THE LINAC COHERENT LIGHT SOURCE PHOTO-INJECTOR OVERVIEW AND SOME DESIGN DETAILS*

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Abstract

The Linac Coherent Light Source (LCLS)[1] is a SASE free electron laser using the last 1/3 of the SLAC two mile linac to produce 1.5 to 15 angstrom x-rays in a 100 meter long undulator for use in a variety of x-ray science experiments. In order to satisfy the demanding electron beam requirements, a new 135 MeV photo-injector will be built in an existing, off-axis vault at the 2/3 point of the main linac. The injector accelerator consists of a BNL/SLAC/UCLA 1.6 cell S-band gun followed by two 3-meter long SLAC accelerator sections. The 6MeV beam from the gun is matched into the first accelerator section and accelerated to 135 MeV before injection onto the main linac axis with a 35 degree bend [2]. Several modifications to the rf gun, linac and beamline as well as the inclusion of several diagnostics have been incorporated into the injector design to achieve the required 1.2 micron projected emittance at a charge of 1 nC. In addition, an inverse free electron laser, the laser heater [3], will be used to increase the uncorrelated energy spread to suppress coherent synchrotron radiation and longitudinal space charge instabilities in the main accelerator and bunch compressors [4]. The configuration and function of the major injector components will be described.

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INJECTOR REQUIREMENTS

Lasing at x-ray wavelengths, the LCLS will require an injector capable of producing the excellent beam quality given in Table I. Simultaneously achieving the combination of the 1 nC charge, 1.2 micron rms emittance and 100 amperes peak current will be difficult, although it has be demonstrated in one experiment.[5] Another experiment has achieved 1.1 micron emittance at 1 nC, but at a much lower peak current.[6]

Table I Injector Parameters

Parameter	**Value**
Peak Current	100 A
Charge	1 nC
Normalized Transverse Emittance: Projected/Slice	≤ 1.2/1.0 micron (rms)
Repetition Rate	120 Hz
Energy	135 MeV
Energy Spread@135 MeV: Projected/Slice	≤ 0.1 / 0.01 % (rms)
Gun Laser Stability	≤ 0.50 ps (rms)
Booster Mean Phase Stability	0.1 deg (rms)
Charge Stability	≤ 2 % (rms)
Bunch Length Stability	≤ 5 % (rms)

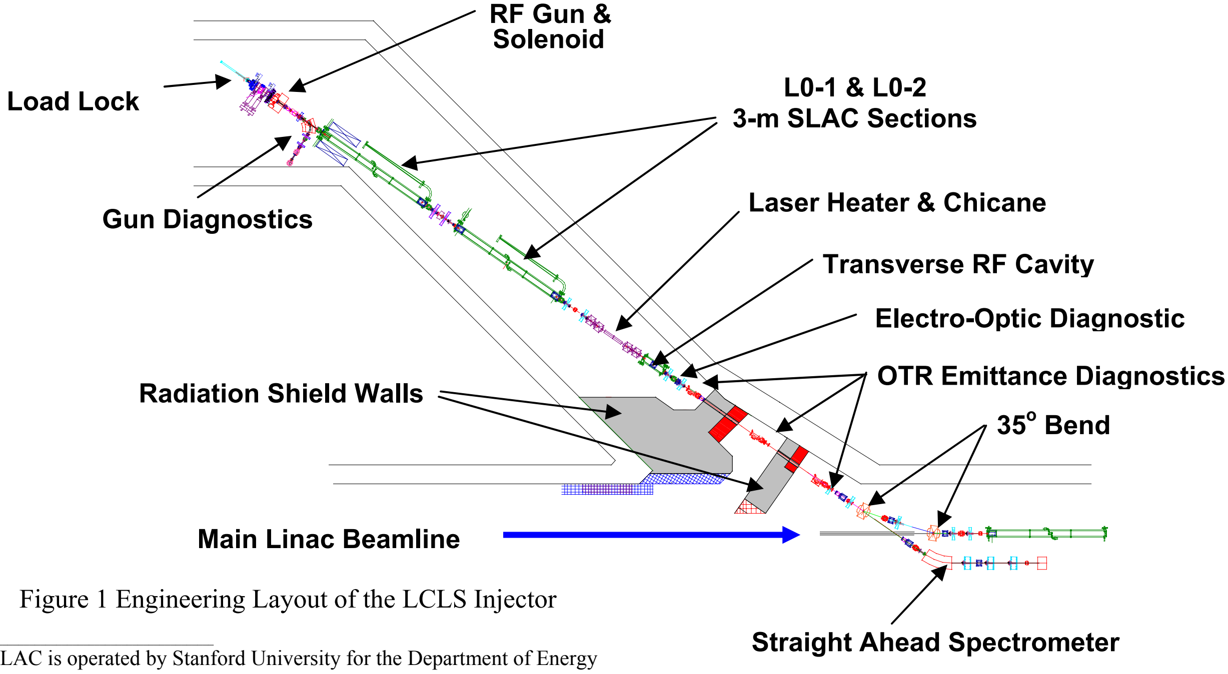

Figure 1 Engineering Layout of the LCLS Injector

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DESCRIPTION OF INJECTOR

The LCLS injector is based upon the standard BNL/SLAC/UCLA 1.6 cell s-band gun followed by two SLAC s-band sections to accelerate the beam to 135 MeV and an achromatic two-dipole bend to bring the beam into the main linac.

RF Gun

The electron source for the injector is the 1.6 cell, s-band gun which will be modified to have dual RF feeds. The dual feed is motivated by the desire to reduce the time-dependent dipole field perturbation introduced by a single feed. In the BNL/SLAC/UCLA gun, the dipole field from the single feed is compensated with another un-powered symmeterizing port opposite the power feed. In addition, for the standard gun, the RF is coupled to the cell using θ-coupling, which also reduces the dipole field [7]. However, even with the symmetric port and θ-coupling, there remains a dipole kick due to the power flowing into the cavity which dual feed eliminates.

On the other hand, the dual feed increases the RF quadrupole field above that of a single feed. Three-dimensional RF field calculations indicate an angular kick of $(\gamma\beta)_T/\gamma\beta$ of approximately $3\text{x}10^{-5}$ radians/mm for a 10 ps long bunch. Assuming an rms beam size of 2 mm at the location of the quadrupole field, the normalized emittance growth is estimated to be 0.12 microns. 3-D Parmela studies are planned. Given the tight emittance budget for the injector it maybe necessary to incorporate a new cavity shape, similar to the race track geometry used to compensate for this effect in the L0-1 RF coupling cell. (See below.)

Another advantage of the dual feed is the reduction of stresses due to pulsed heating of the RF coupling ports. Operating at 120 Hz and 120 MV/m, the LCLS gun will experience over an order of magnitude more thermal stress than other s-band guns, and a major concern is repeated pulsed heating of the rf coupling port causing a mechanical failure along the edge of the port hole. The computed localized heating at one end of the ~22 mm. long coupling port is shown in Figure 2.

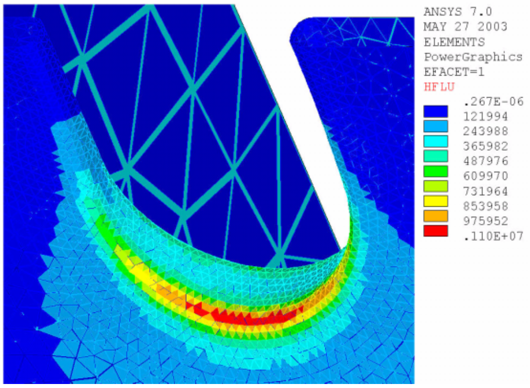

Figure 2 Localized heating of the RF coupling port on the full cell of the gun. The heat flux (watts/m^2) is shown for the gun operating at 140 MV/m and 120 Hz. The total dissipated power is 3676 watts.[8]

Studies for the Next Linear Collider structures show that limiting the temperature rise to 50 degrees C per pulse provides a conservative safety margin [9]. The new coupler design has a 55 degree temperature rise obtained by rounding the coupler iris by 0.09" (2.29 mm). It is 137 degrees for the original design with a 0.02" (0.508 mm) radius. It will be difficult to further reduce this temperature with more rounding. This is for 120 MV/m cathode field and a 3 microsecond long RF pulse. This model includes the transient behaviour of the gun fields.

Another technique for reducing the heat load involves powering the gun initially at 30 MW for 425 ns and then lowering it to 10 MW for the final 575 ns needed to maintain the cathode field at 120 MV/m.[10] Doing this reduces the pulse and average heating by ~2.5 times. The coupler temperature rise in this case is a cool 38^{o}C.

Other gun issues such as 0-pi mode beating are also being studied and will be presented in future publications.

Low Energy Region

The low energy region of the injector is shown in Figure 3 with the typical s-band gun components and some additions. These include a cathode load lock and an energy spectrometer.

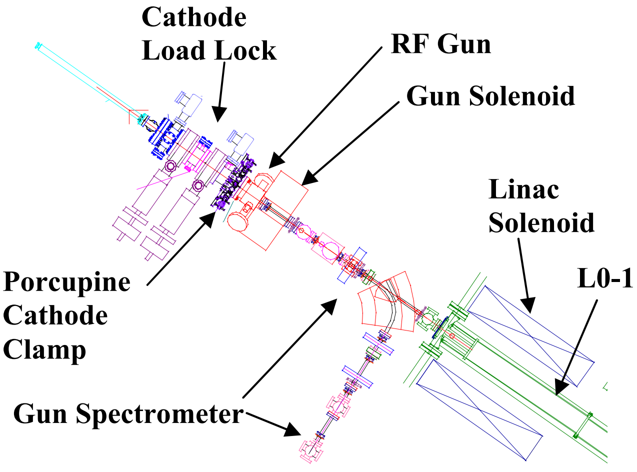

Figure 3 Low energy region of the injector.

The load lock design approach calls for two cathode transporters, each of which carries a single cathode between the gun and the cathode lab located above the injector vault. Each transporter stays with its cathode during the exchange and operation on the gun. The reasoning is that changing the cathode on an s-band gun requires removing the entire back plate of the cathode cell which is large (~10 cm diameter) compared to the cathode area itself. This is done to keep the RF joint at the outer diameter of the cell where the electric fields are low to avoid arcing. Transferring these large items under UHV from a cathode pack to a cathode stick for insertion into the gun is mechanically difficult. In addition, 120 Hz operation requires cooling the cathode. Transferring cooling lines while assuring good thermal conduction with a new cathode would also be difficult.

The motivation for integration of a gun spectrometer into an injector system has been discussed elsewhere [11] and among other things, allows an accurate determination of the beam energy and energy spread out of the gun. This spectrometer uses a 95.5 degree dipole in combination with one quadrupole before and two after it to achieve low (10keV) and high (3keV) resolution modes of operation. [12] Other beam characterizations which can be made are thermal emittance, charge, pulse shape using a streak camera, and longitudinal emittance by streaking the Cherenkov light from the spectrometer screens.

L0-1 and L0-2 S-Band Accelerator Sections

Two SLAC sections, L0-1 and L0-2, after the gun accelerate the beam to 135 MeV. The first section, L0-1, has a solenoid over its first meter of length. The parameters for this solenoid were established by extensive simulations [2]. Between L0-1 and L0-2 are a quadrupole doublet and a RF phase cavity as well as the standard diagnostics.

The 3-meter SLAC travelling wave sections are known to have dipole RF fields in both the input and output coupler cells. In SLAC's original design the coupler cells were transversely offset to compensate for the amplitude portion of the field, however the phase or power flow contribution remains.[13] Our analysis showed the remaining dipole field leads to unacceptable growth in the projected emittance by both the dipole and quadrupole fields.[14] Therefore a new input coupler cell was designed for L0-1 with both dual feed and a race-track shape.[15] The original single feed coupler produced a 0.83 mrad/mm quadrupole kick along an on crest 10 ps bunch. This is equivalent to a 1.2 meter focal length lens. The new coupler design has a quadrupole field 20 times weaker, 0.04 mrad/mm or 25 m focal length.

Beam Diagnostics and Beam Conditioning

Besides the usual beam diagnostics following L0-1 and L0-2, such as beam position monitors, profile monitors and current toroids, there are an electro-optic bunch shape diagnostic, and a transverse RF deflecting cavity. The transverse deflecting cavity can be used with the Straight Ahead Spectrometer to directly measure the longitudinal phase space. The slice emittance can be determined using three OTR profile monitors in front of the 35 degree bend.

The laser heater is located in this section of beamline and consists of a 50 cm long undulator inside a 4-dipole chicane. [3,4]

35 Degree Dog Leg Bend and Straight Ahead Spectrometer

After passing through the radiation shield walls, the beam can be bent onto the main linac axis using the two 17.5 degree dipoles of the Dog Leg 1 (DL1) bend or with the first DL1 dipole off, be transported to the 35 degree straight ahead spectrometer dipole. Similar to the gun spectrometer, the Straight Ahead Spectrometer has an adjustable range of energy resolution with a best resolution of ~5 keV.[11] This spectrometer allows the measurement of beam energy and energy spread at 135 MeV. When used with the transverse RF cavity, one can also determine the longitudinal phase space distribution.

REFERENCES

[1] Linac Coherent Light Source (LCLS) Design Study http://www-ssrl.slac.stanford.edu/lcls/cdr/.

[2] C. Limborg et al., "Sensitivity studies for the LCLS PhotoInjector Beamline", Proceedings of the 2003 International FEL Conference.

[3] R. Carr et al, "Inverse Free Electron Laser Heater for the LCLS," EPAC'04, Luzern, July 2004.

[4] Z. Huang, et. al. "Suppression of Microbunching Instability in the Linac Coherent Light Source," EPAC'04, Luzern, July 2004.

[5] J. Yang et al., EPAC 2002 Proc., p. 1828.

[6] J.-G. Marmouget et al., EPAC 2002 Proc., p. 1795.

[7] D.T Palmer et al., SLAC-PUB-95-6799.

[8] R. Boyce et al., LCLS Tech Note LCLS-TN-04-4.

[9] D.P. Pritzkau and R.H. Seeman, Phy. Rev. ST Accel. Beams 5, 112002(2002)

[10] J. Schmerge, LCLS Tech Note LCLS-TN-02-07.

[11] D.H. Dowell et al., Proc. of 2nd ICFA Advanced Accelerator Workshop, J. Rosenzweig and L. Serafini, ed., World Scientific, 2000, p. 52-71.

[12]C. Limborg-Deprey et al., See link to documentation: http://www-ssrl.slac.stanford.edu/lcls/photoinjector/.

[13] R.B. Neal ed., "The Stanford Two Mile Accelerator," W.A. Benjamin, 1968, pp. 144-148.

[14] C. Limborg-Deprey et al., "Modifications of the LCLS Photoinjector Beamline," EPAC'04, Luzern, July 2004.

[15] Z. Li et al., "Coupler Design for the LCLS Injector L0-1 Structure." To be published as LCLS Technical Note.