Report on the LCLS Injector Technical Review

Stanford Linear Accelerator Center

November 3&4, 2003

Committee Members

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Charge to the Committee

The Technical Review for the Linac Coherent Light Source (LCLS) Injector was held at Stanford Linear Accelerator Center (SLAC) on November 3 and 4, 2003. The review covered the LCLS injector performance requirements, and critically assessed the proposed design and its ability to meet the injector's performance parameters. The Committee was requested to:

1. Determine if the proposed injector design will meet LCLS performance requirements.
2. Identify and quantify technical issues related to the injector design
3. Cite any foreseen technical risks to the current design.
4. Cite any overly optimistic expectations or assumptions that require further investigation.
5. Determine if the design and construction plans for the injector are reasonable, and make comments and suggestions for improving the current plan.

The injector comprises the first 135 MeV of the LCLS beamline, up to the point of injection in to the main linac.

Report

The Committee was presented with a series of presentations as listed in the attached agenda. In keeping with the above charge, the presentations focused almost entirely on the injector, and there was little discussion of the linac, bunch compressors and FEL. The photocathode drive-laser, which will be the subject of a separate review, was not discussed in detail, however we do make some comments in our report that should be considered during the drive-laser review.

Some members of the Committee had been involved in earlier reviews of the LCLS injector, and we are delighted to report substantial progress in the state of the injector since the earlier reviews. Key issues have been identified and acted upon.

The experimental results from Gun Test Facility are quite impressive, and we believe that they are the most comprehensive set of measurements for any s-band gun. The focus on deploying time-dependant diagnostics and on phase-space mapping is very commendable, and has allowed a close connection between simulation and experiment. The quality of the simulations has advanced substantially in the past few years. The systematic error studies are very impressive and heading in the right direction. The system engineering has made substantial strides. Overall, we noted how well the injector team is working well together, as evidenced by the cohesiveness of the presentations. We also note that that the project management recognizes the importance of the injector.

Below we address the specific items in the charge to the Committee.

1. Determine if the proposed injector design will meet LCLS performance requirements.

The Committee believes that achieving the required beam from the injector still represents a technical challenge. The data we have seen are encouraging, but leave lots of work to be done. Transverse emittance, peak current, and uncorrelated energy spread are still not within specification. There is very little margin for error. We believe, however, that the injector team is heading on the correct course and that they will achieve the design goals.

The RF timing issues seem to be well under control. SLAC has a long and distinguished record in running stable RF phase and amplitude, and we do not anticipate any major problems in meeting the LCLS requirements.

The injector is quite different from other parts of the LCLS in that it can easily be modified and upgraded later. We believe that the injector can take advantage of technology improvements in its key components (gun cavity, cathode and drive laser) that will occur, and that upgrades can be incorporated over time. We believe that the right thing for LCLS to do is to proceed along the current design path. We do not advocate any major changes (e.g. gun rf frequency) in the injector design

2. Identify and quantify technical issues.

We note that the injector has several innovative features and diagnostics designed to solve problems that other injectors have encountered. These features are necessary because of the groundbreaking nature of the performance requirements for the injector.

Because the gun will be running at high gradient, and at a much higher repetition rate than any other s-band gun, heat dissipation in the cavity walls is an issue. The injector team has done steady-state thermal analyses, and taken steps to improve cooling, and reduce the head load in certain areas. The concepts of dual RF feeds to the gun, and of profiling the RF pulse to reduce heat dissipated are both excellent concepts. We are, however, concerned about transient and repetitive heat stress on the gun, particularly at the coupling irises and tuners. Such transient stresses could result in premature aging and failure of the gun. We recommend that the team focus on reducing pulsed heating temperature rise, paying particular attention to the waveguide coupling irises. Thermal stress on the cathode/gun rf contact should also be carefully analyzed. Careful consideration should be given to eliminating the full cell cavity tuners unless they are deemed absolutely necessary.

There is a range of issues that need to be addressed in regard to cathode quantum efficiency and lifetime, and LCLS may be able to take advantage of developments that are happening elsewhere. Therefore, LCLS does not need to start a cathode development program.

Commissioning the gun will not be easy. We recommend that there should be two stages of gun diagnostics: a comprehensive set for commissioning the gun, and a second set for operation once the linac sections have been attached. Additional high-charge emittance diagnostics at the exit of the gun should be considered. A transition-radiation or Cerenkov-radiation and streak camera based profile measurement should be considered as a backup to the notoriously tricky electro-optic profile measurement that is planned after the gun.

The injector group aptly pointed out that there are 19 parameters (excluding field multipole errors and misalignment errors) that must be adjusted based on information from the diagnostic suite. As the highest performance is demanded from this injector, the diagnostics should be very carefully thought out.

Intra-pulse current fluctuations, coupled with very low longitudinal incoherent energy spread in the bunch may lead to undesirable coherent synchrotron radiation-driven beam degradation further down the linac. It has been postulated for some time that increasing the incoherent energy spread would mitigate the CSR effect. Initially, a superconducting wiggler in the linac was proposed as a method of introducing incoherent energy spread. Because of the longitudinal space charge instability, and the consequent necessity to make the energy-spread correction much earlier, the concept of using a laser-driven FEL amplifier (laser heater) has been proposed for the end of the injector. The laser heater idea is intriguing, but it is new and needs to be refined. While we believe that the physics behind the concept is sound, there are several engineering issues associated with aligning, focusing and timing the laser/beam interaction.

We note that the spontaneous emission from the heater undulator could be used as a beam diagnostic and we recommend that the team investigate the feasibility of this.

3. Cite any foreseen technical risks to the current design.

Because of the potential for intra-pulse fluctuations, the bandwidth of a Ti: Sapphire laser is a major concern. The longitudinal fluctuations of beam from a Cu and Mg cathode very closely follow any modulations of the drive-laser. This can be great if the modulations are controlled and desirable, but can drive longitudinal space-charge instabilities if not. Either limiting the laser bandwidth or using a cathode with a ps response time would work. This is an important issue for the Injector Drive-Laser Review Committee.

Because of the desire for small intrinsic slice emittance, and hence, small beam radius at the cathode, the beam will be close to the onset of space charge instabilities with short micropulses. The longer micropulse concept looks promising. We understand that this cannot be tested on GTF at present because of drive laser limitations. The team should look into doing such tests soon: either move up the purchase of relevant laser components, or use a gun facility elsewhere, e.g. the DUV FEL at BNL or the gun test facility at ANL.

Engineering details of the load-lock for gun back-plane replacement were not presented. The Committee feels that this setup is a high-risk mechanical system. Thorough testing of the mechanical reliability and rf repeatability of the porcupine cathode seating mechanism should be completed before incorporation into the final design.

4.Cite any overly optimistic expectations or assumptions that require further investigation.

As noted earlier, the gun beamline is under-diagnosed for commissioning. We also note that the commissioning process needs to be fleshed out.

At this review, we did not see any end-to-end simulations of the system consequences of non-optimum injector performance. We recommend that the team move ahead on integrated start-to-end simulations that use realistic phase space distributions from start to end. This is important because there is little or no margin for emittance growth in linac/bunchers. The use of emittances at the exit of the injector as the primary figures-of-merit for assessing tolerances should be backed up by end-to-end simulations using appropriate x-ray photon pulse properties as the figures of merit, at least for the most sensitive machine parameters.

5. Determine if the design and construction plans for the injector are reasonable, and make comments and suggestions for improving the current plan.

The Committee believes that the time allowed for commissioning appears to be very short, and that there is no contingency time. We understand that many items have been deferred because of a lack of proper funding. Unless the funding stream for the injector improves, the commissioning schedule will be adversely impacted.

The ongoing tests at the current Gun Test Facility are of critical importance to the success of LCLS. We encourage SSRL management to allow more operations time for GTF.

Careful consideration should be given to the injector layout in the sector 20 vault, and modifications undertaken if the performance of the injector can be significantly improved.

Is there a better way?

Perhaps, however, the Committee recommends that the Injector team proceed on course, except as mentioned above. It is important to get the injector to the point of being able to deliver beam to the main linac at the earliest possible date, even if that beam is not perfect. The ALARA concept should be applied to the emittance goal for now, with improvements to come later. We note that the injector gun, and drive laser are amongst the least expensive parts of the LCLS, and yet are critical to its performance. They are also relatively easy to upgrade as new developments in injector technology become available.

LCLS Injector Review Agenda

Monday, November 3, 2003

Overview
8:30 - 9:00 Greetings and Charge to the Committee from John Galayda;
9:00 - 9:30 Committee Executive Session
9:30 - 10:00 Overview of the LCLS Injector, D. Dowell
10:00 - 10:30 ***break& discussion***

Simulations and Gun Design
10:30 - 11:15 Injector Simulations, C. Limborg
11:15 - 11:45 120 Hz Gun and Load Lock, J. Schmerge
11:45 - 1:00 ***break for lunch***

Major Injector Components
1:00 – 1:30 RF System, R. Akre
1:30 – 2:15 Specifications for Electron Diagnostics, C. Limborg
2:15 – 2:45 Prototyping at GTF, J. Schmerge
2:45 – 3:00 ***break***

Beam Quality Issues
3:00 – 3:30 Laser Heater Justification, Z. Huang
3:30 – 4:00 Implementation of the Laser Heater, J. Welch
4:30 – 5:00 Expt. Status of Beam Requirements for LCLS, D. Dowell
5:00 – 7:00 ***Open discussion and Committee meeting***

Tuesday, November 4, 2003

Discussion and Closeout

7:30 – 8:30 Committee Executive Session
8:30 – 10:00 Closeout Session