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DESIGN OF THE BUNCH-LENGTH MONITORS FOR THE NEW SUPERCONDUCTING LCLS LINAC

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Abstract

The LCLS x-ray free-electron laser at SLAC uses the third km of the original 3-km copper linac. We are now installing LCLS-II, a superconducting linac that replaces the first km. Two undulators, for hard and soft x rays, will be driven by bunches from either linac. One of the solutions developed at SLAC involves a pyroelectric detector, which converts the infrared emitted by the electron bunch into voltage by measuring fast changes in the temperature of the detecting crystal. Not only are the pyrodetectors used at SLAC but also a method with gap diodes. The radial electric field produced by the bunches leaks through a ceramic gap in the beampipe and is collected by a horn antenna and conveyed through a one millimeter waveguide. The waveguides act as a filter, only passing shorter wavelengths and a zero-bias Schottky diode measures the power. In both methods, a portion of the spectral energy emitted by the bunch is intercepted. After normalizing to differentiate between bunches of the same length with different charge, the detected signal is sensitive to only changes in bunch length. This poster discusses the mechanics and optics behind the LCLS-II bunch length monitors' operations and plans for collaboration.

BACKGROUND

This paper describes the physics requirements and implications for instrumenting the single-shot relative bunch length monitors (BLM) based on coherent edge radiation (CER) at the end of the LCLS-II bunch compressor chicanes. It also describes the physics requirements and implications for instrumenting single-shot, diode-based relative bunch-length monitors (BLEN) based on radiation picked up from a ceramic break in the vacuum pipe and coupled to a GHz detection diode [1, 2].

PYROELECTRIC DETECTOR

The superconducting linac will have two stages of bunch length compression with off-crest RF phasing to energy-chirp the bunch. Afterwards, compression is then achieved in 4-dipole bunch compressor chicanes named: BC1 and BC2. The critical final peak current of 1 kA is generated after these stages, with a nominal 100 pC charge per bunch. The final peak current, which is directly related to the final bunch length, must be stable to < 10% rms from pulse to pulse. The goal is to also have the peak current stable over much longer time periods (e.g., one week), until manual intervention is eventually required [1].

The compression system, and in turn, the final peak current, will be very sensitive to time-dependent variations in things such as: RF phasing, accelerator gradient, bunch charge, and laser timing from the gun. Maintaining the peak current over longer time scales will require a longitudinal feedback system based on continual single-shot electron beam measurements. Such a system has already been described for the LCLS and requires at least one single-shot relative bunch length monitor located immediately after each chicane. A measurement of the absolute bunch length is not necessary for feedback purposes. It is sufficient to produce a relative signal which is approximately proportional (inversely proportional) to the peak current (electron bunch length) over a reasonable dynamic range [1].

Bunch length monitors in the injector and immediately prior to the undulators will also be of great importance, but are not necessary of the critical longitudinal feedback system. The pyroelectric detector diagnostic method as a BLM is the only the single-shot monitors needed for the critical longitudinal feedback system integrated in the BC chicanes. This is crucial to the integrity of LCLS-II operations [1].

A mirror with a long, vertical slot for the electron beam will be insertable into the beamline to reflect the upstream CER from the fourth bend magnet (B4) out of the vacuum chamber. The CER will then be sent up into the optics box containing the diagnostic. See Fig. 1 [3].

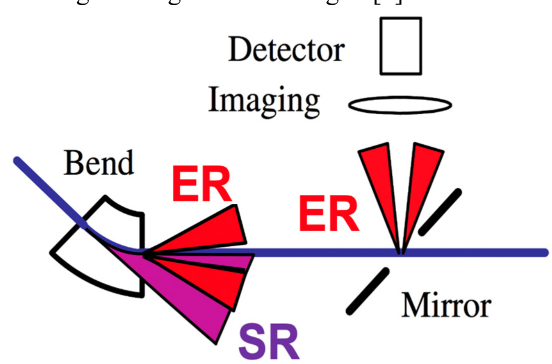

Figure 1: Diagram of the capture of edge radiation.

Once in the optics box, the CER will be guided by a couple of off-axis parabolic mirrors. Then it will pass 4 insertable filters followed by a beam splitter. It is meant to image the CER onto two identical pyroelectric detector elements. There are two pyroelectric detectors for redundancy in the event of a single element failure. Detectors will include preamplifiers with remotely selectable gain [1]. See Figs. 2 and 3.

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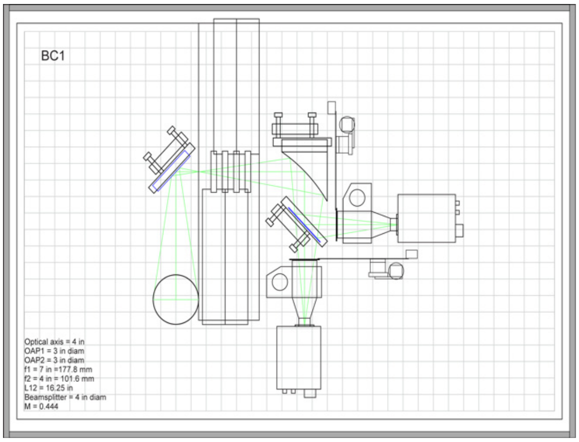

Figure 2: Diagram of the optical breadboard.

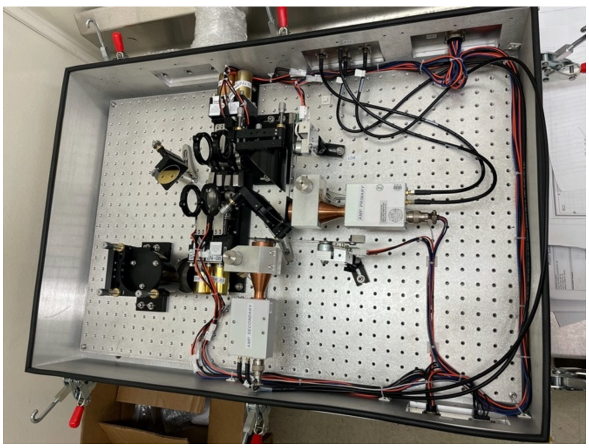

Figure 3: Picture of the completed optics box.

GAP DIODE

Like stated earlier, bunch compression for the LCLS-II beam has two stages of compression that uses off-crest RF phasing to energy-chirp the bunch followed by compression in the 4- dipole bunch-compressor chicanes BC1 and BC2. These stages achieve the critical final peak current of 1 kA with a nominal 100 pC charge per bunch. The stability of the final peak current, which yields the final bunch length, is integral to the operation of the LCLS-II. What's more, those beam parameters must be stable for time periods around one week until things like invasive machine tuning is eventually required. The beam's sensitivity to time-dependent variations makes the need for feedback crucial [2].

Another method being used at the LCLS-II that tackles the same issues as the pyroelectric detectors diagnostic. It is another single-shot monitor needed for longitudinal feedback at two locations where the bunch length is expected to be ≥ 0.1 mm RMS or longer: after the injector capture cavity and, in some cases, immediately after BC1 [2].

As the electron travels in the +z direction along the beamline, it radial emits an electric field in the r direction for all theta. The beam then traverses a ceramic break in the vacuum pipe. The ceramic gap is covered in circular apertures in a metal shield. Two sets of diametrically opposed, pyramidal, high-frequency (GHz-THz) RF horns are placed outside the ceramic gap in the vacuum pipe. These horns pick up signal from the electron bunches by shrinking to the size of the waveguide. The waveguides elongate and attenuate pulses, filters out wavelengths of RF that are unsatisfactory, and are finally measured by high-frequency, Schottky-diode detectors. The diode measures the power and the power can be interpreted as a bunch length. Lastly, like the pyroelectric detector method, the power readings must be normalized so as to differentiate between bunches of the same length but different charge. See Fig. 4.

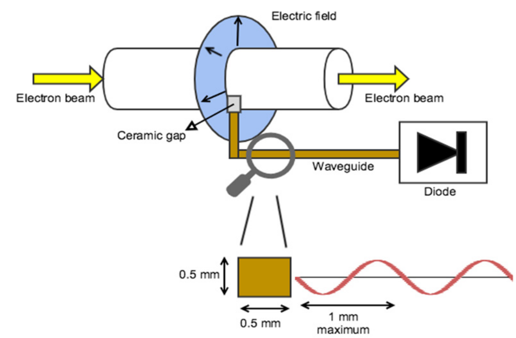

Figure 4: Diagram of gap diode BLM mechanism.

Summing the two opposing horns reduces sensitivity to an off-axis beam. With proper selection of the frequency of the diodes and waveguides, this sum is inversely proportional to the electron bunch duration [2]. See Fig. 5.

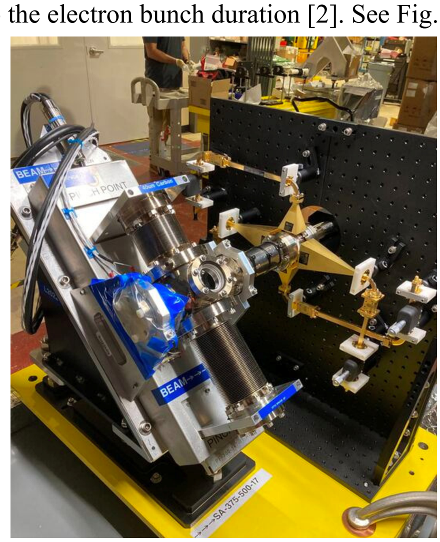

Figure 5: Picture of Gap Diode BLM Mechanism on optical breadboard.

CONCLUSION

Both pyroelectric detector method and the ceramic gap-diode method for the superconducting LCLS-II solve the problem of needing a single-shot monitor with longitudinal feedback. Both have already been constructed and await use when the LCLS-II is commissioned.

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