5th North American Particle Accel. Conf. NAPAC2022, Albuquerque, NM, USA JACoW Publishing
ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-MOPA12

COMMISSIONING OF HOM DETECTORS IN THE FIRST CRYOMODULE OF THE LCLS-II LINAC

J. Diaz Cruz[1]*, J.P. Sikora, N. R. Neveu, B. Jacobson, SLAC, Menlo Park, CA, USA
[1]also at University of New Mexico, Albuquerque, NM, USA

Abstract

Long-range wakefields (LRWs) may cause emittance dilution effects. LWRs are especially unwanted at facilities with low emittance beams like the LCLS-II at SLAC. Dipolar higher-order modes (HOMs) are a set of LRWs that are excited by off-axis beams. Two 4-channel HOM detectors were built to measure the beam-induced HOM signals for TESLA-type superconducting RF (SRF) cavities; they were tested at the Fermilab Accelerator Science and Technology (FAST) facility and are now installed at SLAC. The HOM detectors were designed to investigate LRW effects on the beam and to help with beam alignment. This paper presents preliminary results of HOM measurements at the first cryomodule (CM01) of the LCLS-II linac and describes the relevant hardware and setup of the experiment.

INTRODUCTION

Off-axis beam transport may results in emittance dilution due to transverse long-range (LRW) and sort-range wakefields (SRW) in TESLA-type cavities, as previously showed at the Fermilab Accelerator Science and Technology (FAST) facility [1, 2]. A similar study was performed with an entire cold cryomodule (CM) with 8 SRF cavities and the correlation between beam offset and sub-macropulse centroid slews and centroid oscillations was shown in BPMs downstream the CM [3]. HOMs, which excite LRWs, are proportional to the transverse beam offset and bunch charge; therefore, reducing HOMs may help to mitigate emittance dilution effects, which is critical at the first cryomodule (CM01) of the LCLS-II linac.

Dipolar HOMs are of special interest since they drive beam instabilities which can cause transverse beam dynamic problems. As shown in [4], the dipole modes with the highest R/Q are modes 6 and 7 from the first passband; modes 13 and 14 from the second passband and mode 30 from the third passband. For this project, special interest is taken in the first and second dipole passbands. Each TESLA-type cavity has an Upstream (US) and a Downstream (DS) HOM coupler to damp those modes to avoid beam instabilities, and can also be used to measure HOM signals. A set of HOM measurement chassis were built at SLAC to instrument the US couplers of CM01 with the goal of support injector commissioning activities and to act as beam position diagnostics. Furthermore, the chassis can enable studies in LRW effects on the beam.

* dejorge@slac.stanford.edu

EXPERIMENTAL SETUP

Two 4-channel chassis were built to measure the magnitude of the HOMs at the US and DS couplers of each SRF cavity. Each channel has a 1.3 GHz notch filter to reduce the fundamental resonant frequency; a band-pass filter centered at 1.75 GHz with 300 MHz bandwidth to emphasize the main TE111 HOM dipole modes, in particular modes 7 (f_7 = 1.739 GHz) and 14 (f_14 = 1.873 GHz), since these modes have the highest R/Q in their passband; a 31 dB digital step attenuator with 2 dB per step; two cascaded 23 dB amplifiers with enable/disable control and a Schottky diode for HOM detection. An schematic of a single channel is shown in Figure 1. More details about the design and testing of the chassis at [5].

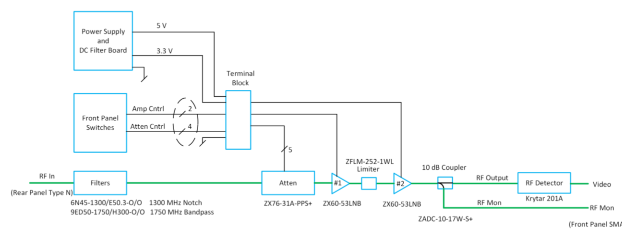

Figure 1: Schematic of a single channel in the 4-channel HOM measurement filter chassis.

All US and DS coupler cables are terminated in loads. The US couplers of CM01 have a -10 dB coupler with the through port followed by a 10 dB attenuator and a termination. This setup is done due to concerns related to the power level of the 1.3 GHz fundamental resonant mode being reflected back to the probe and heating the cable. The -10 dB port of the coupler is connected to the chassis. The two chassis are connected to the US couplers of the cavities inside CM01. The outputs of the chassis are connected to two oscilloscopes, which measure the minimum voltage for each channel, since the output of the Schottky diode is a negative voltage. The scope waveforms are available via EPICS and the minimum voltages can be monitored using PVs. The complete setup is shown in Figure 2. The team is in the process of building another set of chassis to also instrument the DS couplers.

The LCLS-II injector has 5 corrector magnets and 2 BPMs between the RF gun and CM01. There is also a cold BPM inside CM01 in the downstream end, and multiple BPMs downstream CM01, along with other diagnostics and systems, that complete the injector setup.

PRELIMINARY HOM MEASUREMENTS

As part of the injector commissioning activities, the two HOM measurement chassis were tested and are now being

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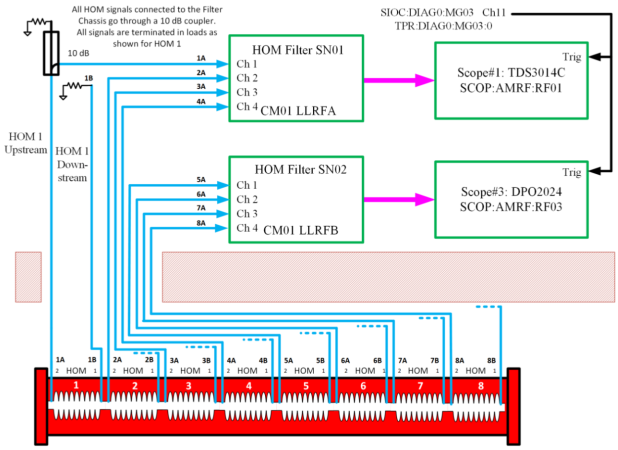

Figure 2: HOM measurement filter chassis connections to HOM couplers and oscilloscopes. All US HOMs are connected for measurements while DS HOMs are connected to loads.

used to help with transverse beam alignment. One of the first experiments was to center the beam manually using the corrector magnets upstream CM01, while verifying correct functionality of multiple diagnostic systems along the injector beamline (upstream and downstream CM01). The HOM signals were used to help with beam alignment. A single bunch electron beam with a bunch charge of 50 pC and an entrance energy of 800 KeV to CM01 was used during these measurements.

Figure 3 shows a representative set of HOM signals. Figure 3b shows the US HOM signals for cavities 1 to 4 before starting the alignment of the beam while Figure 3a shows the same signals after manual alignment of the beam. Notice the reduction in the magnitudes of the peaks for all cavities, meaning the beam was getting closer to the electrical axis of the cavity.

A second experiment using a beam of 24 bunches with a 2 microsecond spacing between bunches demonstrated the capabilities of the chassis to acquire signals under this type of beam configuration, especially important for the continuous wave mode of the LCLS-II Linac. Figure 4 shows the US HOM signals for cavities 1 to 4 for the multi-bunch beam. Notice that signals do not have the same magnitude, being cavity 1 the smallest signal in orange, followed by cavity 2 in blue and cavity 4 in green. The largest signal is for cavity 3, in purple. The different magnitudes of the HOM signals can be a sign of cavity misalignment and that the beam is lost in the cryomodule.

CONCLUSIONS AND FUTURE WORK

Two 4-channel chassis for US HOM measurements have been successfully installed and commissioned at the LCLS-II injector. Single and multi bunch measurements have been demonstrated. HOMs have been used for the ongoing commissioning activities of the LCLS-II injector. Minimizing HOMs using corrector magnets helps with getting the beam on-axis. We are planning to build at least two additional chassis to instrument the DS HOM couplers of CM01. We are also developing a digitizer board and programming a

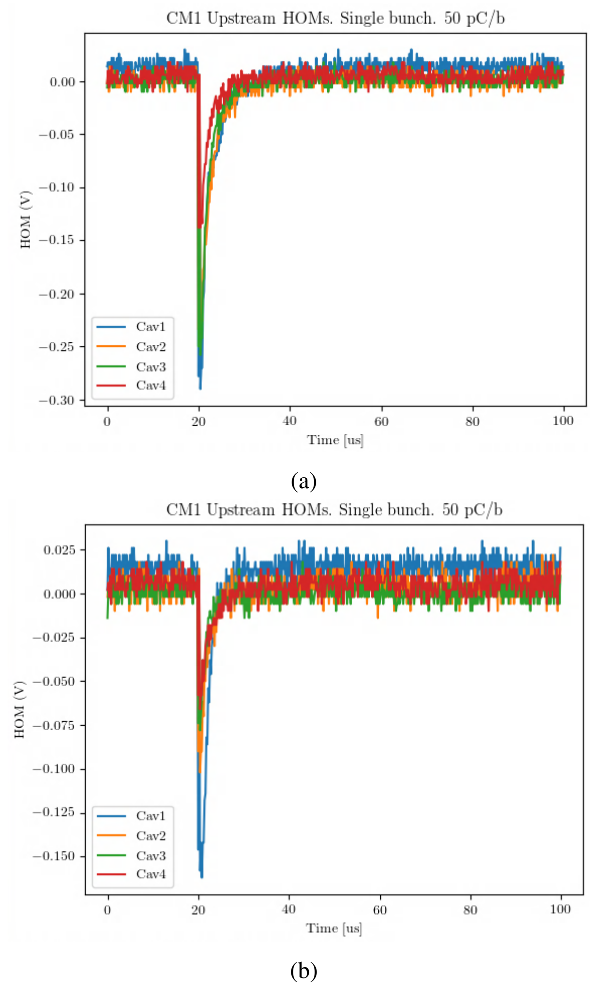

Figure 3: Cavity 1 to 4 US HOMs for a single bunch, 50 pC per bunch beam, (a) before and (b) after manual alignment.

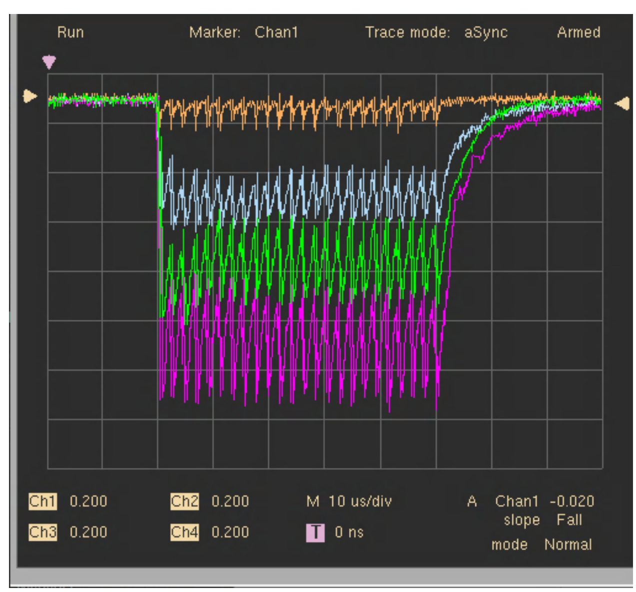

Figure 4: Cavity 1 to 4 US HOMs for a 24-bunch beam.

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Digilent Arty A7 to have remote control of attenuators and amplifiers of the chassis, and to have a control system for HOM signal reduction. Experiments to investigate LRW effects on the beam are also under development.

A PyDM [6] display is under development along with the chassis to instrument the DS couplers. This display will give a raw reading on the voltage returned by the US and DS couplers in the first two rows for each cavity. Below those values, the absolute value of the signals will be calculated and returned for a relative comparison of signal strength across the cavities. In this way, a viewer of the pane can quickly determine which HOM is has the strongest relative signal, and therefore which cavity the beam is misaligned at. The PyDM display in shown in Figure 5.

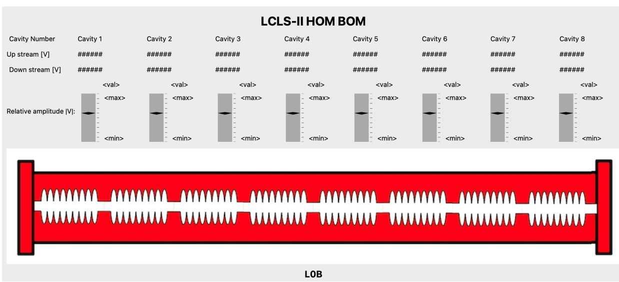

Figure 5: Cavity 1 to 4 US HOMs for a 24-bunch beam.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the injector team and the SRF team at SLAC for their help with the commissioning of the chassis, and the FAST team at Fermilab for the help and guidance with chassis testing and HOM experiments.

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[6] PyDM — Python Display Manager, http://slaclab.github.io/pydm/