INVERSE FREE ELECTRON LASER HEATER FOR THE LCLS[*]

Roger Carr[#], Lynn Bentson, Paul Bolton, Dave Dowell, Paul Emma, Sasha Gilevich, Zhirong Huang, Jim Welch, Juhao Wu, SLAC, Menlo Park, CA 94025 USA

Abstract

The Linac Coherent Light Source (LCLS) free electron laser employs an RF photocathode gun that yields a 1 nC bunch a few picoseconds long, which must be further compressed to yield the high current required for Self Amplified Spontaneous Emission (SASE) gain. The electron beam from the RF photocathode gun is quite sensitive to microbunching instabilities such as coherent synchrotron radiation (CSR) in the compressor chicanes and longitudinal space charge (LSC) in the linac. These effects can be Landau damped by adding energy spread to the electron bunch prior to compression. We propose to do this by co-propagating an infrared laser beam with the electron bunch in an undulator in the LCLS injector beamline. The undulator is placed in a four bend magnet chicane to allow the IR laser beam to propagate co-linearly with the e-beam while it oscillates in the undulator. The IR laser beam is derived from the photocathode gun drive laser, so the two beams are synchronized. Simulations presented elsewhere in these proceedings show that the laser interaction damps the microbunching instabilities to a very great extent. This paper is a description of the design of the laser heater.

INTRODUCTION

Small longitudinal modulations will occur in the few-picosecond long electron bunch created by the LCLS laser photocathode gun. If these modulations are allowed to propagate through the bunch compressor chicanes, they would cause serious beam instabilitites. Initially, we proposed to damp instabilities with a superconducting wiggler placed upstream from the second bunch compressor. This would have caused the beam to emit wiggler radiation, which would generate an uncorrelated energy spread that would smooth out the instabilities. However, when we became aware that there might also be longitudinal space charge instabilities that would not be damped by a wiggler, we adopted the idea of using an inverse free electron laser to add uncorrelated energy to the beam [1] The physical theory behind this concept is described elsewhere in these proceedings [2]. Here we describe the implementation.

LCLS INJECTOR

The LCLS injector is located along the SLAC linac, about 1 km from the end. This system is described elsewere in these proceedings [3]. One km of the SLAC linac is capable of accelerating electrons to about 15 GeV. The injector is located in an off-axis vault underground at the level of the linac, 10 m below ground. The injector beamline is about 20 m long, and includes a photocathode gun, two linac accelerator sections, the laser heater, and two magnetic spectrometers.

At ground level, buildings will be constructed to house the main drive laser for the laser photocathode gun. This laser is a diode-pumped Ti:Sapphire laser that radiates at 765 nm and is frequency tripled for use in the photocathode gun. Originally we proposed to use the ‘waste’ from the tripling process for the laser heater, but the waste pulse would likely not have a clean Gaussian profile. We now plan to take 40 μJ from the 25 mJ beam of the drive laser. This pulse is 10 psec long for use in the gun, which produces an electron pulse of about this same length, so we stretch the IR radiation to 20 psec using a grating pair, to be able comfortably to overlap the electron pulse.

LASER HEATER

The laser heater system is shown in Figure 1:

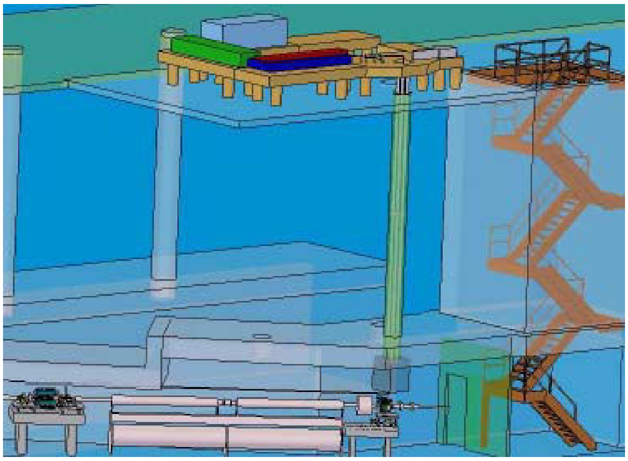

Figure 1: System view. The main drive laser is shown at the top; it is at ground level. The green vertical pipes represent the transport system to the SLAC linac level 10 m below. The photocathode gun is to the right of the pink accelerator sections below, and the laser heater optical table is to the left of the accelerator.

---

[*] This work was supported by the US Department of Energy, contract No. DE-AC03-76SF00515.

[#] E-mail: Carr@SLAC.Stanford.edu

The laser heater system begins on the main drive laser table with beam conditioning optics, as shown in Figure 2:

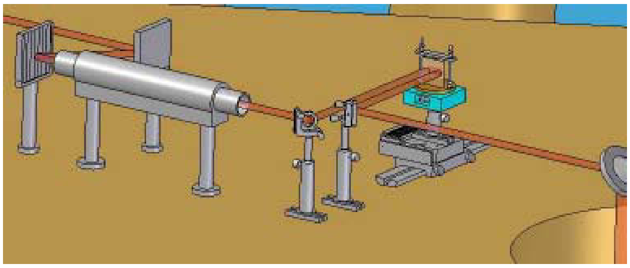

Figure 2: Beam conditioning optics. A grating pair (left) is used to stretch the IR pulse from 10 to 20 psec, a telescope (mid-left) collimates the beam, and a delay stage (center) allows variation of the time of arrival of the IR pulse, relative to the electron pulse.

We use a relatively large diameter (~7mm) beam through the transport train in order to reduce pointing errors. After beam conditioning, the pulse is deflected downwards into a transport system that carries it to the SLAC linac level, and then horizontally about 10 m to the laser heater, shown in Figure 3:

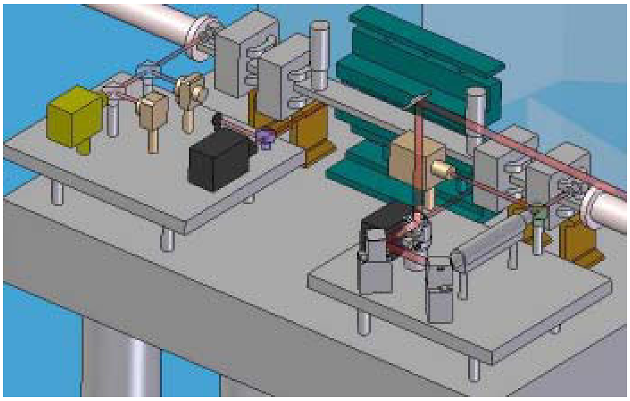

Figure 3: Laser heater. The launch optics breadboard is on the right, the magnet chicane and undulator is shown behind, and the diagnostic optics are to the left.

The laser heater has three subsystems; the chicane and undulator, the launch optics breadboard, and the post-interaction diagnostics optics breadboard. The chicane comprises a four-dipole magnet bend, flat beampipe, and an adjustable gap undulator. The bend magnets are 10 cm long, and cause a 6-degree bend in the 135 MeV beam with a transverse displacement of 25 mm. The beampipe requires a 30 mm magnet gap, and allows the beam to pass through undeflected when the dipole magnets are turned off.

In our first concept, we considered simply crossing the laser beam with the e-beam, using no bend magnets. However, we found that the chicane is not only optically superior, but also that the two downstream dipoles temporally smear the modulation introduced by the undulator. The energy spread introduced by the undulator then allows the unwanted beam modulations to be smeared out by Landau damping in the first bunch compressor.

The undulator is a hybrid adjustable gap device with 18 pole-pairs in an antisymmetric configuration with a 3/4-1/4 pole termination on each end. The poles are vanadium permendur and they are fed flux by NdFeB magnets between them. The periods are 50 mm long, and the minimum gap is 30 mm. The nominal undulator parameter is 1.508, corresponding to a resonance energy of 1.62 eV and a resonance wavelength of 765 nm, to match the IR wavelength within a ±2% bandwidth.

The laser launch optics include a reducing telescope and two 2-axis steering mirrors that will allow the IR beam to be superposed over the electron beam. There is also an insertable waist-size monitor in the form of a CCD camera placed an equivalent distance from a flipper mirror as the beam waist in the undulator.

On the upstream and downstream ends of the undulator there are insertable optical transition (OTR) radiation monitors in the form of CCD cameras and Ti foils at 45 degrees to the e-beam axis. These are used to align both the IR and electron beams, and to steer the IR beam so that it overlaps the e-beam. In addition, one of the OTR monitors will be fitted with a flipper mirror and a photodiode that will be used to monitor the temporal overlap of the beams. A filter will be used so that the intensity of the reflected IR beam will be comparable to the intensity of the OTR from the e-beam. The path length adjustor on the main drive laser table will be used to adjust the IR pulse arrival time to overlap the electron pulse within 10 psec.

After the IR beam exits the chicane beampipe, it comes to a diagnostic optics breadboard where it can be directed into a joulemeter to measure the power, a photodiode to measure its timing, and a CCD camera to monitor the pulse shape. We start with 4 MW of power in a 10 psec IR pulse, and require 1.2 MW in 20 psec to obtain an RMS energy spread of 40 keV; this imposes an efficiency requirement on the transport system. The IR beam has a Rayleigh range of 0.5m and a waist σ of 0.175 mm. The electron beam has a beta function of 10 m and an RMS radius of 0.19 mm.

There is a 35-degree bend spectrometer downstream from the laser heater that may be used to monitor the energy spread imposed on the e-beam by the laser heater. Its design resolution is 3 keV.

The mirrors in the transport system are manually adjusted, but all other motions, including the path length adjustment, the steering mirror adjustment, and flipper mirror insertions are computer controlled. There are safety shutters on the drive laser table and the launch table that will allow personnel override when live laser beam is being used for setup. There is also provision for a HeNe alignment laser on the drive laser table for rough adjustment.

SUMMARY

The LCLS injector laser heater design presented here is intended to smooth energy and longitudinal modulations in the e-beam from the injector, so that they do not cause instabilities in the bunch compression process. The design presented here has been modeled and found to perform this function very well. It passed a physics concept review at SLAC in March, 2003, and construction will begin in October, 2005. Final commissioning is scheduled to occur in February, 2008, in time for LCLS commissioning.

REFERENCES

[1] E. Saldin, E. Schneidmiller, M. Yurkov, "Longitudinal Space Charge Driven Microbunching Instability in the TTF2 Linac", TESLA-FEL-2003-02, 2003.

[2] Z. Huang, et. al., “Suppression of Microbunching Instability in the Linac Coherent Light Source,” EPAC’04, Luzern, July 2004.

[3] D. Dowell, et. al., “The Linac Coherent Light Source Photo-Injector,” EPAC’04, Luzern, July 2004.