LCLS

Stanford Linear Accelerator Center

Stanford Synchrotron Radiation Laboratory

LCLS Physics Requirements Document # 1.1 - 309	Project Management	Revision 0

LCLS Electron Beam Diagnostics Requirements

Patrick Krejcik (Author)	Signature: P Krejcik	Date: 6/2/04
Bob Dalesio (System Manager)	Signature: B. Dalesio	Date: 1/13/05
Patrick Krejcik (System Physicist)	Signature: P Krejcik	Date: 6/2/04
John Galayda (Project Director)	Signature: John Galayda	Date: [illegible]

Brief Summary: This overview document lists the electron beam diagnostics to be used in the LCLS together with their function in tuning, operating and trouble shooting the machine. The parameters for individual diagnostic devices are given in separate requirements documents. This document does list the parameters to be defined as requirements, but the justification for each is given in separate documents.

Keywords: diagnostics, controls, instrumentation, tuning.

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

This overview document lists the electron beam diagnostics to be used in the LCLS together with their function in tuning, operating and trouble shooting the machine. The parameters for individual diagnostic devices are given in separate requirements documents. This document does list the parameters to be defined as requirements, but the justification for each is given in separate documents.

Beam intensity

Toroids are placed at select locations along the beam line to non-invasively record the beam intensity on a pulse by pulse basis. Toroids contain an external calibration circuit and will be calibrated against an absolute measuring device.

A Faraday cup can be inserted in the beam line in the injector for an invasive, but absolute measurement of the beam intensity.

Device parameters are: location, resolution, dynamic range.

Trajectory determination

Beam Position Monitors (BPMs) are placed along the beam line from the injector to the final beam dump to determine the x and y position and intensity of the beam on a pulse by pulse basis. In the linac some 80 existing stripline BPMs will be used. New beamlines, including the injector, LTU, undulator and dumpline will be fitted with new BPMs. These will also be of the stripline type except in the undulator where extremely high position resolution is required and more complex BPM devices are to be considered, like the RF cavity BPM.

The BPM Module processes the analog signal and a trigger input allows a gated ADC to sample the signal and interface to the control system. Additional circuits allow calibration of the ADC for different intensity ranges.

Device parameters are: location, type, resolution, precision, dynamic range, maximum offset, maximum drift.

Energy determination

An energy spectrometer comprising of BPMs in a beam line location with large orbit dispersion allows changes in beam position to be calibrated in units of relative energy change. The resolution of the relative energy measurement is dependant on the BPM resolution and the magnitude of the dispersion. Beamline bends serving as energy

spectrometers are located in the injector, the two bunch compressors, the dogleg bend in the LTU and the main beam dump.
The precision of the absolute determination of the energy is limited by the calibration and geometry of the bend magnets for a particular current setting. The most precise measurement of the final electron beam energy will come from the wavelength measurement of the undulator radiation.

Device parameters are: location, beam energy, beamline dispersion, BPM resolution, precision, dynamic range.

Beam size measurement

Wire scanners are used at locations along the injector, linac and LTU beamlines to measure the average, projected beam size in x and y (and optionally u, at 45°). A wire whose diameter is chosen based on the nominal expected beam size is moved through the beam at a steady speed to record a profile from either secondary electron emission current from the wire or beam loss detected downstream by a radiation monitor. The scans are almost noninvasive except for the emittance increase in the beam for the few pulses when it intercepts the wire, during which time the *sase* operation in the undulator will degrade.

Profile monitor screens inserted in the beam path are used to image the beam cross-section by the light generated from the electrons intercepting the screen. OTR screens are to be used in the linac and LTU and YAG crystal fluorescent screens in the low energy injector. The OTR screens will interfere with the *sase* operation in the undulator but will not prevent beam from being transported to the main dump. The screens compliment the wire scanners since they can return single shot full profiles of the beam. They are therefore part of the slice emittance and energy spread diagnostic system.

Device parameters are: location, beam energy, beamline dispersion, nominal image size, image resolution, dynamic range.

Bunch length measurement

Several techniques with varying levels of invasiveness and effectiveness will be used, as summarized in table 1 below.

RF Transverse Deflecting Cavities are to be installed in the injector and in the linac after the second bunch compressor to streak the beam on an off-axis profile monitor screen. Three machine pulses are taken away from normal accelerator operation for an absolute determination of the bunch length profile.

Coherent radiation detectors are used at the exit of the bunch compressor chicanes to make fast, single-pulse measurements of relative changes in bunch length based on the spectral power of the CSR from the final dipole of the bunch compressors. The wavelength of the coherent radiation is related to the electron bunch length, and is in the THz range for nominal linac bunch lengths. Microbunching instabilities will also be visible with this technique since they will generate signature coherent radiation at much shorter wavelengths. CTR can also be used for this purpose but the intercepting screen is more invasive to machine operation than the off-axis screen for CSR detection. The relative bunch length determination can be calibrated against the measurements from the RF transverse deflecting cavities and also from autocorrelation measurements with the CSR and CTR.

Energy wake loss scans where the energy of the beam at the end of the linac is measured while the bunch length is scanned over several consecutive beam pulses gives an additional redundant method of determining relative bunch length for tuning purposes.

Electro optic sampling is a pump-probe technique where the coulomb field of the electron bunch is used to change the birefringence of a crystal close to beam and modulate the transmission of a probe laser. Sufficient resolution is obtained when an ultra-fast, high-bandwidth laser is used as the probe. Part of the gun laser light can be used for this purpose in the injector beamline, and in the LTU beamline laser light from pump-probe experiments can be diverted to this diagnostic system.

Device Type	Invasive measurement	Single shot measurement	Abs. or rel. measurement	Timing measurement	Detect micro-bunching
RF Transverse Deflecting Cavity	Yes: Steal 3 pulses	No: 3 pulses	Absolute	No	No
Coherent Radiation Spectral power	No for CSR Yes for CTR	Yes	Relative	No	Yes
Coherent Radiation Autocorrelation	No for CSR Yes for CTR	No	Absolute (2nd moment only)	No	No
Electro Optic Sampling	No	Yes	Absolute	Yes	No
Energy Wake-loss	Yes	No	Relative	No	No

Device parameters are: location, beam energy, nominal bunch length, resolution, dynamic range.

Emittance measurement

Multiple wire scanners use the projected beam size measured at 3 or 4 consecutive locations along a quadrupole transport line to reconstruct the phase space area of the beam. The emittance and betatron parameters provide tuning information for the beam. A high degree of automation is required in these measurements so that scans can be done rapidly during tuning of the machine. Automating the scans to be done on a regular basis is required to monitor the performance of the machine.

Quadrupole scans are used where only one wire scanner or profile monitor is available at a given location on the beamline. Beam size is measured for several quadrupole settings to reconstruct the phase space area of the beam. This technique is used during setup of the machine only, since changing the quadrupole strength is invasive to machine operation.

Energy spread measurement

These are done at the dispersive beamline locations in the injector spectrometer, DL1, DL2, BC1, BC2 and the main dump. The slice energy spread in the beam is intrinsically very small so that only in the spectrometers in the injection line and in the main dump, where the betatron size of the beam has been intentionally reduced, is it possible to resolve the incoherent energy spread along the bunch.

Wire scanner profiles are the least invasive and give the average energy spread over several beam pulses during the scan.

Profile monitor beam size measurements of energy spread can be single shot, but are invasive (except at the main dump).

Bunch slice measurement

These can differ from the projected measurements across the whole bunch and are therefore necessary to distinguish in diagnosing *sase* operation of the undulator.

Slice emittance can be measured from transverse beam profiles when a correlation is introduced between the z-position along the bunch and the x or y transverse axes. The RF transverse deflecting cavities used for bunch length measurement introduce a z-y correlation so that the x-width can be measured along the z-coordinate of the bunch in the streaked image. Measuring the x-width in combination with a *quadrupole scan* gives the horizontal slice emittance.

In the BC1 bunch compressor there is a strong, linear correlation between the z-position along the bunch and the x axis. Measuring the vertical beam size along the horizontal extent of the beam image on a profile monitor in combination with a *quadrupole scan* gives the vertical slice emittance.

Slice energy spread can be measured at high dispersion locations with profile monitors where the beam is streaked by a transverse RF deflecting cavity. The slice energy spread in the beam is intrinsically very small so that only in the spectrometers in the injection line and in the main dump, where the betatron size of the beam has been intentionally reduced, is it possible to resolve the incoherent energy spread along the bunch. Only the injection line spectrometer is equipped with a transverse deflecting cavity.

Beam phase measurement

Resonant S-band RF cavities are used to measure changes in beam phase relative to the low level RF reference system. The cavities are subject to drift and so the measurement is useful only for determining phase jitter over a few consecutive beam pulses.

Device parameters are: location, type, resolution, dynamic range, maximum drift.

Bunch timing measurement

Precision timing of the bunch arrival can be reference to a laser system used for pump-probe experiments. The electro optic sampling technique for single-shot bunch length measurement also yields arrival time of the electron bunch relative to the laser.