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LCLS Beam Position Measurement System Requirements

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Brief Summary: The electron beam position monitoring (BPM) system is to provide high-resolution measurement of the electron trajectory and charge on a pulse-by-pulse basis under a variety of operating conditions and provide this information to a number of users. The users can range from an operator looking at a graphical display of the orbit along the accelerator to various software application packages that use the BPM data to analyze and tune the accelerator.

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System description

The electron beam position monitoring (BPM) system is to provide high-resolution measurement of the electron trajectory and charge on a pulse-by-pulse basis under a variety of operating conditions and provide this information to a number of users. The users can range from an operator looking at a graphical display of the orbit along the accelerator to various software application packages that use the BPM data to analyze and tune the accelerator.

Table 1: General operating requirements

Resolution for single pulse measurement, over 10% of the aperture: Injector-linac-LTU, stripline LTU-undulator, cavity style	 5 1	microns
Dynamic range: Nominal LCLS operating range	 0.2 – 1	 nC
Maximum drift: Stripline BPMs Cavity BPMs	 5 1	Microns/hour
Maximum systematic position offset, including mechanical and electrical offsets: Stripline BPMs Cavity BPMs	 200 100	Microns
Minimum bit size: Stripline BPMs Cavity BPMs	 1 0.2	Microns at 0.2 nC
Noise floor: Stripline BPMs Cavity BPMs	 5 1	Microns rms
Repetition rate: For single pulse readback with pulse i.d.	 120	 Hz
Non-LCLS operation		
Resolution: Linac only	 20	 microns
Dynamic range: single pulse maximum charge long pulse train maximum total charge maximum number of bunches per train e+/e- functionality	 8 150 1500 t.b.d.	 nC nC - -
Repetition rate:	120	Hz

The BPM system requirements can be divided according to the components of the system:

- The BPM pick-up on the beam line
- Cabling to the BPM processor
- BPM processor module
- Timing inputs to the BPM processor module
- Data transfer from the processor to other applications

The BPM pick-up on the beam line

Existing BPM pick-ups will be used in the linac. These are of the stripline type and are captive with in the quadrupole vacuum chambers. New construction for the injector beamline will include 15 new BPMs which will also be of the stripline type in order to be closely compatible with the BPM processors used in the linac. The aperture of the new BPMs will also be dictated by the nominal beam stay-clear of the linac. Protection collimators are 0.67" and the linac striplines have a 0.84" i.d.

The transport line at the end of the linac will use existing stripline BPMs in the BSY and will reuse existing FFTB style stripline BPMs in the LTU.

The higher resolution requirements of the undulator call for RF cavity BPMs. These are new constructions and will be designed based upon the resolution requirements and the stay-clear aperture of 6mm in the undulator beamline. There will also be 8 of these identical cavity BPMs installed in the end of the LTU beamline in order to satisfy the requirement for beam measurement redundancy before enabling the beam transport in the undulator. The redundancy requirement is part of the Machine Protection System (MPS) strategy for the undulator.

The locations of the BPMs are given in Table 2 which is derived from the optics listing of the accelerator and beam lines.

Cabling to the BPM processor

In the case of the stripline BPMs the signal is transported from the accelerator housing to the processor module located in an instrumentation rack that is normally accessible during operation. Attenuation and bandwidth of the cable limit the length of the cable to typically 150' maximum for semi-rigid coaxial cable. This in turn requires that in the linac, for example, that there be 3 instrumentation crates per linac sector to house the BPM processor modules.

The processing of the signals from the undulator cavity-style BPMs is sufficiently different that the cable requirements cannot be specified before further design work is done.

BPM processor module

The processor module design satisfies the following constraints.

- Gain sensitivity to satisfy the position resolution at the minimum charge of 0.2 nC on the linac-style stripline BPM
- Sufficient dynamic range in the ADC to accommodate beam excursions up to 1/3rd of the beam stay clear aperture without saturating over the range of charge from 0.2 to 1 nC. This implies a minimum of 14 bit ADC resolution.
- Bit resolution is specified as some reasonable fraction of the resolution of the BPM, so 1 micron bit resolution is called for stripline BPMs and 0.2 microns bit resolution for cavity BPMs.
- Noise floor of the processor is specified such that the rms noise in apparent beam position of a static test signal should not exceed half of the resolution specification.
- Self-calibrating feature to allow the gain to be set for a given bunch charge in operation in order to maximize the dynamic range of the ADC. In order to minimize interruption to the beam the calibration should be done between beam pulses.

The calibration process needs to be accomplished with out beam and should minimize any systematic offsets in the BPM position reading.
The calibration procedure should automatically detect and flag a bad calibration so that client applications ignore the data from a badly calibrated BPM. This is especially important for feedback applications.
This initial offset requirement is particularly important in the undulator cavity-style BPMs where the BPM performance is relied upon for the beam based alignment of the undulator system. Furthermore, the absolute position of the beam is critical for the machine protection of the undulator. The BPM offset of the undulator system must be accounted for, at the 100 μm level (rms), before the first electron beam pulse is sent through the undulator.

- *Drift*: Drift in the apparent position of the beam for the **stripline** BPMs, has been specified as 5 microns (the resolution) per hour, while the **cavity** BPMs are specified as 1 micron (the resolution) per hour. This is based on the idea that the user could be reasonably expected to recalibrate the BPMs once per hour, and that beam-based alignment in the undulator, using the cavity BPMs, requires about 1 hour to complete.
- *Averaging*: Normally the position and charge of the beam should be read out on a single machine pulse. Some applications require that the position and charge be averaged over a number of consecutive machine pulses. The user should be able to specify an integer from 1 up to at least 100, over which the data will be averaged. Since the averaging is user specific it should be done in the IOC.
- *Linearity*: Linearity is determined by the geometry of the stripline electrodes in the vacuum chamber and is therefore already fixed into the existing design. The front-end analogue signal processing may, according to the type of design chosen, introduce further nonlinearities. The IOC should provide optional correction to the linearity, individually to each user.

Timing inputs to the BPM processor module

The BPM signal is gated so there must be trigger signals sent to each processor. The trigger is derived from the accelerator-wide RF fiducial system whose requirements are described in a separate document. Each timing event will have a unique pulse ID and the trigger will have an adjustable delay time in steps of 8.4 ns (the inverse of the period of the SLAC 119 MHz system). The duration of the beam signal from the stripline BPMs is very short (in the nanosecond range). The BPM timing system will allow the trigger time of each BPM to be scanned in steps of 8.4 ns and return the intensity signal (TMIT) from the BPM, as a function of time, in order to locate the presence of the beam signal in time. The width of the gate will be set internally in the processor. The width of the gate should be at least as large as the timing step size of 8.4 ns in order to overlap the beam pulse. The maximum size of the gate should not be significantly larger than the minimum timing step in order to exclude noise from parasitic beam in adjacent RF buckets. Placing this upper limit on the width of the gate will also allow future upgrades to be considered for multi-bunch operation in the LCLS.

Data transfer from the processor to other applications

The timing system will supply a trigger with a unique pulse ID to the BPM module as part of the user requirement to be able to read out all BPMs (from the gun to the final dump) on the same pulse.

BPM data must be read out from the module, either on selected pulses as determined by the beam code pattern associated with the trigger from the distributed timing system, or all consecutive beam pulses must be read out up to the maximum 120 Hz beam rate. In both cases the pulse ID needs to be preserved in order to identify any event in the machine with a particular beam pulse.

The BPM data should be accessible to more than one user application simultaneously. A beam orbit should be viewable to an operator at the same time as a feedback application is reading trajectory information and further users may be collecting BPM data in correlation with other machine parameters.

This has important consequences for choosing the appropriate calibration for a given measurement, since all users share the same calibration under this scheme. The SLC control system allowed private calibrations but at the cost of not sharing BPM data between clients.

The BPM data also needs to be stored in a circular buffer to allow the retrieval of consecutive pulses and also to allow access to earlier pulses when some non-synchronous event occurs. Initiating the readout of the circular buffer should be both on demand from a user or triggered by a fault condition so that the data is written to a file for fault analysis.

The ring buffer provides a tool for quantifying beam jitter, analyzing the transient behavior of feedback systems and providing fault analysis capability after a machine trip (abort).

The ring buffer should provide a running estimate of average and rms values that can be sent to an archiver for longer term monitoring of the performance.

Table 2: BPMs from the optics listing

BPM name in optics listing (MAD deck)	BPM Type	Maximum rms resolution for LCLS operations
BPMG1	Injector, new stripline	20
BPMG2	Injector, new stripline	20
BPMS1	Injector, new stripline	20
BPMS2	Injector, new stripline	20
BPMS3	Injector, new stripline	20
BPMS4	Injector, new stripline	20
BPM1	Injector, new stripline	20
BPM2	Injector, new stripline	20
BPM3	Injector, new stripline	20
BPM4	Injector, new stripline	20
BPM5	Injector, new stripline	20
BPM6	Injector, new stripline	20
BPM7	Injector, new stripline	20
BPM8	Injector, new stripline	10
BPM9	Injector, new stripline	10
BPM10	Injector, new stripline	10
BPM11	Injector, new stripline	10
BPM12	Injector, new stripline	10
BPM13	Injector, new stripline	10
BPM14	Injector, new stripline	10
BPM15	Injector, new stripline	10
BPMA11	Injector, new stripline	20
BPMA12	Injector, new stripline	20
BPM21201	linac stripline	20
BPMS11	Injector, new stripline	20
BPMM12	Injector, new stripline	20
BPM21301	linac stripline	20
BPMM14	BC1, new stripline	20
BPM21401	linac stripline	20
BPM21501	linac stripline	20
BPM21601	linac stripline	20
BPM21701	linac stripline	20
BPM21801	linac stripline	20
BPM21901	linac stripline	20
BPM22201	linac stripline	20
BPM22301	linac stripline	20
BPM22401	linac stripline	20
BPM22501	linac stripline	20
BPM22601	linac stripline	20
BPM22701	linac stripline	20
BPM22801	linac stripline	10
BPM22901	linac stripline	10

BPM23201	linac stripline	10
BPM23301	linac stripline	10
BPM23401	linac stripline	10
BPM23501	linac stripline	10
BPM23601	linac stripline	10
BPM23701	linac stripline	10
BPM23801	linac stripline	10
BPM23901	linac stripline	10
BPM24201	linac stripline	10
BPM24301	linac stripline	10
BPM24401	linac stripline	10
BPM24501	linac stripline	10
BPM24601	linac stripline	10
BPM24701	linac stripline	10
BPMS21	BC2, new stripline	40
BPM24901	linac stripline	10
BPM25201	linac stripline	10
BPM25301	linac stripline	10
BPM25401	linac stripline	10
BPM25501	linac stripline	10
BPM25601	linac stripline	10
BPM25701	linac stripline	10
BPM25801	linac stripline	10
BPM25901	linac stripline	10
BPM26201	linac stripline	10
BPM26301	linac stripline	10
BPM26401	linac stripline	10
BPM26501	linac stripline	10
BPM26601	linac stripline	10
BPM26701	linac stripline	10
BPM26801	linac stripline	10
BPM26901	linac stripline	10
BPM27201	linac stripline	10
BPM27301	linac stripline	10
BPM27401	linac stripline	10
BPM27501	linac stripline	10
BPM27601	linac stripline	10
BPM27701	linac stripline	10
BPM27801	linac stripline	10
BPM27901	linac stripline	10
BPM28201	linac stripline	10
BPM28301	linac stripline	10
BPM28401	linac stripline	10
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BPM28601	linac stripline	10

BPM28701	linac stripline	10
BPM28801	linac stripline	10
BPM28901	linac stripline	10
BPM29201	linac stripline	10
BPM29301	linac stripline	10
BPM29401	linac stripline	10
BPM29501	linac stripline	10
BPM29601	linac stripline	10
BPM29701	linac stripline	10
BPM29801	linac stripline	10
BPM29901	linac stripline	10
BPM30201	linac stripline	10
BPM30301	linac stripline	10
BPM30401	linac stripline	10
BPM30501	linac stripline	10
BPM30601	linac stripline	10
BPM30701	linac stripline	10
BPM30801	linac stripline	10
BPM30400	linac stripline	10
BPM46002	linac stripline	10
BPM46003	linac stripline	10
BPM46005	linac stripline	10
BPM92002	linac stripline	10
BPM92003	linac stripline	10
BPM92005	linac stripline	10
BPM92101	linac stripline	10
BPM92102	linac stripline	10
BPM92103	linac stripline	10
BPMVM1	FFTB stripline	5
BPMVM2	FFTB stripline	5
BPMVB1	FFTB stripline	5
BPMVB2	FFTB stripline	5
BPMVB3	FFTB stripline	5
BPMVM3	FFTB stripline	5
BPMVM4	FFTB stripline	5
BPMDL1	FFTB stripline	5
BPMT12	FFTB stripline	5
BPMDL2	FFTB stripline	5
BPMT22	FFTB stripline	5
BPMDL3	FFTB stripline	5
BPMT32	FFTB stripline	5
BPMDL4	FFTB stripline	5
BPMT42	FFTB stripline	5
BPMEM1	FFTB stripline	5
BPMEM2	FFTB stripline	5

BPMEM3	FFTB stripline	5
BPMEM4	FFTB stripline	5
RFB01	Undulator cavity style	1
BPME31	FFTB stripline	5
BPME32	FFTB stripline	5
RFB02	Undulator cavity style	1
BPME33	FFTB stripline	5
BPME34	FFTB stripline	5
RFB03	Undulator cavity style	1
BPME35	FFTB stripline	5
BPME36	FFTB stripline	5
RFB04	Undulator cavity style	1
BPMUM1	FFTB stripline	5
RFB05	Undulator cavity style	1
BPMUM2	FFTB stripline	5
RFB06	Undulator cavity style	1
BPMUM3	FFTB stripline	5
RFB07	Undulator cavity style	1
BPMUM4	FFTB stripline	5
RFB08	Undulator cavity style	1
RFBU	Undulator cavity style	1
RFBU	Undulator cavity style	1
RFBU	Undulator cavity style	1
RFBU	Undulator cavity style	1
RFBU	Undulator cavity style	1
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RFBU	Undulator cavity style	1
RFBU	Undulator cavity style	1
RFBUE1	Undulator cavity style	1
RFBUE2	Undulator cavity style	1
BPMUE1	FFTB stripline	20
BPMDD	FFTB stripline	20