

RF QUALITY CONTROL OF SRF CAVITIES FOR LCLS-II CRYO-MODULES*

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Abstract

LCLS-II project is gearing up to build 36 cryo-modules of the 1.3 GHz TESLA style cavities. Half of those cryomodules are being built at Fermilab, while JLAB is carrying the production of the other half. In this paper, we present the process of quality controlling the RF performance of cavities until they are qualified for the final string assembly at Fermilab. The RF quality control process includes monitoring the frequency spectrum of each cavity and tuning/adjusting of the notch frequencies before testing at the Vertical Test Stand (VTS). Measured data during income QC is presented and in addition we show the notch frequencies before and after testing at the VTS. Moreover, we report some of the RF measurements taken while the cavity is cooled down to 2K temperature.

INTRODUCTION

A total of 18 cryomodules are being built at Fermilab for LCLS-II project [1-2]. Each cryomodule encompasses eight Tesla-style superconducting cavities operating at 1.3 GHz [3]. Superconducting cavities are received from two different vendors jacketed in helium vessels. Cavities are shipped under vacuum and ready for vertical testing. Cavities, once received, undergo a detailed incoming quality control (QC) process before testing. The incoming QC includes visual inspection, RF measurements, and leak check.

The RF quality control process is critical during the test cycle of the cavities until they get qualified for string assembly. Cavity vitals; operating passband spectrum, feedthrough capacitances, notch frequencies, external couplings (Q_{ext}) of cavity ports, and the Higher Order Modes (HOMs) are monitored during the QC process.

RF QC PROCESS

Figure 1 illustrates the RF quality control process that we carry until the cavity gets qualified for the final string assembly. Each cavity passes through three stages of RF measurements. First is the income RF QC after the cavity is received from vendor where various measurements are taken as it will be detailed in next section. Next stage is done before the cavity is tested at VTS, where we tune the HOM notch frequencies such that any leakage from the pi-mode is minimized using the notch filters incorporated at the HOM couplers of each cavity. This is a critical operation since it can impede the cold test if the notch frequencies are quite off causing high power to flow to the HOM ports, which in turn will cause heating to the RF cables connected the HOM ports. The maximum output power from the HOM ports shouldn't exceed 10W in any

test scenario to protect the RF cables on the stand from excessive heating. The goal of notch frequency tuning is $Q_{ext} > 2.7e11$ corresponding to $< 1W$ at nominal operating gradient for the fundamental mode. After completion of the cold test, cavities warm up back to room temperature then we carry the third round of RF QC measuring again the operating passband frequency spectrum and notch frequencies of each cavity, ideally before removing it from the stand. This is performed to make sure that the cavity's frequency change is < 50 kHz and to check the change in notch frequencies after the cold cycle. If the cavity is not qualified for string assembly and needed further surface processing (like high pressure rinsing), we repeat the RF QC process before and after VTS testing in each test cycle until the cavity is qualified.



Figure 1: RF quality control process on dressed cavities. (a) Process on dressed cavities until gets qualified for string assembly. (b) Income RF QC measurements.

INCOMING RF QC

Incoming RF quality control measurements comprises five categories of measurements, as shown in Figure 2, namely;

- Frequency Spectrum: we check how far the cavity's frequency changed from the last vendor reported measurement. Cavity will fail this step if the change in frequency is > 50 kHz. A larger change will trigger additional measurement to check the operating mode field flatness inside the cavity. This necessitates opening the vacuum sealed incoming cavity. Figure 3 shows the pi-mode frequencies of cavities (up to CAV0050) in(a), while it indicates in (b) the frequency change when compared to the vendor last measured value.

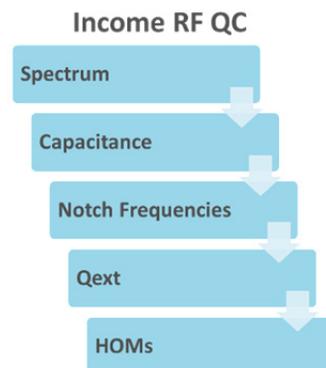


Figure 2: Income RF quality control measurements.

*Operated by Fermi Research Alliance, LLC, under Contract DE-AC02-07CH11359 with the U.S. DOE
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The average of pi-mode frequencies is 1298.280MHz. Except of few cases frequency change was within the 50kHz goal.

- Capacitance: we check the feedthrough capacitance of all cavity's ports. Each port depending on the configuration of the installed antenna has an acceptance range for the capacitance.
- Notch Frequencies: cavities received from vendors don't have the notch frequencies tuned however, they are expected to be within a certain range (1200 -1400 MHz). Figure 4(a) shows the notch frequencies for both downstream (coupler side) HOM₁ and upstream (pickup side) HOM₂ measured during the incoming quality control. Again, except of few cases they were within the acceptance range. We could tune the ones that are off range.
- Qext Measurements: we check in this measurement the external quality factor of the pickup; Q₂ and both HOM ports; Q-HOM₁, Q-HOM₂, assuming a given Q_{ext} for the main coupler port; Q₁. Figure 4(b) shows the produce of Q₁ and Q₂ measured at room temperature during incoming RF QC. The product of Q₁ and Q₂ should be ~7e21. The first few cavities demonstrated lower Q₁ of ~5e9. We had to trim the coupler antenna to increase Q₁ to 1.5e10, which worked well with later cavities as shown in Figure 4(b).
- HOMs: last operation we carry during the income RF QC is measuring HOMs spectrum, where we find all resonant frequencies up to 3.0 GHz and we calculate Q_{ext} of each mode.

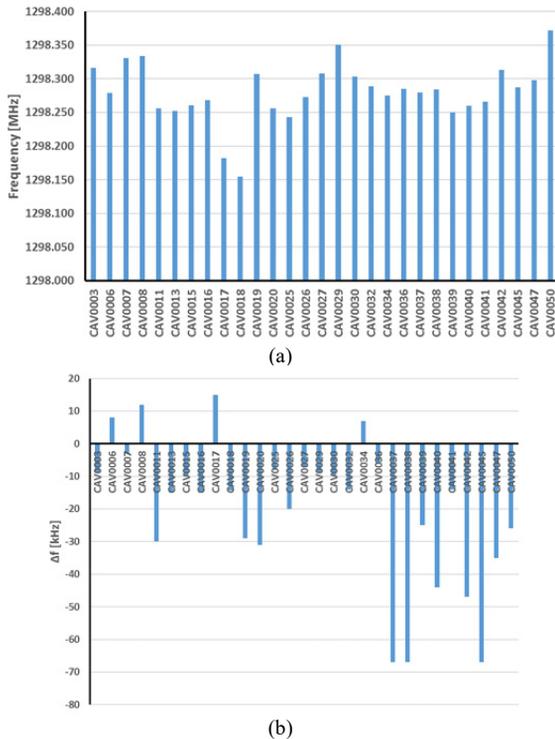


Figure 3: Income RF QC. (a) Pi-mode frequency. (b) Frequency change relative to vendor last measurement.

NOTCH FREQUENCY MEASUREMENTS

We tune the notch frequency of both HOM₁, and HOM₂ couplers on each cavity before each test cycle. Figure 5 presents the measured data for both notch frequencies before and after each test cycle as measured at VTS.

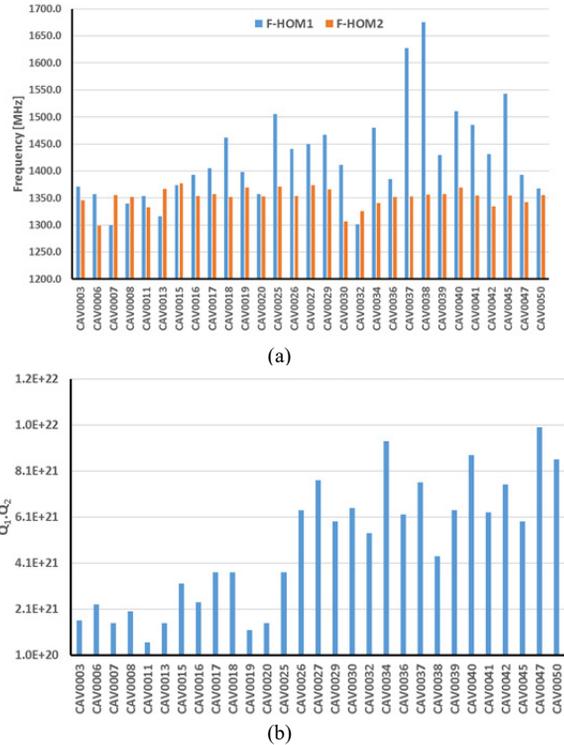


Figure 4: Income RF QC. (a) HOM notch frequencies. (b) Qext measurement (Q₁.Q₂).

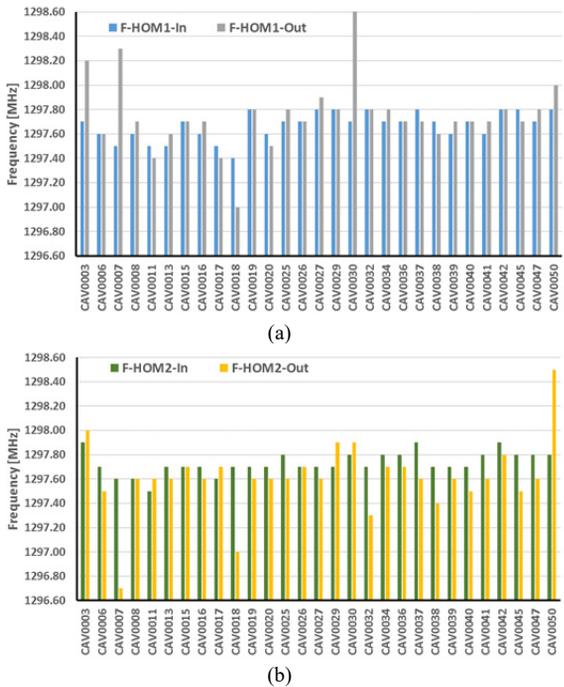


Figure 5: Notch frequencies measured at VTS before and after old test cycles. (a) HOM1 (coupler side). (b) HOM2 (pick-up side).

Typically, the notch frequencies are tuned to 1297.7 ± 0.2 MHz. However, after the cold test cycle they do change by an average of $+0.15$ MHz for HOM_1 and -0.15 MHz for HOM_2 .

COLD MEASUREMENTS

During cold testing, various RF measurements are taken beside the Q vs E main cavity performance curve. Figure 6 shows the measured pi-mode frequency at 2K, approximately $+2$ MHz above the warm measurements, which accounts for the shrinkage of the cavity due to cool-down. Given that LCLS-II cavities will have end lever tuner in the cryomodule, cavities are required to be above 1300 MHz since the tuner has a pushing mechanism. The average cavity frequency at 2K is 1300.207 MHz.

Meanwhile, after tuning the notch frequencies warm, Q_{ext} of both HOMs are measured cold. Q - HOM_1 ranges from 1.9×10^{12} to 7.9×10^{13} , while Q - HOM_2 ranges from 4.5×10^{11} to 5.8×10^{12} as shown in Fig. 6(b), which is mostly within the acceptance range for testing securing $<1W$ output power.

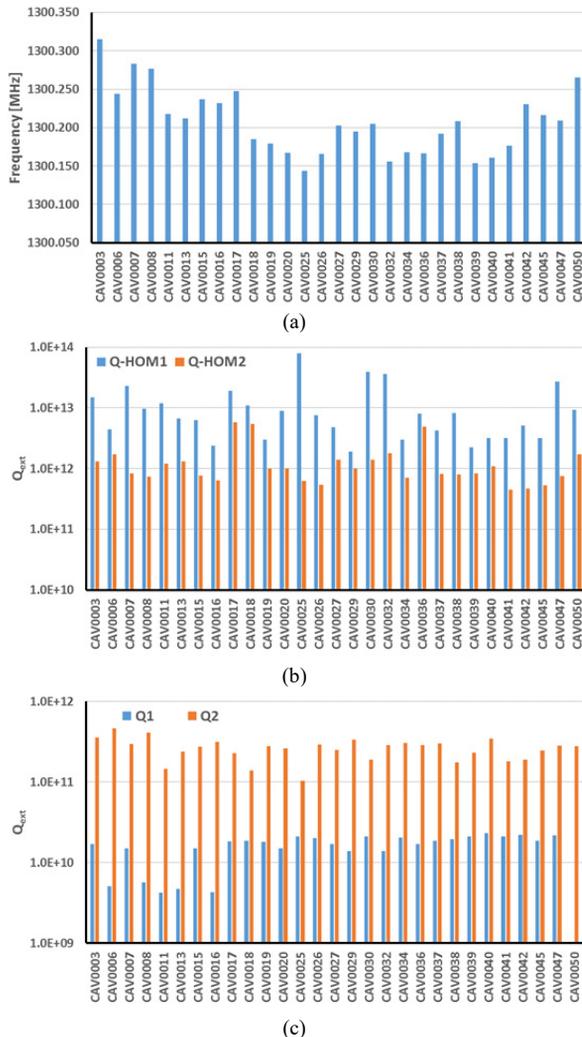


Figure 6: Cold RF measurements. (a) Pi-mode frequency. (b) Q_{ext} of HOMs. (c) Q_{ext} of coupler and pickup; Q_1 and Q_2 , respectively.

Finally, external quality factors of both the main coupler; Q_1 , and the pickup port; Q_2 are measured as shown in Fig. 6(c). Q_2 should be in the range of 2.5×10^{11} to 7×10^{11} , which is satisfied by almost all cavities, while Q_1 should be around 1.5×10^{10} to have the required critical coupling to the cavity.

CONCLUSION

We have developed a detailed RF quality control process during the production of LCLS-II cryomodules. Cavities pass through three phases of RF quality control until gets qualified for the final string assembly. The income RF QC is the first phase where several cavity vitals in terms of frequency spectrum, capacitance, notch frequencies, external quality factor, and HOMs, are measured to determine the cavity acceptance. Then HOM ports notch frequencies are tuned before VTS cold test and checked again afterwards. The goal of the quality control process is to maintain a good performance for all cavities by continuous monitoring of changes in frequency spectrum and notch frequencies.

REFERENCES

- [1] Galayda, J. "The new LCLS-II project: Status and challenges", Linac14, Geneva, Switzerland (2014).
- [2] <http://lcls-ii.fnal.gov/>
- [3] Peterson, Thomas *et al.*, "LCLS-II 1.3 GHz Cryomodule Design-Modified TESLA-Style Cryomodule for CW Operation", 17th International Conference on RF Superconductivity (SRF2015), Whistler, BC, Canada, Sept. 13-18, 2015.