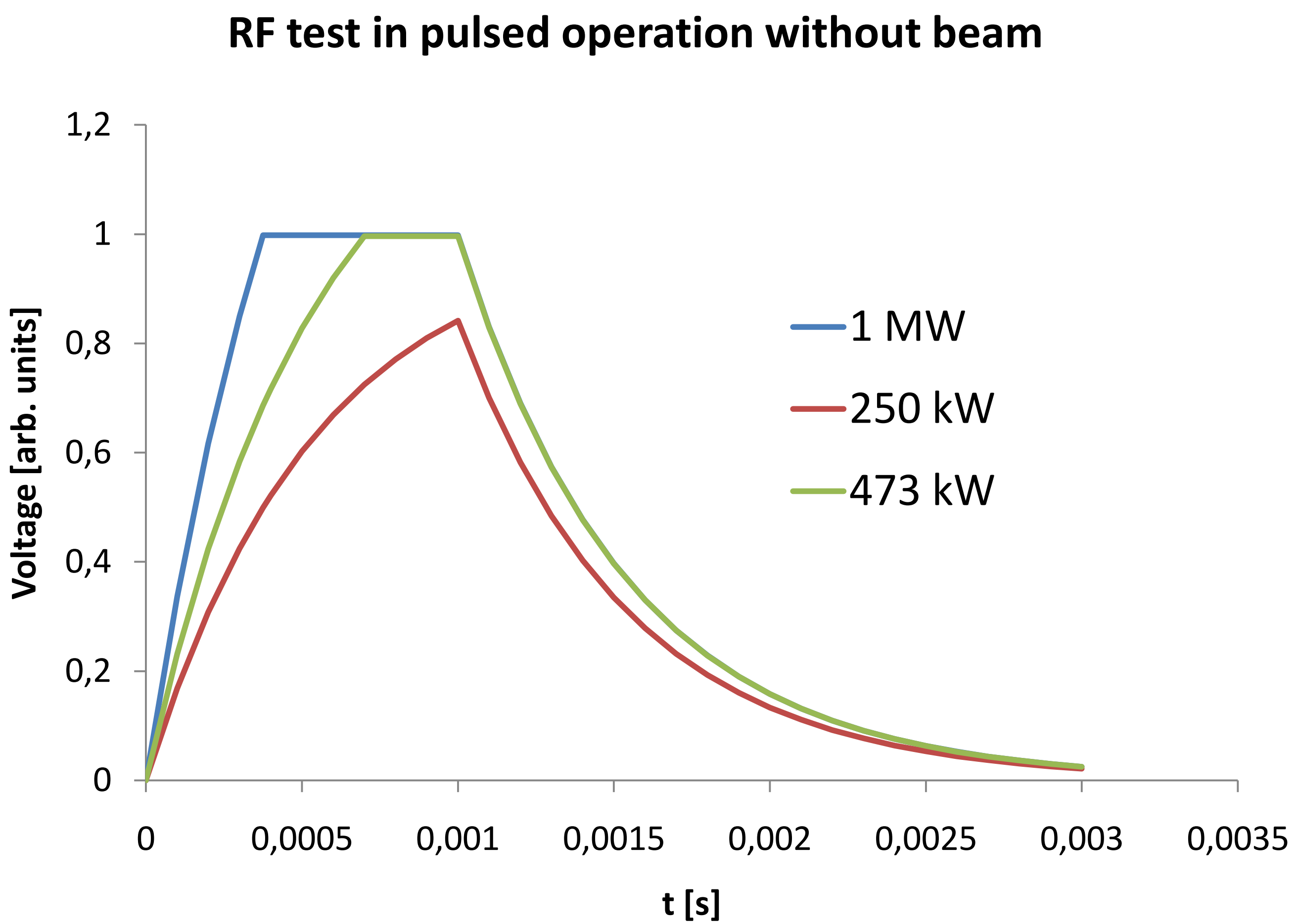
- **The cryomodule is equipped with**
  - 4 β=1 5-cell Nb bulk cavities at 704 MHz joined with lHe tank
  - 4 power couplers (2 per klystron) with ancillaries (gHe feeder lines with heater) and interlock equipment (e-current, temperature, vacuum gauge)
  - 4 pickup antennas (50 Ω)
  - 4 tuners (slow and piezo)
  - 1 thermal shield with (possibly) magnetic shield (Cryoperm) thermally anchored to it (need of 2nd magnetic shield to be discussed)
  - 2 gate valves at extremities (plus protection flanges)
  - slow control & interlock system
  - …

Test object 2

- … **the cryomodule is equipped with**
  - He pressure gauge
  - lHe level sensors (redundancy)
  - temperature-sensors at strategic points (bellows, magnetic shield, HOM couplers, power coupler
  - 8 HOM couplers with (broadband) feedthrus and RF cables to room temperature loads (rated 100 W) sufficiently thermally anchored
  - pressure gauges for cavity vacuum and insulation vacuum
  - 4 heaters inside He tank (among others used for measurement of Q-value)
  - RF-DC filters for e^--current measurement (outside cryo-module) at HOM and pick-up cables
- Radiation monitor available inside bunker
- All sensor signals remotely logged

Test object [3]

RF power tests with 1/2/4 cavities per 1 MW klystron



Cryogenic design parameters

Updated values in red

Cf. also
https://twiki.cern.ch/twiki/bin/view/SPL/SPLparameterList

Parameter	Unit	low-beta	high-beta
		nominal/ultimate	
Cavity bath temperature	[K]	2.0	2.0
Beam loss	[W/m]	1.0	1.0
Static loss along cryo-modules at 2 K	[W/m]	?	?
Static loss at 5-280 K	[W/m]	?	?
Accelerating gradient/voltage	[MV/m]/[MV]	19.3/13.3	25/26.5
Quality factor Q	[10^9]	6/3	10/5
R/Q value	[Ω]	290	570
Cryogenic duty cycle	[%]	4.09/8.17	4.11/8.22
Coupler loss at 2.0 K	[W]	<0.2/0.2	<0.2/0.2
HOM loss at 2.0 K in cavity	[W]	<1/<3	<1/<3
HOM coupler loss at 2.0 K (per coupler)	[W]	<0.2 /0.2	<0.2/0.2
HOM & Coupler loss 5-280 K	[g/s]	0.05	0.05
Tunnel slope	[%]	1.7	1.7
Cavities per cryostat		3	4/8
Dynamic heat load p. Cavity	[W]	4.2/16.8	5.1/20.4
Intercavity bellows hom loss (ss/copper) for 2.112 GHz	[W]	?	<3/<0.1

Test sequence [1]

- **At room temperature**
  - The cryo-module is installed and connected to the cryo-line but not yet to the RF power waveguide system proper (2 cavities per klystron) but instead to a waveguide-coax 50 Ω line
  - Check vital components such as tuners (range), temperature sensors, low level RF system
  - Measurement of fundamental mode (704 MHz) resonant frequencies of cavities and Q_{ext} for 704 MHz of power couplers, pickup probes and HOM couplers
  - Calibrate directional couplers on waveguides for forward and reflected wave
  - Interlock tests
  - If vacuum OK ($p < 10^{-6}$ mbar) start cool down
    - Sequence of cool down: thermal/magnetic shield – cavity end group (beam tubes) – cavity proper

Test sequence 2

- **During cool down**
  - Logging of temperature sensors/lHe level/vacuum

Test sequence 3

- **At 4.5 K**
  - Measurement of fundamental mode resonant frequencies of cavities and Q_{ext} of power couplers, pickup probes and HOM couplers (optional)
  - Measure transfer-function of fundamental and prominent HOMs between adjacent cavities
  - Connection with RF power waveguide system and adjustments of Q_{ext} of power coupler to nominal, if needed
  - Switch on moderate RF power and check for RF leaks in waveguide system
  - Activate LLRF system for tuning cavities on master frequency
  - Have all interlocks and all diagnostics equipment active and actuators on REMOTE, close door of bunker

Test sequence [4]

- **At 1.8 K**
  - Increase RF power slowly to nominal value under pulsed conditions and careful observation of
    - Power coupler diagnostics signals (to be specified)
    - Cavity signals (forward, reflected, transmitted power, vacuum)
    - HOM power at 704 MHz
    - X-radiation
    - e^--current
  - Check for helium pressure oscillations without RF as well as "microphonics"
  - Measure static heat load of cryo-module
  - Increase acc. gradient to nominal; when at nominal gradient,
    - measure Lorentz-force detuning in pulsed mode
    - measure dynamic cavity heat dissipation by adjusting the He gas pressure with the heater power inside the He tank
    - measure critical heat removal threshold in super-fluid helium

Wish-list for accessibility for in-situ intervention

- **Inside cryo-module**
  - Tuner
    - Motor and mechanical parts
  - HOM coupler
    - re-tuning of notch-filter or in situ tuning from outside, if possible
  - RF vacuum transitions
    - all type N (or similar)
- **Outside cryo-module**
  - 3-stub tuner
    - for RF coupler re-adjustment
  - gHe pipes
    - mass flow in power coupler heat exchanger

Thank you for your attention