Longitudinal Feedback for the LCLS-II Superconducting Linear Accelerator at SLAC

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INTRODUCTION

SLAC has commissioned a new superconducting continuous-wave MHz repetition-rate free electron laser utilizing separate dedicated soft and hard x-ray undulator lines. The total design energy is 4 GeV. The electron beam energy is measured along the linear accelerator in four dispersive regions, using beam position monitors and their accompanying dispersion as shown in Fig. 1:

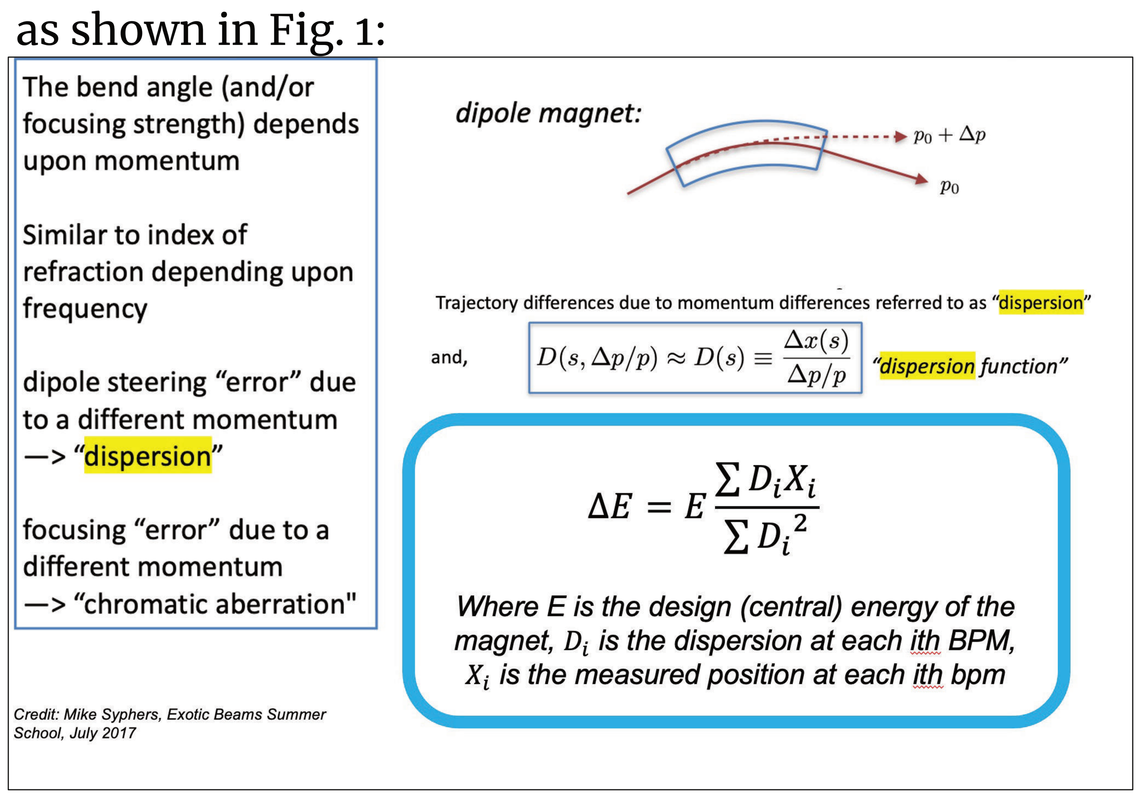

Figure 1: Energy Measurement using Beam Position Monitors

The bunch length is also measured in the two bunch compressor chicanes BC1B and BC2B. Together with the energy at four locations, this makes a total of six parameters to be controlled using feedback (Fig. 2):

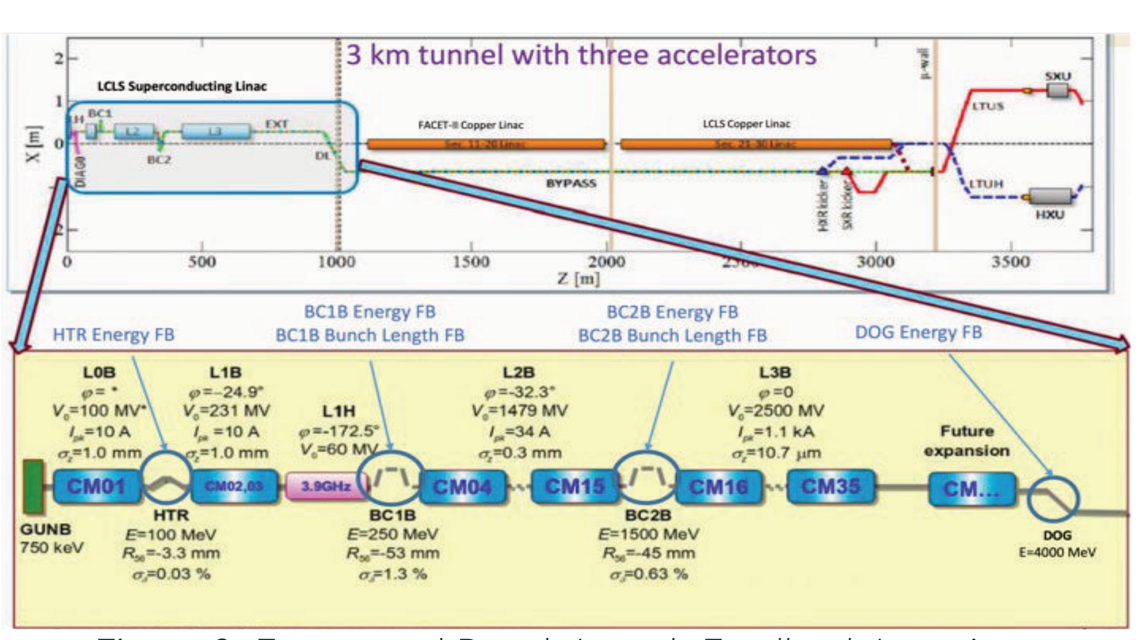

Figure 2: Energy and Bunch Length Feedback Locations

The superconducting continuous-wave RF cavities are relatively slow to change phase and also prefer to have a fixed amplitude due to Lorentz Force Detuning. For these reasons, it was decided to make a simple and relatively slow feedback to control the energy and bunch length in various regions using only cavity phases. But first, there needed to be a way to collectively control the phases of 296 individual cavities!

RF ABSTRACTION LAYER

The RF Abstraction Layer (RFAL) controls all superconducting RF cavities in an orchestrated manner. It calculates and distributes individual cavity phases, at up to ~20 Hz, to achieve a user-specified beam energy and energy spread (aka chirp). The RFAL is a dedicated EPICS soft IOC that uses pyDevSup to integrate Python control code with EPICS. There are also accompanying Python Display Manager (PyDM) user interfaces. The energy and chirp can be set for multiple regions of the accelerator, and *gang phase* offsets can be applied to each region to compensate for global phase or time of flight changes (Fig. 3):

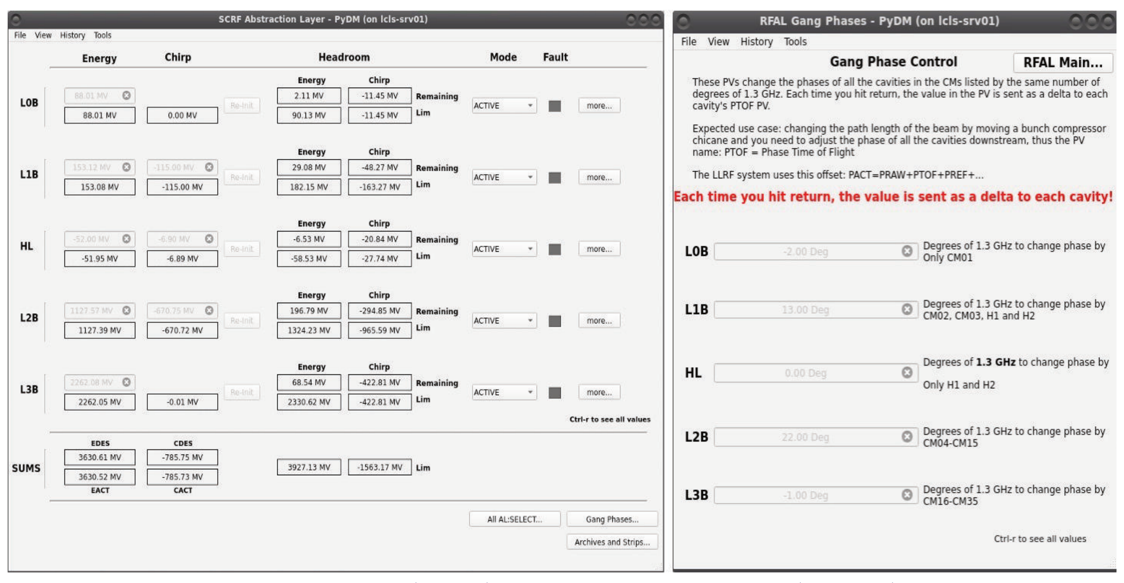

Figure 3: RFAL Main (Left) and Gang Phase (Right) Displays

The user can also specify in real-time which RF cavities are used for which purpose:

- NOTA: Abstraction Layer does not control
- Chirp Only: Used to impart energy spread
- FB Negative: Used to adjust energy, maintain chirp
- FB Positive: Used to adjust energy, maintain chirp

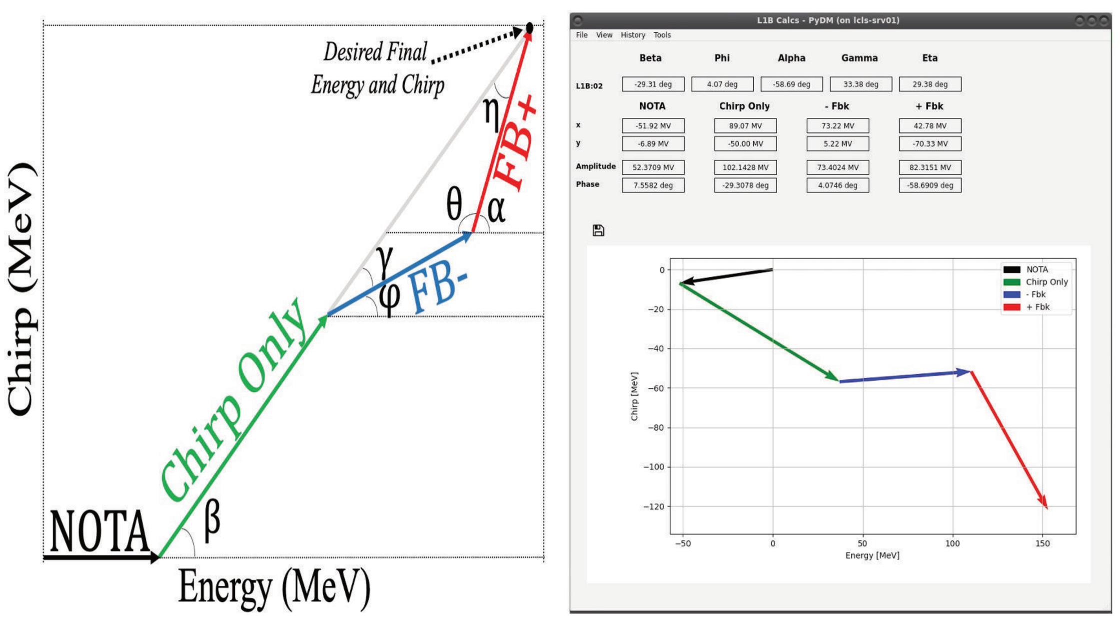

Figure 4: Cavity Modes Illustration (Left) and Real-Time Display (Right) for a region

The abstraction layer lets a human easily set up the desired energy and chirp and provides the perfect actuator interface for a longitudinal feedback!

LONGITUDINAL FEEDBACK

The longitudinal feedback is fully Python-based and self-contained with minimal, widely-available dependencies. It runs as a standalone process on a central server, independent of any user interface, and utilizes EPICS Process Variables (PVs) that wholly control the feedback. The feedback code in its entirety is just over 700 lines and is easily maintained or ported to other machines/applications with minimal configuration file changes.

There is an accompanying PyDM user interface (with expert panel) that allows the end user to easily control the feedback. Options are provided for on the fly adjustment:

- PID Gains and overall gains
- Feedback actuation rate
- Energy verniers (can shift target energy)
- Maximum step sizes
- Ability to save and restore setup

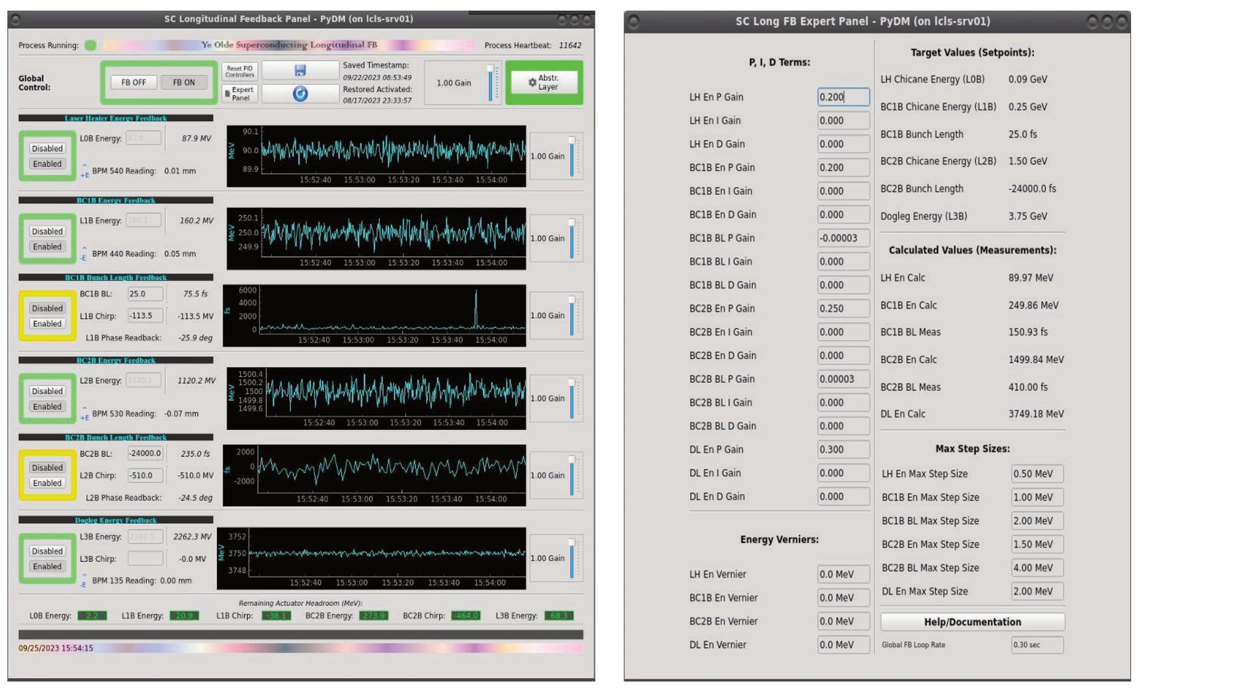

Figure 5: PyDM Main (Left) and Expert (Right) Displays

CONCLUSION

LCLS-II achieved first light using the superconducting linear accelerator in both the Soft and Hard X-ray Undulator lines in August and September of 2023. The Abstraction Layer and Longitudinal Feedback have been running smoothly for several months in advance of that important milestone and have proven to work reliably while not introducing additional jitter or variability. The bunch length monitors are still being commissioned, but the bunch length feedbacks are expected to work well as they utilize the same root code and have been tested on the original LCLS Copper Linac.

ACKNOWLEDGEMENTS

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pyDevSup: http://mdavidsaver.github.io/pyDevSup/