LCLS

Stanford Linear Accelerator Center

Stanford Synchrotron Radiation Laboratory

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Controls Requirements for LCLS Feedback Systems

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Brief Summary: This specification describes the number of feedback loops and their locations throughout the accelerator that need to be incorporated into the LCLS control system. The functionality of the loops is summarized and a table of readback and actuator devices for each loop is listed. Performance requirements are given in terms of diagnostic device resolution and beam stability. Requirements are also imposed on the control system layout to ensure 120 Hz response time and interaction between the loops.

Keywords: Feedback, linac, injector, diagnostics, orbit, energy, bunch-length.

Key WBS#'s: 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.9

The software feedback control loops for providing fast, single-pulse stabilization of accelerator parameters at rates up to 120 Hz are listed together with their locations. The broad categories of the feedback loops and their locations are:

1. beam energy
    a. injector inflector DL1
    b. injector energy spectrometer dump
    c. BC1
    d. BC2
    e. LTU dogleg DL2
    f. BSY FB31 50B1 stopper
2. orbit x,y position and angle
    a. L1 launch
    b. L2
    c. L3
    d. LTU
    e. Undulator launch
3. bunch length
    a. BC1
    b. BC2
4. beam phase of the diagnostic transverse deflecting cavity
    a. injector
    b. L3
5. Injector bunch charge
6. injector laser steering

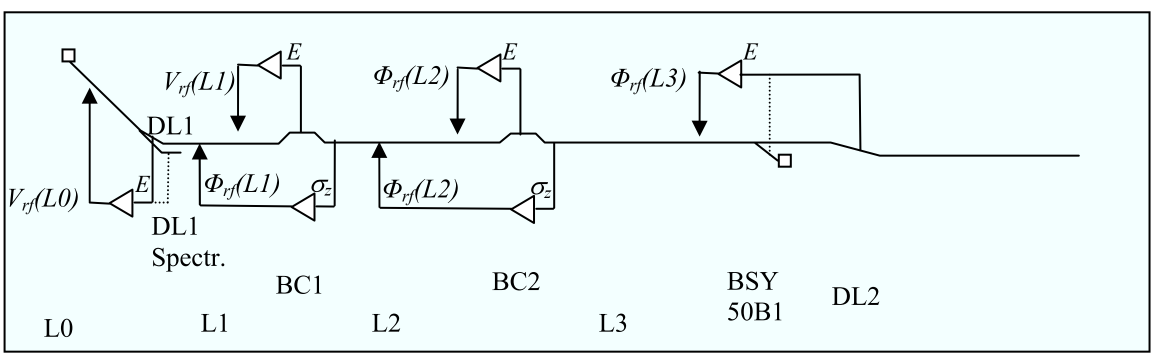

Figure 1: Schematic layout of energy and bunch length feedbacks

Description of the Feedback Loop Function

1. Beam energy

Energy is calculated from a BPM reading at a location with large (horizontal) dispersion. Adjacent, upstream BPMs in non-dispersive locations are also read in order to subtract out any incoming (betatron) oscillation in the beam orbit that is not energy dependant.
The actuator to control the energy will be either the AMPLitude of a single, unsaturated klystron tube, or the PHASe of a pair of saturated klystrons. In the latter case the phase of the two klystrons will be moved equally in opposite directions symmetrically on either side of the RF crest to maintain a zero net phase change on the beam while causing a net change in the energy of the beam.
The feedback loop is calibrated empirically by making a number of prescribed step changes in the actuator setting and measuring the change in energy seen by the BPM. The software package uses the online optics model to transform the measured beam motion into physical units of energy change for the user display.
The software will allow the number of beam pulses to be specified to be integrated for each measurement (nominal=1). The feedback gain of the loop can also be user-specified (nominal=1).
The feedback package will buffer the last ~1000 beam pulses and display them so that the user can observe the performance of the loop. The display will calculate the rms jitter in the buffered sample and this number will be logged in a history file at specified intervals.

2. Orbit x, y position and angle

Orbit feedback is used at numerous locations along the linac and transport lines, where ever it is necessary to keep the amplitude of the orbit displacements small, or where the launch into the downstream section is critical. The orbit feedback also provides a convenient method of putting in a closed orbit bump for tuning purposes. In particular, localized orbit bumps are used in the linac to correct wakefield-induced emittance growth.
The beam position at several beam line locations is read on a single pulse to which an orbit is fitted to yield a position and angle of the beam at a reference location. Two upstream steering correctors are specified in each plane and are chosen with suitable betatron phase advance so as to give orthogonal correction of position and angle at the reference location.
The R-matrix values between correctors and BPMs, from the online optics model, are used to derive the orbit position and angle in physical units. However, the loop is always calibrated with an experimentally measured transfer matrix. The steering correctors used by the loop are scanned in strength and the relative change in orbit at each of the BPMs is measured to reconstruct the loop transfer matrix.

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3. Bunch length

The bunch length feedback relies on a relative measurement of bunch length from a detector that responds to the rms bunch length distribution of the beam. The bunch length monitors will be placed after each of the bunch compressors, BC1 and BC2, and will be used to control the RF phase of the bunch as it enters each of the bunch compressor chicanes.
In order to converge on a specific setpoint for the bunch length feedback several signals (at least two) will be sent back from the detector to indicate the amount of signal power in the low frequency band and in the high frequency band of the bunch length spectrum. The feedback algorithm will look at the ratio of these signals and will determine whether the bunch is over or under compressed by the RF phase. The actuator for the feedback loop is a phase shifter at the input of an upstream klystron which will change the phase of the bunch.
The exact specification of this feedback loop requires further R&D work to be carried out. A simpler form of this loop has been implemented at the SPPS where so far the THz power has been detected in only one frequency band, which means that dynamic dithering of the phase has been necessary to determine the sign of the correction. As further studies are done, more detailed specifications can be expected.
Phase and amplitude changes in the RF alter both the bunch length and the beam energy. Whether the energy and bunch length loop can operate independently or through coupled matrices will be investigated by simulation studies.

4. Beam phase of the diagnostic transverse deflecting cavity

The RF transverse deflecting cavities are used to streak the beam in the accelerator so that a transverse profile monitor image can be used to measure the bunch length. The phase of the beam with respect to the RF field in the deflecting cavity needs to be kept precisely at the zero phase crossing otherwise large deflections of the beam will result. A fast feedback similar to the orbit feedbacks above is used to monitor the the orbit downstream of the deflecting cavities and calculate the effective angular kick to the beam originating at the cavity. Instead of using a steering magnet to correct the orbit this loop uses the RF phase shifter for the deflecting cavity to apply the correction.

As with the orbit feedbacks the loop is empirically calibrated by measuring the response of the BPMs to a change in the actuator phase shifter. Nominal settings are specified for averaging and loop gain. This loop is presently implemented at the transverse cavity test implementation at klystron 29-4 in the linac.

5. Injector bunch charge

A beam current toroid measures the charge from each pulse in the injector beam line. The laser intensity at the cathode is adjusted to maintain a constant bunch charge. Nominal settings are specified for averaging and loop gain.

6. Injector laser steering

The bunch charge loop above is sensitive to the position where the laser light hits the photocathode. Optimum operation of the injector is only possible if the position of the laser light is controlled independently of the intensity reaching the cathode. Laser light position monitors and laser steering devices will be specified in more detail later.

Component Specifications for Each Loop

Loop Name	Sensor[1]	Actuator
Inj. Launch Loop – engy (dog-leg DL1)	Dispersive BPMS Inj 13 Betatron BPMS Inj 6, 7, 8, 9, 10, 11, 12	L0 Klystron 20-8 amplitude
Inj. Launch Loop - xpos	BPMS Inj 6, 7, 8, 9, 10, 11, 12	XCOR Inj SC8, SC10
Inj. Launch Loop - xang	BPMS Inj 6, 7, 8, 9, 10, 11, 12	XCOR Inj SC8, SC10
Inj. Launch Loop - ypos	BPMS Inj 6, 7, 8, 9, 10, 11, 12	YCOR Inj SC8, SC10
Inj. Launch Loop - yang	BPMS Inj 6, 7, 8, 9, 10, 11, 12	YCOR Inj SC8, SC10
BC1 engy	Dispersive[2] Li21 BPMS11 Betatron BPMS Li21 201 BPMS Inj 14, 15	L1 Klystron 21-1 amplitude

BC1 blng	BL11	Klystron L1 21-1 phase
BC2 engy	Dispersive BPMS Li24 S21 Betatron BPMS Li23 701, 801, 901 BPMS Li24 201, 301, 401, 501, 601, 701	L2 Klystrons 24-5 &24-6 phase pair
BC2 blng	BL21	Klystron L2 av. phase
LTU engy (dog-leg DL2)	Dispersive[3] BPMS DL1, DL3	FB31 PHAS 271, 281
Inj. Spect – engy (Inj. spectrometer dump, only used during invasive tuning)	Dispersive BPMS4 Betatron BPMS Inj 6, 7, 8, 9, 10, 11, 12, and BPMS1	L0 Klystron 20-8 amplitude
BSY engy (only used when beam is stopped in BSY with 50B1 bend magnet on)	BPMS FB31 57, 302, 702	FB31 PHAS 271, 281
L2 xpos	BPMS Li22 201, 301, 401, 501, 601, 701, 801, 901	XCOR Li21 702, 900
L2 xang	BPMS Li22 201, 301, 401, 501, 601, 701, 801, 901	XCOR Li21 702, 900
L2 ypos	BPMS Li22 201, 301, 401, 501, 601, 701, 801, 901	YCOR Li21 702, 900
L2 yang	BPMS Li22 201, 301, 401, 501, 601, 701, 801, 901	YCOR Li21 702, 900
L3 xpos	BPMS Li26 201, 301, 401, 501, 601, 701, 801, 901	XCOR Li25 702, 900
L3 xang	BPMS Li26 201, 301, 401, 501, 601, 701, 801, 901	XCOR Li25 702, 900
L3 ypos	BPMS Li26 201, 301, 401, 501, 601, 701, 801, 901	YCOR Li25 702, 900
L3 yang	BPMS Li26 201, 301, 401, 501, 601, 701, 801, 901	YCOR Li25 702, 900
LTU xpos	BPMEM1, BPMEM2, BPMEM3, BPMEM4, BPME31, BPME32, BPME33, BPME34, BPME35, BPME36	XCDL3, XCDL4
LTU xang	BPMEM1, BPMEM2, BPMEM3, BPMEM4, BPME31, BPME32, BPME33, BPME34,	XCDL3, XCDL4

	BPME35, BPME36	
LTU ypos	BPMEM1, BPMEM2, BPMEM3, BPMEM4, BPME31, BPME32, BPME33, BPME34, BPME35, BPME36	YCDL3, YCDL4
LTU yang	BPMEM1, BPMEM2, BPMEM3, BPMEM4, BPME31, BPME32, BPME33, BPME34, BPME35, BPME36	YCDL3, YCDL4
UND xpos	BPMUM1, BPMUM2, BPMUM3, BPMUM4	XCUM1, XCUM4
UND xang	BPMUM1, BPMUM2, BPMUM3, BPMUM4	XCUM1, XCUM4
UND ypos	BPMUM1, BPMUM2, BPMUM3, BPMUM4	YCUM2, YCUM3
UND yang	BPMUM1, BPMUM2, BPMUM3, BPMUM4	YCUM2, YCUM3
Inj TCAV	BPMS Inj 8, 9, 10, 11, 12	TCAV1 Klys. phase
L3 TCAV	BPMS Li25 601, 701, 801, 901	TCAV2 Klys. phase
Inj chrg	Inj TORO	Laser power

Notes:

1. device names are taken from both the current optics listing and the SLC control system and will be enhanced with LCLS control system names later.
2. in locations where only one BPM is available in a dispersive section then several upstream BPMS are used to fit the incoming betatron component
3. in locations where two dispersive BPMS are located +I apart the signal can be differenced to cancel the incoming betatron term.

Stability and Resolution Requirements

1. Beam energy
    a. DL1 – The 263 mm dispersion at BPMS 13 produces a relative energy resolution at 135 MeV of $\delta < 2\times10^{-5}$ with a 5-μm resolution BPM
    b. BC1 – The 238 mm dispersion should produce a relative energy resolution of $\delta \approx 8\times10^{-5}$ with a 20-μm resolution BPM
    c. BC2 – The 363 mm dispersion should produce a relative energy resolution of $\delta \approx 5.5\times10^{-5}$ with a 20-μm resolution BPM.
    d. LTU – The 125 mm dispersion produces a relative energy resolution of $\delta \approx 4\times10^{-5}$ with two 5-μm resolution BPMs.

2. Beam orbit
   A noise equivalent of 10 microns rms or better is sufficient to keep the beam steady at 1/10th of the beam size at the high energy end of the linac. The specification is looser at lower energies.

Cascade Requirements

A downstream feedback loop should be decoupled from upstream feedback loops in such a way that the two loops do not simultaneously try to correct the same error. This requires a high speed control link between the feedback processors and an adaptive algorithm to calculate the propagation of the error along the beam line from one loop location to the next. It is not yet clear whether single cascade is adequate or if multi cascade is necessary. In single cascade mode a feedback loop only receives information from a loop immediately upstream from it and passes this information only to the next feedback loop immediately downstream of it. This works if the transfer matrix between the loops is perfectly linear, but can breakdown if collective effects from transverse wakefields introduce nonlinear transport terms. A multi-cascade mode is then needed where each loop broadcasts the information to all loops downstream. This behavior should be modeled in a particle tracking code such as *LIAR* which can model the nonlinear response to an upstream trajectory perturbation, taking into account collective effects from wakefields in the linac.

Control System Requirements

The control system needs to accommodate feedback devices that can be remotely located from each other and operating in different crates with different processors.

The overall goal of the feedback system is to provide controlled correction at the full rate of 120 Hz for the machine. This implies that the devices such as BPMS and other signals read through gated ADC’s need single-pulse readback with beam pulse identification to allow all signals to be coherently buffered. Similarly, the feedback actuator devices like magnet correctors and RF phase shifters and attenuators need to be commanded to respond on a single pulse basis at 120 Hz.

Furthermore, the feedback actuator needs to respond on the very next machine pulse following the measurement. This requirement is referred to as system *latency*, and should be carefully scrutinized in all links in the feedback chain. It is possible, for example, to have a feedback operating at 120 Hz but the command signals to the corrector are pipelined so that there is no response to the corrector until *n* pulses later.

The LCLS control system requirement for fast feedback systems is therefore 120 Hz response and zero latency.