PIP-II HB650 Prototype Cryomodule

Acceptance Criteria List

Document number: ED00XXXXX, Rev. -

**Document Approval**

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Revision History

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| --- | --- | --- |
| Revision | Date of Release | Description of Change |
| - |  | Initial Release |
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# Purpose

This Acceptance Criteria List (ACL) provides an overview of the critical performance parameters for the High Beta (HB) 650 MHz cryomodule that cannot otherwise be verified in individual or sub-system testing (e.g., as part of the nominal production QA/QC program), but must be verified during testing of the completed cryomodule, before it can be accepted for operation in the PIP-II SRF Linac. These parameters are consistent with and derived from the HB650 cryomodule requirements outlined in the PIP-II Parameters Physics Requirements Document (ED0010216), the PIP-II SRF Cavity Parameters document (ED0010222), the PIP-II HB650 MHz Cryomodule Functional Requirements Specification (ED0001322) and the PIP-II HB650 MHz Cryomodule Technical Requirements Specification (ED0009659).

Verification of performance parameters is to be carried out following the HB 650 Cryomodule Acceptance Testing Plan (Test Plan), ED00XXXXX, in conjunction with the HB 650 Testing Traveler (# XXXXXX). These two latter documents will contain the explicit measurement requirements, testing protocols, and test procedures.

# Acronyms

|  |  |
| --- | --- |
| CM | Cryomodule |
| CW | Constant Wave |
| FPC | Fundamental Power Coupler |
| FRS | Functional Requirements Specification |
| LFD | Lorentz Force Detuning |
| LLRF | Low-Level Radio Frequency |
| PLL | Phase-Locked Loop |
| RF | Radio Frequency |
| SEL | Self-Excited Loop |
| TRS | Technical Requirements Specification |

# Acceptance Criteria

| Requirement ID | Performance Criteria or Quantity | Verification Method | Procedure Summary |
| --- | --- | --- | --- |
| T-9659HB650pCM-1509 | Cavity Beamline Vacuum  a.) Cold (2K) ≤ 1x10-9 mbar  After cryomodule thermal equilibrium reached at 2K (cavity temperatures stable to within 0.2K over last 24hrs), vacuum level reaches specification no later than 48 hrs after all pumps except beamline ion pump are valved out to allow cryopumping. | Measurement by vacuum gauges on pumping system |  |
| T-9659HB650pCM-1506 | Cavity Beamline Vacuum  b.) Warm (RT) ≤ 1x10-6 mbar  After no more than 72 hours of pumping with scroll and/or turbo pumps, with beamline isolated (gate valves closed). | Measurement by vacuum gauges on pumping system |  |
| T-9659HB650pCM-1514 | Insulating Vacuum  a.) Cold (2K) ≤ 5 x 10-6 mbar  After cryomodule thermal equilibrium (defined in above) reached at 2K. Turbo pump may be valved out to allow cryopumping. | Measurement by vacuum gauges on pumping system |  |
| T-9659HB650pCM-1511 | Insulating Vacuum  b.) Warm ≤ 5 x 10-4 mbar  Measured within 72 hrs of beginning pumpdown with scroll and turbo pumps | Measurement by vacuum gauges on pumping system |  |
| T-13631HB650pCMDC-101 | Center Frequency @ 2K = 650.000 MHz ± 10kHz for all cavities | Network Analyzer |  |
| T-13631HB650pCMDC-513 | Couplers capable of being operated off resonance in CW mode at their maximum required power level of 43 kW (representing operation with beam and LFD compensation) in a thermally stable condition. Coupler HV bias applied. | Measurement of coupler temperatures and electron pick up while operating at maximum RF power. |  |
| T-13631HB650pCMDC-1102  T-13631HB650pCMDC-1103 | Power coupler intercept temperatures during steady-state operation, cryogenic equilibrium reached:  5K intercept ≤ 15K  50K intercept ≤ 125K | Measurement of coupler temperatures via attached RTDs. |  |
|  | Individual cavities reach a nominal operating gradient of 18.8 MV/m (nominal operational gradient + 0% margin), as measured with appropriate SS amplifier and LLRF system in SEL (PLL) mode. |  |  |
| T-13631HB650pCMDC-506  (need to include spec in CM TRS, revise DCav TRS) | Field Emission not to exceed a radiation dose rate of 250 mR/hr when an individual cavity is operated at its maximum operating gradient (20.7 MV/m), as measured by FOXes situated 2m from cavity centerline. | Measurement/detection of field emission induced radiation by FOX detectors, situated 2m from CM centerline. |  |
| T-13631HB650pCMDC-508 | Each cavity Q0 ≥ 3.3x1010 at 19 MV/m (corresponding to 20W cavity dynamic heat load) as measured using calorimetric techniques in PIP2IT, after “Fast Cooldown[2]”. Cavity can either be individually measured or as an average value of all cavities operating simultaneously | Calorimetric heat load measurement using 2K He mass flow, calibrated using in-situ heater in liquid level cannister. |  |
| T-13631HB650pCMDC-1507  T-13631HB650pCMDC-1508  T-13631HB650pCMDC-1509 | Slow Tuner range ≥ 60kHz measured at 2K, for b=0.9 cavities  Slow Tuner range ≥ 200kHz measured at 2K, for b=0.92 cavities  Stepper motor resolution < 2 Hz/step  Slow Tuner hysteresis ≤ 100 Hz | Measurement of cavity frequency using network analyzer or LLRF system while exercising slow tuner. |  |
| T-13631HB650pCMDC-1513  T-13631HB650pCMDC-1514 | Fast (piezo) Tuner range ≥ 1200 Hz measured at 2K, for b=0.9 and b=0.92 cavities.  Fast Tuner resolution < 0.5 Hz, measured at 2K, for b=0.9 and b=0.92 cavities. | Measurement of cavity frequency using network analyzer or LLRF system while exercising fast tuner. |  |
| T-9659HB650pCM-202  T-9659HB650pCM-203  T-9659HB650pCM-204 | Cavity alignment, both warm and cold, to within alignment error as follows :  Vertical < 0.5 mm RMS  Transverse < 0.5 mm RMS  Angular ≤ 1 mrad RMS |  |  |
| T-13631HB650pCMDC-1012 | Nominal FPC Qext (measured at 2K at low power (Network Analyzer)) = 9.8 x 106 with range ± 20% | Measurement via network analyzer or decay measurement using LLRF system. |  |
| T-9659HB650pCM-401  T-9659HB650pCM-402  T-9659HB650pCM-403  T-9659HB650pCM-404  T-9659HB650pCM-405  T-9659HB650pCM-406 | Measure heat loads of the CM. Measure static and dynamic (and hence, total) heat loads on the 5K, 50K, and 2K circuits, and compare with values found in PIP-II Cryogenic Heat Load Analysis (ED0008200). A summary of these values (to the nearest W) is listed below for reference, assuming cavity Q0 = 3.3 x 1010 and all 6 cavities are operating at nominal voltage.   |  |  |  | | --- | --- | --- | | 2K Static = 10W | 5K Static = 27W | 50K Static = 144W | | 2K Dynamic = 119W | 5K Dynamic = 0W | 50K Dynamic = 7W | |  |  |
| T-9659HB650pCM-121 | CM total voltage acceptance = 119 MV, when individual cavity gradients are defined as the lower of (as achieved in CM tests):  Maximum operating gradient of 20.7 MV/m  0.5 MV/m below quench gradient  Gradient at which FE reaches 100 mR/hr |  |  |

Notes:

[2] Fast cooldown = 20 K/min in the range of 40K to 4.5K; FRS : F-121.02.04.0-B008. This typically requires a cryogen supply rate of 50 g/sec for LB650 and 80 g/sec for HB650. See Ref (6), ED0013072 “PIP-II 650 MHz Cryomodule Cooldown Rate”

# References

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| **#** | **Reference** | **Document #** |
| 1 | PIP-II Parameters Physics Requirements Document | ED0010216 |
| 2 | PIP-II SRF Cavity Parameters | ED0010222 |
| 3 | PIP-II HB650 MHz Cryomodule Functional Requirements Specification | ED0001322 |
| 4 | PIP-II HB650 MHz Cryomodule Technical Requirements Specification | ED0009659 |
| 5 | PIP-II HB650 Cryomodule Test Plan | ED00XXXXX |
| 6 | PIP-II 650 MHz Cryomodule Cooldown Rate | ED0013072 |
| 7 | PIP-II HB650 pCM Testing at PIP2IT (traveler) |  |