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RF INCOMING INSPECTION OF 1.3GHz CRYOMODULES FOR LCLS-II AT SLAC NATIONAL ACCELERATOR LABORATORY *

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Abstract

The main part of the SRF linac for the Linac Coherent Light Source II (LCLS-II) at SLAC National Accelerator Laboratory will consist of 35 cryomodules with superconducting RF cavities operating at 1.3 GHz. The cryomodules are assembled and tested at Fermi National Accelerator Laboratory and Thomas Jefferson National Accelerator Facility. Following the transport to SLAC, the cryomodules undergo several incoming inspection steps before ultimately being moved to the tunnel for installation in the linac. The RF part of the incoming inspection covers measurements of a number of parameters like cavity frequency spectrum, notch filter frequency of the higher order mode couplers and external quality factor Q_{ext} of the input coupler. The inspection results are compared to measurements at the partner labs prior to shipping and the nominal values in order to verify that the cryomodules have not been damaged during the transport and are ready for installation. We present an overview and analysis of the inspections for the cryomodules received to date.

INTRODUCTION

The cryomodules for the Linac Coherent Light Source II (LCLS-II), currently under construction at SLAC National Accelerator Laboratory, are assembled tested at Fermi National Accelerator Laboratory and Thomas Jefferson National Accelerator Facility. Following the successful acceptance test at the partner labs the cryomodules are shipped to SLAC. Figure 1 shows the unloading of a cryomodule from the truck. Prior to installation in the accelerator tunnel the cryomodule is staged in the sector 10 adit for several incoming inspection steps including metrology and alignment checks, checkout of the instrumentation and the RF incoming inspection.

Since all RF properties and components have been tested several times at the partner labs the main purpose is to check for deviations from the measurements before shipping to see if anything was damaged during transportation and have the opportunity to fix it before the cryomodule is installed in the tunnel.

At the time of this conference RF incoming inspection has been completed for 14 cryomodules.

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Figure 1: Cryomodule during unloading from truck at SLAC.

MEASUREMENTS

Power Coupler Q_{ext}

The external quality factor Q_{ext} of the input power coupler can be adjusted for the LCLS-II 1.3 GHz cryomodules. Figure 2 shows a photograph of the adjustment knob that is used to either extend the power coupler antenna further into the cavity or retract it.

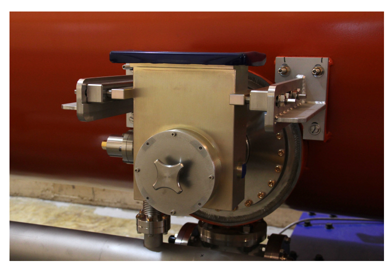

Figure 2: Photograph of waveguide to coaxial transition of the power coupler with adjustment knob for Q_{ext}.

During the cryomodule acceptance test at the partner labs all couplers are set to their design value of 4.1×10^7 at 2 K. Q_{ext} is measured again before shipping of the cryomodule but not necessarily re-adjusted.

As the first measurement of the RF incoming inspection Q_{ext} is determined by measuring S11 on the fundamental power coupler around the center frequency of the π-mode. The resulting resonance curve is then fitted for extraction of the coupler quality factor Q_{ext}. The coupler position is then varied via the adjustment knob until the measured value for Q_{ext} lies within $\pm 0.1 \times 10^7$ around the design value of 4.1×10^7.

Figures 3 and 4 show examples for measurements from cryomodules F1.3-08 and J1.3-13 comparing the values mea-

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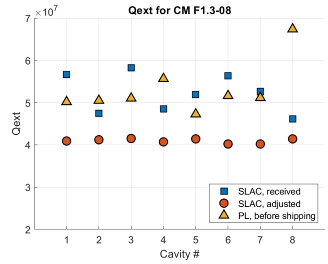

Figure 3: Q_{ext} of the power coupler for CM F1.3-08. Shown are the measurements at Fermilab before shipment, at SLAC as received and after adjustment.

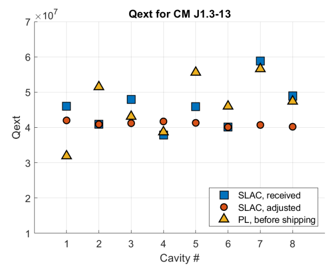

Figure 4: Q_{ext} of the power coupler for CM J1.3-13. Shown are the measurements at JLab before shipment, at SLAC as received and after adjustment.

sured at the partner labs before shipping, at SLAC as received and after adjustment to the design value.

A few cavities have been re-checked after being moved from the sector 10 adit to their final positions in the tunnel on no significant change in Q_{ext} was observed.

HOM Notch Frequency

The higher order mode (HOM) coupler housings are among the parts of a cavity most sensitive to mechanical deformation. Since the deformation could result in a change of the notch filter frequency set to reject the fundamental mode of the cavity leaking out through the HOM couplers during operation, the location of this notch frequency is checked.

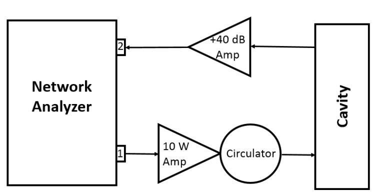

Figure 5: Schematic of RF setup for HOM notch frequency S21 measurements.

A schematic of the RF setup for the HOM notch frequency measurement is shown in Fig. 5. The network analyzer is connected to two ports of the cavity for an S21 measurement. The forward signal is boosted by a 10 W amplifier and the return signal from the cavity is amplified with a low noise +40 dB amplifier. S21 is measured over the nine modes of the fundamental passband in three configurations: between the FPC and HOM coupler on the pickup antenna side of the cavity, between the HOM coupler on the FPC side of the cavity and the pickup antenna, and between the FPC and the pickup antenna for reference. The HOM notch frequency is extracted from the location of the $\frac{6}{9}\pi$-mode through π-mode.

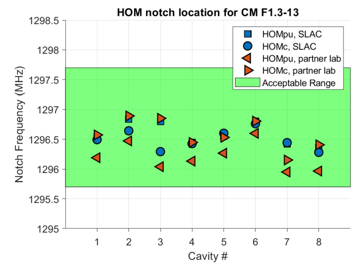

Figure 6: Comparison of the HOM notch frequencies measured at the partner lab and at SLAC for CM F1.3-13. The acceptable range is shown in green.

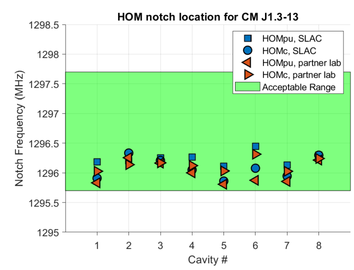

Figure 7: Comparison of the HOM notch frequencies measured at the partner lab and at SLAC for CM J1.3-13. The acceptable range is shown in green.

Figure 6 and Fig. 7 show examples for measurements from cryomodules F.1.3-13 and J1.3-13. As can be seen there is a slight variation in HOM notch frequencies but they all stay well within the allowed range of 1295.7-1297.7 MHz. To date no significant detuning out of the acceptable range has been observed.

Cavity Frequency Spectrum

A significant change in the frequency spectrum of a cavity can indicate that it has been deformed in some way during the transport of the cryomodule from the partner lab to SLAC. In order to quantify the overall change in the spectrum between two measurements, the so-called *R-parameter* is used.

$$R_{cavity} = RMS(R_i)_{i=1...9} \tag{1}$$

$$R_i = \frac{f\left(\frac{i}{9}\pi \ mode\right)_{SLAC}}{f\left(\frac{i}{9}\pi \ mode\right)_{PL}} - \frac{f(\pi \ mode)_{SLAC}}{f(\pi \ mode)_{PL}} \tag{2}$$

As defined in Eq. (1) and (2) the R-parameter R_{cavity} for a given cavity is calculated from the RMS over the R_i of the 9 modes of the fundamental passband. For each mode i the ratio of the frequency f between the measurement at SLAC

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and the measurement at the partner lab is subtracted from the ratio for the $\frac{i}{9}\pi$ mode. Generally a value of R_{cavity} < 10 kHz is deemed acceptable.

Figure 8 shows box-and-whisker plots for the R-parameter of all 14 cryomodules. Almost all cavities satisfied the R_{cavity} < 10 kHz criterion. Cryomodules F1.3-07 and J1.3-13 had one cavity each that was just above 10 kHz (10.6 kHz in both cases). J1.3-14 had two cavities with bigger change in the frequency spectrum, 13.2 and 22.2 kHZ. All cavities were accepted as-is after expert review.

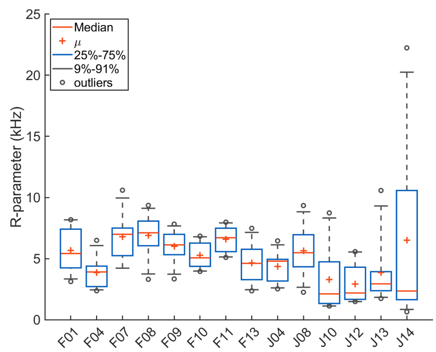

Figure 8: Box plots of R-parameter for all 14 cryomodules.

Tuner and Piezos

The objective for the checkout of the tuner system [1] consisting of the stepper motor and piezo tuners during incoming inspection is to verify that the stepper motor works and shifts the resonance frequency of the cavity by a certain amount and that the piezo tuners are engaged and acting on the cavity.

Initially a unit of the LCLS-II resonance control chassis that will be used in the linac during operation to control stepper motor and piezos was used for this inspection step. The drawback of using this system that is designed to be operated longterm in a fixed location in the tunnel is the rather complex infrastructure needed. Communication is established through the EPICS control system and therefore a dedicated CPU and physical access to the cabled network is needed.

Instead, the setup being used at Fermilab for tuner and piezo testing [2] was adopted with motor controller hardware, breakout boxes and cables being provided by Fermilab. Figure 9 shows the setup for the piezo checks. A waveform generator is used to drive piezo 1 with a 5 Vpp sine wave with a +2.5 V offset. Piezos 2-4 are used as sensors. The signals of piezos 1 through 4 are monitored on an oscilloscope, as shown in Fig. 10.

Since piezo 1 and 2 are encapsulated together at the top part of the tuner their signals are in phase. Piezos 3 and 4 are encapsulated together on the bottom of the tuner and pick up the cavities reaction to the drive signal from piezo 1, hence a 180 degree phase shift.

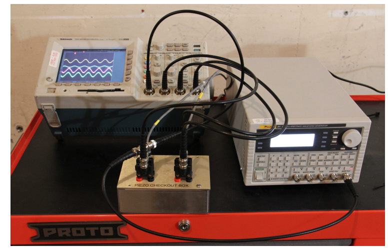

Figure 9: Setup for piezo checkout, including breakout box, oscilloscope and waveform generator.

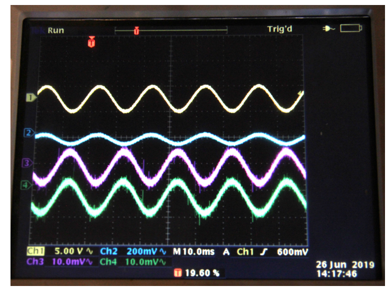

Figure 10: Oscilloscope traces for piezo checkout. Piezos 1 through 4 from top to bottom.

If the tuner is in the right position and the piezo capsules are both engaged, the signal on 3 and 4 there will be a clear sine wave as seen in Fig. 10.

Beam Position Monitor

Each LCLS-II 1.3 GHz cryomodule is equipped with a beam position monitor consisting of four button-type electrodes. S11, S12, S21 and S22 are measured with the two ports of the network analyzer connected to all possible pairwise combinations of the 4 electrodes over the range of 200 MHz to 2.8 GHz.

SUMMARY

The RF incoming inspection has been completed for 14 of the 35 LCLS-II 1.3 GHz cryomodules. Power coupler Q_{ext}, HOM notch frequencies and cavity frequency spectrum are checked and compared to the measurements before shipment. The function of tuner system is verified. No damages due to transportation have been found so far.

ACKNOWLEDGMENTS

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REFERENCES

[1] Y. M. Pischalnikov *et al.*, “Design and Test of the Compact Tuner for Narrow Bandwidth SRF Cavities”, in *Proc. 6th Int. Particle Accelerator Conf. (IPAC’15)*, Richmond,

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VA, USA, May 2015, pp. 3352–3354. doi:10.18429/JACoW-IPAC2015-WEPTY035

[2] J. P. Holzbauer, Y. M. Pischalnikov, W. Schappert, J. C. Yun, and C. Contreras-Martinez, “Production Tuner Testing for LCLS-II Cryomodule Production”, in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 2678–2680. doi:10.18429/JACoW-IPAC2018-WEPML004