LCLS Physics Requirements Document # 1.1-323	Project Management	Revision 2

Linac Wire Scanner System Requirements

Patrick Krejcik Author	P Krejcik Signature	8·4·06 Date
Hamid Shoaee Controls System Manager	Hamid Shoaee Signature	8-7-06 Date
Paul Emma Physics Team Leader	Paul Emma Signature	8-7-06 Date
Cecile Limborg Injector Physicist	Paul Emma FOR CECILE L. Signature	8-7-06 Date
Darren Marsh Quality Assurance Manager	D Marsh Signature	8/7/06 Date
John Galayda Project Director	John Galayda Signature	8/7/06 Date

Brief Summary:
The electron beam wire scanner system in the injector and linac is designed to provide high-resolution measurement of the electron beam transverse profiles (horizontal and vertical) under a variety of operating conditions and provide this information to a number of users. The measured profile is obtained over a number of consecutive beam pulses and therefore represents the time-averaged beam size. The measured profile is a projection into either the *x* or *y* plane depending on the wire orientation. The users can range from an operator looking at a graphical display of a single beam profile, to various high-level software application packages that use the beam size data to calculate the emittance and Twiss parameters of the beam. The undulator wire scanners are described in a separate document.

Check the LCLS Project website to verify that this is the correct version prior to use.

Change History Log:

Rev Number	**Revision Date**	**Sections Affected**	**Description of Change**
000	Aug. 1, 2005	All	Initial Version
001	Mar. 29, 2006	All	Increase wire diameters for WS01, 2, 3, 4, and WS11, 12, and 13.
002	Aug. 4, 2006	wire speed	Reduce max. wire speed from 15 mm/sec to 7.5 mm/sec.

System description

The wire scanner system is made up of a number of component parts that have individual physics requirements:

1. wires and holder system, or card, which suspends the fine wires as they are scanned across the beam
2. movable vacuum stage
3. motor connected to the stage
4. sensor for stage position
5. secondary emission sensor for wire signal
6. downstream scattered radiation detectors
7. control system interface

1. General requirements

The wire scanner measurement resolution is based on the minimum beam size likely to be encountered. For the nominal LCLS design with 1-micron normalized emittance, the smallest beam size at a wire location will be 30 microns rms. However, with low-charge operation, emittance levels as low as 0.5 microns might be anticipated, where the minimum beam size is then reduced to 20 microns. In order to sample an adequate number of points to get a good measurement of the beam sigma, the specification is set for a minimum step interval of 5 microns. The relative position accuracy of each measurement point should be 2-micron rms. (This level will reproducibly measure a 20-micron rms beam size to a precision of 2% rms.)

The number of points fitted to the profile also depends on the wire speed and the beam rate. A 5-micron step size and minimum rate of 10 Hz for doing precision wire scans (scan direction oriented at 45º) implies that the minimum wire speed (in the direction of travel) should not exceed $\sqrt{2}\times0.05$ mm/sec $\approx$ 0.07 mm/sec, and the minimum available speed should probably be somewhat lower than this, or ~0.05 mm/sec. The maximum speed can be up to 7.5 mm/sec (500-micron rms beam size at 120 Hz over ±4-sigma with 100 data points, including $\sqrt{2}$ speed reduction due to the 45-degree scan direction).

Note that the position accuracy of each measurement point has been specified as 2 micron rms during one scan of the beam over a range of about 500 microns. The scan should also be reproducible to an absolute position tolerance of ±10 microns. This means that on a subsequent scan the centroid position of the beam is going to appear within 10 microns of its previous location on the position readback scale. This will allow an operator to choose a narrow scan range and still ensure that the peak of the scan will always be reasonably well centered in the scanning range.

The detection of the beam intensity signal from the wire scanner gives a sensitivity requirement based on the minimum charge density likely to be encountered. A large beam with low charge will require the greatest detector sensitivity, so the specification is made for a 0.2-nC beam with an rms size of 500 microns as the most extreme case.

Reliability and radiation hardness are also general requirements, especially for wire scanners installed in the linac where access is limited.

2. The wires and holder system

The holder should be able to accommodate wires of different diameters and materials on a card, or cassette that can be interchanged between wire scanners, according to the requirements at different locations. Experience at SLAC has shown that wires ranging from carbon filaments a few microns in diameter to tungsten wires that are 10's of microns in diameter may be used. The wire diameter is specified in Table 2.

Two wire orientations will be used on the card to measure either the *x*- or the *y*-profile of the wire. In some SLAC applications a third wire rotated at 45 degrees (commonly called the *u*-wire) is used to determine the skew of non-round beams. However, with equal *x* and *y* emittances, it is not anticipated that this *u*-wire will be required for LCLS applications, although provisions should be available to add this *u*-wire to the card later.

High *Z* materials such as tungsten will be used for wires where a large signal is required from the scattered beam, and low *Z* materials such as carbon will be used where scattered radiation losses from the wire should be minimized to protect sensitive downstream components (see Table 2).

The wires should be tensioned so that a broken wire does not remain in the beam path to disturb operation with the other wires.

3. The movable vacuum stage

The movable vacuum stage is to allow manipulation of the internal wire card through a bellows to an external motion controller. The motion is linear and should be at 45° to the beam to allow the two orientations of the wires on the card to make horizontal and vertical scans of the beam. The travel should be large enough to ensure that the card can be moved far enough to remove all wires from the stay clear aperture of the beam. The total travel is the stay clear aperture plus the length of the card populated with wires.

4. The *possible* sensor for stage position

In the ideal case, a sensor should provide position readback with a resolution of 2 microns rms over the central part of the ~50 mm range of travel. This is not easy to satisfy given the other constraints on the system. Radiation hardness for linac applications limits the number of sensing devices that can be used. SLAC has used LVDT devices in the past, (Linear Variable Differential Transformers) using an inductance element that produces an electrical output proportional to the displacement of a separate movable core. These have resolution levels typically of one part in 10^3, so would only meet the wire scanner resolution specification if the travel were limited to a few mm, not 50 mm. An optical encoder device would have sufficient resolution over the full range of travel, but the optical components darken in a radiation environment.

In the absence of a suitable position sensor with the required resolution, the SLAC wire scanners have been forced to use stepping motors and counting the number of steps to determine the wire position. The LVDT is used only to calibrate the motion by comparing a large number steps (~1000) to the large displacement measured with the LVDT.

Recent experience at KEK shows that radiation hard position sensors are available that meet our resolution requirements[[i]]. The Magnescale position sensor is adopted at KEK, because it does not have processing electronics near the sensor. It includes a magnetized rod with very fine pitch and a pickup coil. The processing electronics is placed outside of the accelerator tunnel. The resolution of the Magnescale is 0.5 µm for 100-mm travel, small enough for a beam size measurement of 10 µm.

5. The secondary emission sensor for the wires

Two methods are commonly used to detect the beam intensity signal during a wire scan. The bremsstrahlung radiation can be detected by a downstream radiation loss monitor or the secondary emission from the wire can be measured from the current drawn through the wire. The secondary emission is known to be inaccurate at high intensities because high bunch fields introduce non-linearites in the response. However, at the low LCLS bunch charge this may be an ideal way to measure the beam intensity. The wires mounted on the card should therefore be electrically isolated from the vacuum chamber and should be connected to a 50 Ω vacuum feedthrough for connection to a gated, charge-sensitive detector system.

6. The downstream scattered radiation detectors

The bremsstrahlung radiation generated by the wires intercepting the beam is to be detected downstream by a radiation loss monitor. The challenge here is to configure the radiation loss monitor detector to see a sufficiently large signal from small wires and low bunch charge. The bremsstrahlung gamma radiation is forward scattered so the ideal location of a detector is just downstream of a bending magnet where the gammas will exit the beam pipe in a straight ahead path. Bending magnets are not always conveniently located near wire scanners, in which case one has to rely on the muons and other lower energy charged particles being overfocused by quadrupoles where they then exit the beam pipe over a limited distance. The optimum location for placing a detector in the linac to detect this radiation can be empirically determined.

Additional Information:

The most sensitive detection method is to use a photomultiplier tube to detect Cherenkov radiation generated by the bremsstrahlung. The components of the Cherenkov detector are a shower generator, a Cherenkov medium, and a photon detector. The shower generator multiplies the number of particles for detection and consists of a layer of high Z material such as lead. The Cherenkov medium can be an enclosed volume of air which generates light which in turn is detected by the PM tube. The PM tube itself should not be struck by the shower particles so a mirror is used in a periscope arrangement to allow the PM tube to be located away from the beamline.

It is also important that the bremsstrahlung generated by the wire is detected symmetrically with respect to the beam axis. If the detector is placed only to one side of *the beam pipe the measured intensity profile of the beam will appear asymmetric as the wire moves through the beam. To overcome this problem the detectors should be placed above, below, and on both sides of the beam pipe. Ideally, the detector should have an annular acceptance geometry around the beam pipe. Finally, there should be at least 2-3 different detectors available per wire scanner in order to empirically determine the best choice.*

7. The control system interface

The controls system provides remote manipulation of the moveable stage motor and readback of the position and signal.

The controls are integrated into the LCLS epics controls system, through a VME module interface. The control signals are:

1. drive signal for the motor
2. readback signal for position sensor of the moveable stage (if present)
3. limit switches indicating the extremes of the stage travel
4. charge sensitive gated-ADC input for the wire secondary emission current monitor, with trigger.
5. photomultiplier controllers for the Cherenkov beam loss detectors. The PM controller consists of:
    a. a remotely adjustable HV supply with readback
    b. a triggered gated-ADC for the tube output

The controls software will provide a generic interface for:

1. selecting the wire scanner location and plane to be scanned
2. setting up the wire scanner motion ranges and step size (and hence wire speed)
3. selecting the detector to be used for the intensity detection
4. setting up the detector controls for PM tube HV supply
5. setting up the triggers for the GADC signals
6. selecting upstream BPMs for monitoring the trajectory and bunch charge for each pulse during the scan
7. saving and restoring scan set ups
8. single scan procedure (once the above setups are done) for the wire through the beam and recording the intensity profile as a function of position. Processing the scan data includes:
    a. buffering the scanner position, scanner detector intensity signals, and selected BPM and charge monitor signals for each pulse during the scan
    b. graphically displaying position vs. detector intensity and detector intensity normalized to relative bunch charge
    c. compensating the wire position value for upstream trajectory jitter measured on the BPMs (and a user toggle for switching this feature ON/OFF)
    d. calculating the centroid position, RMS width and asymmetry of the distribution (1^{st}, 2^{nd} and 3^{rd} moments of the distribution) as well as FWHM and area under the curve.

i. allow a user-specified cut to the distribution to ignore background tails

e. fitting the measured profile to either a Gaussian or asymmetric Gaussian function and calculating the centroid position, sigma and asymmetry of the fitted profile.

f. saving the scan data to a temporary file, with the option of permanently saving it during a session.

g. subtracting one quarter of the wire diameter in quadrature from the measured rms beam size and reporting this as the real beam size.

9. the single scan procedure should be a able to be incorporated into a higher sequential procedure for automating multiple scans using saved default setups whereby the measured beam sizes can be used for emittance calculations and other high-level applications.

Table 1: Wire-scanner operating parameters.

Minimum step size along beam's *x* or *y* axis	5	microns
Minimum step size along direction of wire travel	7	microns
Bunch charge range	0.2 - 1	nC
Minimum wire speed (in direction of travel)	0.05	mm/sec
Maximum wire speed (in direction of travel)	7.5	mm/sec
Minimum beam rate for precision beam scanning	10	Hz
Maximum beam rate for precision beam scanning	120	Hz
RMS position precision over 500 μm range	2	microns
Absolute reproducibility of wire scanner position	±10	microns
Orientation of scan direction	45	degrees

Table 2: Wire scanner location, function, beam energy, nominal beam sizes, and suggested wire diameter.

MAD deck Name	Acc. Area	linac sector	Measures ε, σ_E, $\sigma_{x,y}$ or σ_z	Energy [GeV]	Hor. rms beam size [μm]	Ver. rms beam size [μm]	wire diameter [μm]	wire material
WS01	pre-DL1	~21-1	ε	0.135	130	130	60	W
WS02	pre-DL1	~21-1	ε	0.135	65	65	30	W
WS03	pre-DL1	~21-1	ε	0.135	130	130	60	W
WS04	in DL1	21-1a	σ_E	0.135	200	120	60	W
WS11	post-BC1	21-2c	ε	0.25	80	80	40	W

WS12	post-BC1	21-2c	ε	0.25	40	40	20	W
WS13	post-BC1	21-2d	ε	0.25	80	80	40	W
WS21	end of L2	24-4a	ε	3.9	75	40	20	W
WS22	end of L2	24-4d	ε	4.0	30	75	20	W
WS23	end of L2	24-5d	ε	4.2	65	30	20	W
WS24	end of L2	24-7a	ε	4.3	70	55	20	W
WS044*	L3 (s-28)	27-6d	ε	8.7	40	60	20	W
WS144*	L3 (s-28)	28-1d	ε	9.2	55	40	20	W
WS444*	L3 (s-28)	28-4d	ε	9.8	40	55	20	W
WS544*	L3 (s-28)	28-7d	ε	10.4	50	40	20	W
WS31	end LTU	-	ε	13.6	40	40	20	C
WS32	end LTU	-	ε	13.6	40	40	20	C
WS33	end LTU	-	ε	13.6	40	40	20	C
WS34	end LTU	-	ε	13.6	40	40	20	C

* existing wire scanners, 2 of which get moved ~24 meters (in sector-28).

[i] H. Hayano, “**Wire Scanners for Small Emittance Beam Measurement in ATF”,** XX International Linac Conference, Monterey, California, p. 146-148.