LCLS-II-HE Vertical Acceptance Testing Plans

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Vertical Acceptance Test Criteria

The LCLS-II-HE cavities will undergo qualification in vertical test (VT) at FNAL and JLab. The acceptance criteria are largely similar to those used in LCLS-II. Some changes have been introduced to meet the **higher performance requirements** for LCLS-II-HE and to incorporate **lessons learned** in LCLS-II.

The acceptance threshold for **accelerating gradient** has been increased to 23 MV/m in order to meet the CM target gradient of 20.8 MV/m and mitigate measurement uncertainty and gradient degradation.

Cavities will be required to be free of **field emission** in vertical test up to their peak gradients. This is a stricter requirement than in LCLS-II, which allowed a small amount of radiation. Dark current is of concern at the higher operating gradient of LCLS-II-HE, and experience shows that field emission rarely improved and often got worse after VT.

Qualification Parameter	Acceptance Condition	Relevant Cryomodule Acceptance Criteria
Resonant frequency of accelerating mode (f_0)	f_0 = 1300.25 ± 0.1 MHz	Cavity frequency = 1300.00 ± 0.02 MHz
Peak accelerating gradient (E_{acc})	$E_{acc} \geq 23.0$ MV/m	Cavity nominal gradient ≥ 20.8 MV/m
Intrinsic quality factor (Q_0) measured at T = 2.0 K, E_{acc} = 20.8 MV/m	$Q_0 \geq 2.5\times10^{10}$	Cavity average $Q_0 \geq 2.7\times10^{10}$
Field emission	No detectable field-emission-induced radiation up to peak gradient	Cryomodule captured dark current < 30 nA
Multipacting	Any multipacting must be fully processed before final Q_0 vs. E_{acc} measurements	*none*
High-Q antenna coupling in operating mode ($Q_{ext,1}$)	$1.1\times10^{10} \leq Q_{ext,1} \leq 1.9\times10^{10}$	*none*
Field probe coupling in operating mode ($Q_{ext,2}$)	$7.5\times10^{11} \leq Q_{ext,2} \leq 2.5\times10^{12}$	*same as in VT*
HOM antenna coupling in operating mode ($Q_{ext,HOM}$)	$Q_{ext,HOM} \geq 2.7\times10^{11}$	*same as in VT*
HOM coupler emitted power (P_{HOM}) measured at E_{acc} = 20.8 MV/m	$P_{HOM} \leq 1.7$ W	*same as in VT*

LCLS-II-HE will operate within the **multipacting** band of the 1.3 GHz TESLA cavity design. Determining the true peak gradient limit of the cavities will be critical for the success of LCLS-II-HE. As such the project will require that efforts be made to identify and fully process any multipacting encountered in vertical test.

The requirements for the **intrinsic quality factor** are the same as in LCLS-II, though the gradient spec of the Q requirement has increased to the target operating gradient. The VT acceptance threshold is lower than the cryomodule requirement to compensate for the lossy stainless steel flanges equipped in vertical test.

Vertical test acceptance requirements for **frequency** as well as **external quality factors** of the high-Q antenna, field probe, and HOM antennas remain the same as those in place at the end of LCLS-II.

A second check of antenna coupling a limit on the **HOM emitted power** in the fundamental mode at the target operating gradient. Excessive emitted power leads to heating in the insulation vacuum. Here the power limit has been increased in comparison to LCLS-II in order to account for the higher fields.

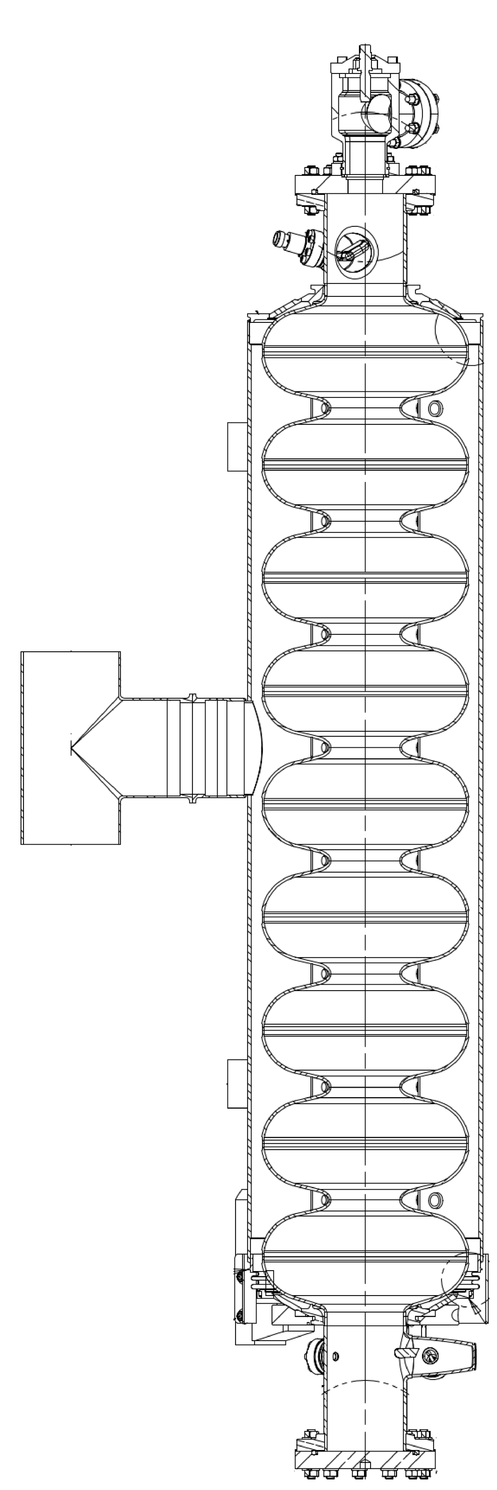
Vertical Acceptance Test Procedure

The LCLS-II-HE cavities will arrive at the partner laboratories from the cavity vendor under vacuum and equipped for vertical test. Equipment will include a fixed high-Q coupler feedthrough, all-metal angle valve, burst disk, and 316LN stainless steel blank flanges.

Prior to test, the cavities will be equipped with **additional instrumentation** at the partner labs, including Cernox thermometers and fluxgate magnetometers.

Cavities in vertical test will be **fast cooled** in a liquid helium bath to ensure full flux expulsion. This is necessary in order to minimize trapped flux losses, which can be severe in nitrogen-doped cavities. The thermal gradient across the length of the cavity must be at least 50 K when the cavity begins to pass through the superconducting transition.

Tests will take place in a **high magnetic hygiene** environment, with ambient fields < 5 mG. Active field compensation may be used to reach this low level.



RF measurement procedures will be much the same as those performed in LCLS-II. Vertical testing will begin with "RF Off" calibration measurement and then proceed with **steady-state Q_0 vs. E_{acc} measurements**.

Measurements will also include readings from forward, reflected, and transmitted power meters (including from HOMs), as well as temperatures, magnetic fields, and radiation monitors.

Special attention will be paid to identify and assess any **field emission or multipacting** encountered during vertical test. Operators will attempt to process any such limitations encountered in order to push the cavities to their ultimate gradient limits. Any such processing will require a final Q_0 vs. E_{acc} curve to confirm that the cavity meets all performance requirements. If Q_0 degrades as a result of processing, a thermal cycle may be required.

Additional care will be taken to detect parasitic excitation of the **7π/9 mode**. If necessary, quasi-pulsed testing will be utilized to avoid excessive 7π/9 effects.

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