February 2, 2004

Report of the Review Committee for the LCLS Linac Technical Design Review

Review date:

December 12, 2003

Committee members:

Scott DeBarger, Bob Hettel, Rusty Humphrey, John Seeman (Chair)

Review Scope:

The review discussed many aspects of the design of the Linac portion of the LCLS covering the area from the injection point of the beam into the linac downstream of the gun, through the two bunch compressors, the Beam Switch Yard, transport lines and, finally, the dump line. The undulator and x-ray beam regions were not covered.

The presented materials covered in the review were well planned and presently in a coherent manner. The committee appreciated the large amount of time put into making the strong presentations and the technical efforts on the LCLS design.

The charge to the committee is contained in Appendix A.

The agenda of the review is included in Appendix B.

Comments from the committee on specific linac areas are found below.

Linac Accelerator Design:

A summary of requirements for the operation of a 1.5 Å SASE FEL was presented. These requirements include a 14.1 GeV electron linac with bunch compressing chicanes and X-band linac structure to reduce the length of a ~1 nC bunch to the order of 200 fs rms in order to reach 3.4 kA peak bunch current. The micron slice emittance of the beam must be preserved over the length of the linac and FEL, which should not add more than 20% to the initial normalized emittance, and the slice energy spread must be kept to 0.01%. Successful FEL operation will only be achieved if the jitter in charge, accelerating voltage and rf phase is maintained below stringent (and challenging) limits.

The optics and physical layout of the accelerator system and FEL have been meticulously analyzed and optimized using a suite of simulation codes, including “Parmela” for the low energy injector beam (accounting for space charge effects), “Elegant” for the linac (accounting for bunch compression effects, wake fields, and coherent synchrotron radiation) and “Genesis” for the FEL (accounting for SASE and wake fields). The results of these simulations have been cross-checked with other codes and by other researchers. The technical challenges include restricting the potential for emittance growth from coherent synchrotron radiation in bunch compressor dipoles, the micro-bunching instability, transverse wake fields, and misalignments and chromaticity, and reducing gun and rf system jitter to tolerable levels. The LCLS designers plan to mitigate these problems with a laser heating system in the injector to reduce CSR and micro-bunching, maintaining tight (but reachable) component alignment tolerances, implementing low-jitter controls for the RF and gun system, using feedback to control “slow” changes in beam energy and bunch length, and using beam monitors and a beam-based alignment technique to achieve and maintain a precise beam trajectory through the whole facility. The facility is being designed to operate over an electron energy range of 3-15 GeV, and future upgrade plans include the possibility of multi-bunch operation.

The review committee was impressed with the thoroughness and quality of the accelerator design and the quantification of design issues. All apparent issues seem to have been identified and the committee members made the following comments regarding the design of the accelerator and transport systems:

The number of bunches that can be accelerated in a future multi-bunch mode might be limited by several design parameters, for example the X-band macro-pulse length. It is easier to include more bunches in the design now rather than later.

While linac sections L2 and L3 have in-situ standby klystrons that can be switched in very quickly after the failure of a working klystron, L1 does not have standby klystrons. The recovery from an L1 klystron failure will therefore be more time-consuming. Steps might be taken to minimize this recovery time.

The electron beam diagnostics at the end of the undulator are presently minimal and do not include a device for measuring beam size or emittance. The committee recommends that such a device (or devices) be included, if possible, to enable evaluation of the effects of the undulator structure on beam emittance. If the beam entering the undulator is of good quality but the undulator does not make laser light, then knowing the properties of the exiting electrons will be very important.

Linac quadrupoles must operate over a wide range of beam energies. The last third of the linac is to be shared between the LCLS and high energy beams. The quadrupoles in the last third of the linac have special steel to allow low remnant fields at low excitations. Laboratory measurements should be done to determine the proper hysteresis curves and standardization cycles to arrive at the best low field situation for the LCLS quadrupoles. The new magnets build for the linac should use the same steel as the existing quadrupoles to make standardization easier.

Trim windings are being provided for the chicane dipoles so that their remnant fields can be zeroed out when straight-ahead beam operation is needed.

The component specifications were alluded to but only one example was shown. If a future committee is to comment if the designs are reasonable, then many more examples, if not all, need to be shown.

A computer simulation of cascaded beam-based feedbacks along the LCLS for position, angle, energy, energy spread, and bunch length from the front to the end should be done. The review team believes that this simulation would help the operation of the feedback systems across the two chicanes interact with one another.

If and when the LCLS project changes the power supplies for the quadrupoles in the regions Sector 20 to 30, care must be taken to allow quadrupole strengths for both low and high energy beams. A plan needs to be worked out with the Technical Division.

The LCLS linac will need feedback magnets that operate at 60 Hz or so. Where will these magnets be located and what do the associated vacuum chambers look like?

Overall LCLS:

A “Vacuum Czar” should be identified for the LCLS project to standardize the vacuum requirements and establish mechanical quality of the project to assure that components are carefully constructed and that vacuum processing is done properly.

A project wide nomenclature list for installed components should be made. The SLAC/SSRL maintenance crews will have a much easier time if the Linac components in Sectors 20-30 have a nomenclature which is the same as is in use now. There are sufficient label numbers available to name all new LCLS components added to the existing linac scheme.

Linac Project Management:

The person in the “Head Controls” position in the linac organization needs to be identified soon.

There should be a “Head RF” person identified to coordinate RF activities and specifications.

The number of components including “overage” and “spares” of the various manufactured items should be determined relatively soon.

The persons in the organization who have budget authorization should be clarified.

The WBS spread sheet shown was an out-of-date one but indicated a problem that should be fixed in the new one. There were large fluctuation in the total money spent each quarter, e.g. ranging from 160 k$ to 2400k$ and then back down for one group. These numbers should be spread more evenly during the various quarters, while, of course, taking into account single large purchases. It is hard to move manpower in and out of a group that quickly.

Many of the FFTB magnets belong to BINP in Novosibirsk. Has the project arranged to have the magnets that will be used by the LCLS linac transferred to the LCLS project?

There were two schedule issues in the review. 1) The present FFTB is to be removed according to the LCLS linac group in October 2005 but the SLAC Technical Division believes the FFTB is taken apart in January 2006 or later. 2) The LCLS Linac schedule shows installing BSY components in Spring 2006 but the PEP-II program runs beam through there until August 2006. These schedule conflicts and the overall downtime dates should be resolved between the Technical Division and the LCLS project.

Access to the Linac housing during LCLS commissioning will be restricted and must the controlled in coordination with the PEP-II program. Nominally, beams will be running constantly during that time.

The present component layout for the LCLS linac should take future LCLS upgrade plans into account so as to not force major movements of newly installed LCLS components during the upgrades.

The overall design effort for the LCLS Linac calls for two engineers and two designers. The committee feels that there is significantly more work to do than these four people can perform in the time allowed.

Linac Safety System:

A Safety Officer should be assigned to the LCLS Linac System.

The LCLS proposal for the PPS system redefines the geography of the present LINAC PPS in the LCLS region. In addition, the team proposes to go to a PLC (Programmable Logic Controller) design approach. The review committee believes that it will require a full-time effort on the part of the LCLS PPS system manager to shepherd such a redesign through the necessary reviews and manage a design and construction team. Please do not forget that the SLAC linac can deliver a 660 KW electron beam to the LCLS beam line.

Linac LSC/CSR Instabilities:

The committee suggests that the complete specifications of the laser beam and electron beam (position, energy, area overlap, time overlap, etc.) in the devise for the “emittance increase” at the 100-MeV location be completed in the near future.

Linac Controls:

The LCLS Control System will integrate two existing control system technologies – the SLAC SLC Control System and EPICS. Such integration has been done at PEP-II, but the LCLS will take this another step further in the LINAC. Careful planning must be done.

An important control item will be the integration of a common LINAC timing system across both the control systems. The LCLS team proposed using the present timing system. This proposal should be looked at in more detail. The number of beam codes available may not be sufficient for LCLS operation. The present timing system uses obsolete components and the maintenance for this system over the 30 year lifetime of the LCLS will certainly be problematic. The review team believes that for this reason alone, a new LCLS timing system should be developed. Technology (fiber optics) which has been successfully tested at the proof of principle level for the NLC could be applied here. The design of a new timing system will have to meet the requirement that the LCLS timing system operates with the timing system for the PEP injection lines.

The fact that the timing and machine protection systems work in such a way that there is a three pulse pipeline before any MPS required shutoff can occur was brought up in this meeting. This could mean that the undulator would have to take three LINAC pulses in the case of an MPS fault. The LCLS team will have to investigate this issue.

The control system functional requirements for software and system integration have yet to be developed at the necessary levels of detail. The LCLS team is adding staff to work in this area. One point raised in this review is that the nomenclature for the two control systems differs significantly. The LCLS needs to have some mechanism to name devices in a consistent fashion across the two systems.

Linac Diagnostics:

The LCLS diagnostics involves a large number of different systems. The review did not cover all these systems in detail. In the area of conventional beam diagnostics and their upgrades, the review team can make the following observations:

BPMs: According to Table 7.26 of the CDR, there are only 19 new BPMs required for the LINAC. However, we do know that new modules are required for the LCLS stripline BPMS in general. As pointed out in this review, no resources (manpower, dollars) are presently assigned to work on a new electronics design, which will require two calendar years; this includes the electromagnetic field analysis effort. We also note that the cavity BPMs (eight of which are required for the LINAC) also require a new module design (as well as a mechanical design); this is an ANL responsibility, but there is not yet a design effort for the module although there is a mechanical engineer assigned at ANL.

The connection between BPMs readout by the SLAC linac controls and the BPMs readout by the new EPIC control systems should be determined.

Both CAMAC and VME circuits need to be designed. A time and effort plan to do this work should be made.

Toroids: The LCLS requires toroid accuracy at the 1-3 % level. An accuracy better than 10 % for toroids is controversial. There is a component of the user community which does not believe that the present technology can meet this requirement. The LCLS team needs to find out if the present technology meets the LCLS needs or if a better design approach is necessary.

Profile Monitors: As the LCLS team states, careful optical and system engineering is needed. This effort cannot wait until late in the project schedule.

LLRF: The LCLS team proposes that the low level RF system be housed in a temperature controlled room to meet the LCLS requirements for temperature induced drifts. In order to maintain the temperature stability in transporting the signals to the klystron systems, LCLS proposes that the signal cables be routed down through a penetration into the LINAC tunnel, and then up through the appropriate penetrations to the klystron systems. The review team believes this is a poor idea, since anything in the LINAC tunnel has an access problem for maintenance. The LCLS team responded to this criticism by noting that cables are passive, and therefore require minimal maintenance. The review team wonders why not just use temperature controlled cable, which has a successful history here at SLAC.

The LCLS team discussed research efforts for a number of new and exciting diagnostic tools which will be necessary to achieve LCLS performance specifications. As the team noted, "[The] LINAC relies heavily on several new and complex bunch length and timing diagnostics. Development work on these has started at SPPS." There is a significant schedule risk associated with carrying these research efforts through a development phase to produce operational and maintainable diagnostics for the LCLS. The LCLS needs to manage that schedule risk at an acceptably low level by supporting the research and development efforts with the necessary resources (manpower, money, and time).

The number, location, and detailed specifications for all the instrumentation needed in the LCLS Linac should be tabulated.

Power Conversion:

The LCLS LINAC Power Supply Status Report (Linebarger, December 7, 2003) was reviewed. The list of power supplies looks in reasonable shape. This reviewer discussed the tables of power supplies with the PSOG Deputy (Craft) with responsibility for LINAC power supplies. In the footnotes to the list on page 7, which lists power supplies for the LINAC up to the undulator, it is pointed out that the list does not contain power supplies for corrector magnets (XCORs and YCORs). The LCLS team notes that this reflects a deliberate choice not to replace the present LINAC SCORs because they have been measured to meet the LCLS stability and accuracy requirements. However, the committee believes that these power supplies should be replaced with the newer MCORs because the SCORs are of a very old water cooled design which has become unreliable and a significant maintenance problem over the years. They are inadequate from the maintenance standpoint for the LCLS. We also note, as does the LCLS team, that the list of power supplies for the line from the undulator to the dump, on page 8, is incomplete.

Linac Component Specification:

The concept of a project database to collect, record, organize, and publish information was presented. Discussion was centered on the integration of component design requirements and CAD documentation, both released, and in progress. Sample input and reporting forms were presented.

The component database was presented as an interim tool until an LCLS project-wide database could be established. While use of the Linac component database *could* be extended to the entire project, this was not necessarily assumed to be the specific tool that the project would select.

Experience of the review team leads us to caution that the details of the implementation of this plan will be critical if the LCLS Linac project is to realize the potential benefits that such a database offers. Similar databases have been attempted at other projects at SLAC and elsewhere with varying results. Failure of individuals to comply with data entry requirements, or failure to complete component documentation in even a small number of instances, reduces the usefulness, and thus the acceptance, of the database. Also, appropriate resources must be assigned to the development and maintenance of the database and its associated tools.

Special attention must be given to the selection and documentation of nomenclature. The LCLS Linac group presented a plan that allows for multiple aliases for a single component. Their ideas concerning the naming conventions have covered Beam Modeling and Mechanical Design in some detail, but are less advanced in the area of Control Systems. There will need to be attention paid to the handling of SCP and EPICS naming, as these systems follow differing naming conventions.

As the LCLS Linac project involves the modification of beamlines within an existing facility, naming standards should be selected to follow the existing nomenclature as much as is possible. This should help with the integration of the LCLS into the existing operations and support efforts.

LI20 – LI30 Accelerator:

Conceptual plans for the Bunch Compressor 1 and Bunch Compressor 2 were presented. Specific descriptions of the work to be performed were discussed. The current design calls for a four dipole chicane at each location, complete with correcting quadrupoles and diagnostic devices. Two of the dipoles, and the diagnostic devices, will translate in the X-Z plane to permit straight ahead operation for (non-LCLS) programs where the bunch compression is not needed. To achieve success with the translating dipoles, attention to backlash/repeatability issues is crucial. The needed tolerances have been identified, but engineering effort will be needed to meet these tolerances.

LTU & Electron Beam Dump:

The current Linac To Undulator (LTU) design was presented. The design has evolved since CD1 to allow for up to 5 beamlines, although the initial phase of the project will include only one beamline. The beam optics for this area have been determined and preliminary layouts have been passed to Radiation Physics for comment. The initial device lists have been prepared.

Plans to dump the beam upstream of the undulator will need to involve Radiation Physics involvement. The suggested tunnel shielding of 70 inches of concrete will probably not be sufficient, by itself, to permit 120 Hz dumping of the beam in the tunnel. Local shielding at the dump, and any other points of continuous beam loss, will be needed.

The vacuum system has not had its components identified yet, although money has been budgeted to purchase vacuum components. The LCLS performance will be negatively impacted if pressure in this area rises above 1×10^{-7} torr. To achieve this pressure, attention to vacuum standards and procedures is needed. A “Vacuum Czar” should be designated; this person’s expertise could be used to good effect in the other LCLS areas outside of the LTU.

The alignment technology to be used in this area has not yet been selected. The LTU group has suggested that the initial device alignment should be good to the 50 μm level. Meeting this goal will require appropriate alignment technology and procedures.

Linac RF Systems:

The main drive-line will be used for the LCLS and for the high energy beam in the last third of the linac. A plan combining the two uses should be made.

Linac RF Waveguide and Structures:

The x-band RF accelerating section should be specified soon and ordered from the NLC group. These structures are long lead time items and these structures have to get “into the pipeline” in the NLC manufacturing chain.

Acknowledgments:

We wish to thank the LCLS linac group and SSRL for their hospitality during the review.

Appendix A:

Charge to the TDR LCLS Linac Review Committee

- The purpose of the Linac TDR is to carry out an integrated examination and assessment of the technical design of the LCLS Linac System. In carrying out its charge, the committee should review and evaluate the scope of the Linac System, in consideration of the following:
  - Do the performance specifications for the Linac provide an adequate basis for evaluation of the Linac design?
  - Is the Linac preliminary design adequate , including any specifications, to meet the LCLS performance functions and requirements?
  - Are all ES&H and technical requirements adequately addressed by the structures, systems and components incorporated into the Linac preliminary design?
  - Is the preliminary design of the Linac defined to the extent that its basis can be used to set the baseline cost and schedule, including contingency?
  - Is the Linac work scope organized logically such that its management team can successfully construct, install and commission its deliverables?

- We would like to get a short, concise report (2-3 pages) from the review team with a general assessment of technical maturity followed by recommendations and action items. The following format is proposed;
  - Section I. General assessment of the overall Linac scope and design maturity based upon the previous questions.
  - Section II. Bulleted sections
  - Comments
    - Cite any open design issues and/or missing components
    - Cite any areas of risk and/or any suggestions for follow-up R&D
    - Cite any potential conflicts with a shared use of the SLAC Accelerator and Controls.
  - Recommendations and/or Action Items
    - Cite any recommendations and/or action items that the committee feels should be addressed.
    - Cite any overly optimistic expectations or assumptions which require further investigation.

Appendix B: LCLS Linac Review Agenda

Friday, December 12, 2003: SLAC SSRL Building 137; 3rd Floor Conference Room

Overview

9:00 - 9:15	**Greetings & Welcome –** John Galayda
9:15 - 9:30	**Charge to the Committee –** Mark Reichanadter
9:30 – 10:00	Committee Executive Session

Linac Organization & Design

10:00 - 10:45	**Project Management –** Eric Bong
10:45 – 11:45	**Accelerator Design –** Paul Emma
11:45 – 12:15	**LSC/CSR Instabilities –** Zhirong Huang
12:15 - 1:00	***break for lunch***

System Control, Components & Engineering*

1:00 – 2:00	**Diagnostics & Controls –** Patrick Krejcik
2:00 – 2:20	**Component Specifications –** Carl Rago
2:20 – 2:40	**Linac Engineering –** Leif Eriksson
2:40 – 3:00	**LTU & Dumpline –** Tim Montagne
3:00 – 3:20	**RF Systems –** Peter McIntosh
3:20 – 3:40	**RF Waveguide & Structures –** Carl Rago
3:40 – 4:00	***break***
4:00 – 4:30	**Open discussion**
4:30 – 5:00	Committee meeting
5:00 – 5:30	**Committee Closeout**