11/5/2018

LEReC Laser Systems –Past Reviews and Recommendations

Contents:

DOE Review (Nov 4-5, 2015)

Executive Summary: "The effects of DC gun energy droop and drive laser jitter need further study."

Recommendations:

- "Generate a schedule, list of long-lead procurements, performance specifications for the drive laser and submit to the Office of Nuclear Physics (NP) by December 1, 2015. A detailed description of the laser system including a commissioning plan should be presented at the next review." *done*
- "At the next review: … Present refined tolerance requirements including the laser timing jitter and demonstrate that these requirements are achievable." *Tolerance (1 ps rms) presented in Apr, 2016 review by AP group,<200 fs rms measured (reference Dec, 2015 informal review) in 100 Hz-1 MHz range, later measurements over wider range (recommendation)**:** <500 fs rms in 1 Hz-10 MHz range.*

Technical status, findings: "The design of most subsystems is advanced and procurement of many of them has started. A few exceptions included: Details of several key subsystems, specifically the drive laser, transverse deflector cavity, and machine protection systems, were not presented."

Technical status, comments:

- "Early testing of critical components, such as the laser and the DC gun, at final performance levels should be accelerated when possible "

- "… In addition, drive laser jitter (pulse energy, arrival time at cathode, transverse and longitudinal profile) should be incorporated into the jitter/tolerance studies. The drive laser system uses the Cornell birefringent crystal pulse-stretching scheme. While successful in an experimental setting, when used in long-duration tests (e.g. at Thomas Jefferson National Accelerator Facility, or TJNAF) they have shown drift even in highly temperature stabilized environments. Operational requirements are needed."

Technical status, recommendations:

- "Generate a schedule, list of long-lead procurements, performance specifications for the drive laser and submit to the Office of Nuclear Physics (NP) by December 1, 2015. A detailed description of the laser system including a commissioning plan should be presented at the next review." *done*
- "At the next review … Present refined tolerance requirements including the laser timing jitter and demonstrate that these requirements are achievable." *Done. Tolerance (1 ps rms) presented in Apr, 2016 review by AP group,<200 fs rms measured (reference Dec, 2015 informal review) in 100 Hz-1 MHz range, later measurements over wider range (**recommendation):** <500 fs rms in 1 Hz-10 MHz range.*

Informal Review (Dec 16, 2015) with M. Shinn

Recommendations:

- "The oscillator has a spec of < 200fs which is very good. However, the bandwidth of the measurement was in the range 100Hz – 1MHz and my first suggestion is that the company be contacted to see if they can extend the measurement to at least 10Hz. The lower, the better." *Measurements performed in-house, rms phase jitter < 500 fs in 1 Hz – 10 MHz range (specification is 1 ps)*
- "What harmonic of the laser and master oscillator will be used for synchronization? The higher the better. Since there will be 3rd harmonic of the fundamental used to drive the energy compensation cavity, that would be the lowest harmonic to consider. *Initial commissioning performed with synchronization at 704 MHz (before multiplication for 3rd harmonic cavity frequency generation). Laser-to-rf phase stability shown to be within (1 ps rms) specification with this configuration.* Working with the laser oscillator company to have a "local/remote" capability to drive both the slow and fast length mirror is very important. *"Investigated. Manufacturer of local oscillator (Calmar) was non-responsive – not willing to collaborate on non mass-produced application nor share documentation of internal electronics. Spare unit procured and available for in-house modifications if needed.*
- "…the laser transport system can be copied over from … JLab, or possibly … something at C-AD or … NSLS-II" *Some (but not all) documentation received from JLab, no issues with the as-designed and installed laser transport.*
- "…the environment needs to be better defined to ensure 24/7 stability in phase…" *laser phase stability OK however incremental improvements to laser trailer environment (particularly humidity) have been made and continue to locally correct environmental effects on laser intensity*

(now controlled well within tolerance by feedback) and laser position stability (implementation of slow and fast feedback in progress)

- "mount a clear panel (polycarbonate works well) on a unistrut platform to serve as an air deflector" *oscillator shielded, drive laser components isolated / covered, some areas still open due to space constraints and ongoing testing of component spares*
- "…monitor the air temperature at the laser over the course of 24 hours, many times throughout the year to make sure the stability is better than 1°C (± 0.5°C)." *Temperature and humidity sensors added with continuous data logging, observe +/- 1° variations (winter), +/- 1.5° variations (summer). Have placed more concentration on humidity control and avoidance of thermal/humidity transients (upgrade to variable control AC unit underway).*
- "…mount an XYZ accelerometer on one of the laser components, perhaps the fiber laser rods, and again on a fold mirror, and measure the level of vibration as the HVAC cycles and then as it operates." *Not done (manpower limited). Laser position measurements indicate negligible correlation with temperature/humidity cycling.*
- "As a final suggestion … the milestones for the laser, shown in slide 33, should be incorporated into the schedule and tracked to make sure there is adequate float."

DOE Mini-Progress Review (Apr 11, 2016)

Executive Summary: "The specification and buildup of the drive laser since the last review is very impressive and to be commended, with good progress to date. The project team was advised to continue the strong effort on drive laser fabrication, installation, integration and testing as well as the incorporation of machine protection requirements into the system as appropriate."

Recommendations: "At the next review, provide expanded jitter simulations to model the drive laser arrival time jitter as a correlated phase shift across all radio frequency (RF) cavity phases." *Done, AP group.*

Technical Status, Findings: "Plans for incorporating the drive laser into the machine protection system have been initiated"

Comments:

- "The specification and buildup of the drive laser since the laser review is very impressive and to be commended, with good progress to date. Steady-state measurements are very encouraging. While there are some potential issues regarding switching to a "macropulse" mode of operation, the laser system seems to have enough overhead to minimize these concerns, and they will be explored over the next several months. The team should continue the strong effort on drive laser fabrication, installation, integration and testing."
- "The use of a pulse picker in the drive laser train … is an appropriate choice for a fast shut-off for machine protection. Given the laser trailer-to-tunnel transport line will be in vacuum, incorporation of a simple gate valve into the transport line would provide a second independent (if slower) protection methodology and is guaranteed to block all light to the photocathode. The team should continue incorporating machine protection requirements into the drive laser system, and other systems as appropriate (e.g. RF, magnets)."

- "Continue incorporating machine protection requirements into the drive laser system and other systems as appropriate as appropriate (e.g. RF, magnets)."

Recommendations: "At the next review, provide expanded jitter simulations to model the drive laser arrival time jitter as a correlated phase shift across all radio frequency (RF) cavity phases." *Done, AP group.*

DOE Review (Nov 16-17, 2016)

Executive Summary: "The laser system has been installed on a solid platform and is operational. Long duration testing of the laser stability is advised."

Recommendations: "Perform long-duration (multiple day) operational tests of the drive laser as soon as possible and prior to beam tests. (Report on progress in the monthly project phone calls with NP." *Drive laser running 24/7 starting in FY18. Long-term operational demonstration of entire laser system deferred to after development and installation of Laser Machine Protection System – Laser MPS (completed May, 2018, high reliability 24/7 operation started immediately thereafter).*

Technical status, findings: "As a response to the April 2016 review, simulations of the impact of the laser time jitter onto the electron beam momentum spread have been carried out and showed the appropriateness of the specifications. In addition, a lot of progress has been made with the laser system. Issues with vibrations of the building have been addressed by anchoring the laser table to a platform supported from the ground below the trailer. The drive laser system has advanced significantly since the last review. The laser proper is meeting most of its operational goals. The laser has not been subjected to test runs of more than several hours' duration; and the pulse shaping and transport systems have yet to be installed and tested."

Technical status, comments:

"The drive laser team has made excellent progress since the last review, and this is to be commended. While the laser system proper has demonstrated that it met the specifications, transport of the laser pulse to the gun cathode at interaction region (IR)-2 remains a challenge. In particular, there are questions about phase locking with the RHIC RF. *Phase locking with the LEReC RF systems was not required until FY18 and was commissioned on time with no issues.* Demonstrating extended operation of the laser (multi-day operation without intervention) in the near term prior to gun commissioning activities is extremely important." *Drive laser was running 24/7 starting in FY18. Long-term operational demonstration of entire laser system was deferred to after development and installation of Laser MPS (completed May, 2018, high reliability 24/7 operation started immediately thereafter) after which 24/7 beam operation was demonstrated with high reliability.*

- "Imaging the laser spot on the photocathode can be a very useful diagnostic. However, the LEReC laser system does not incorporate a virtual cathode, which has proven to provide complementary and highly useful information in other photoinjector systems. Incorporation of a virtual cathode in LEReC should be straightforward and can help to identify and address issues such as beam jitter, drive laser vignetting, etc." *implemented*

Technical status, recommendations: "Perform long-duration (multiple day) operational tests of the drive laser as soon as possible prior to beam tests." *Drive laser was running 24/7 starting in FY18. Long-term operational demonstration of entire laser system was deferred to after development and installation of Laser MPS (completed May, 2018, high reliability 24/7 operation started immediately thereafter) after which 24/7 beam operation was demonstrated with high reliability.*

Informal Review (Dec 16, 2016) with S. Zhang

Laser oscillator: "We recommend careful phase monitoring be performed continuously for at least 8 hours at different times. In case undesired phase drift over time does exist, which is quite likely, then the solution is to install an additional stabilizing control loop to adjust the EOM to keep the laser near optimal condition. While monitoring the phase, it is a good idea to check on the spectrum and pulse width to make sure they consistently meet the specs." *During the FY17-FY18 shutdown, environmental control in the laser trailer was improved and the S/N on the oscillator's input rf reference was improved resulting in no loss of oscillator mode-lock in FY18 during routine beam operations (with two minor exceptions: one related to clogged chiller water lines, one after installing additional dehumidifier in laser trailer)*

Amplifiers: "We recommend performance tests for at least 8 hours be conducted in the very beginning, including power, pointing and phase stability. Ideally, further extend the test to 24 hours, eventually to a few days to see the stability and the trending …, *24/7 laser system operation was deferred to after development and procurement of system spares and installation of Laser MPS (completed May, 2018). High reliability 24/7 operation started immediately thereafter.*

Such tests at various power levels are also very helpful in revealing the characteristics of the laser. *Long-term, steady-state laser operation under constant conditions is stable. Thermal lensing related issues (changes in beam profile and delivered intensity) revealed during LEReC beam commissioning involving large dynamic range in delivered laser power. Programmatic needs requiring variable laser power are being addressed (reference: presentation by P. Inacker).*

It is highly recommended environment temperature be concurrently recorded while taking other data such as power, phase and pointing, etc." *done*

Drive laser pulse control:

(a) "During the review, we found an important fail-safe protection on the pulse picker (pulse pick 1 in Fig. 3) between the oscillator and the high power amplifiers was not taken into consideration and imposes a threat to the system safety. It should be incorporated into the design as soon as possible…" *Incorporated in laser MPS (completed May, 2018).*

(b) Intensity control:

- "During the review, we found an important fail-safe protection on the pulse picker (pulse pick 1 in Fig. 3) between the oscillator and the high power." *Incorporated in laser MPS (completed May, 2018).*
- "Such concern also applies to other actively-controlled systems such as pointing-stability feedback systems." *Have designed-in exception-handling for laser position feedback systems.*

(c) Macro-pulse generation: "There appears to be conflicting requirements or limited functionality on the LEReC pulse (structure) control system design. We suggest to carefully review the requirement and design and make necessary modifications as needed." *All envisioned pulse structures demonstrated, new '76 kHz mode' in development (reference: presentation by G. Narayan)*

(d) Pockels cell and pulse contrast: "We recommend contrast measurement be taken near the beam entrance to the gun chamber to make sure the actual contrast meet the specs. *Pulse contrast measured directly using electron beam current measurement. Identified system latency (in Pockels cell driver) which translated into factor 3 higher specification on extinction ratio (300:1 versus 100:1) for 50 mA design electron beam current. Demonstrated >200:1 extinction ratio (sufficient for FY18 requiring demonstration of 30 mA beam operation. High power operation of Pockels cell found to degrade extinction ratio with time (from 1000+:1 to >200:1). Plan to replace with AOM.* It should be mentioned that the 10^6 design value is different from the concept of electron beam contrast. *Presently achieve (with shutter) 10^7:1*. If necessary, the pulse contrast enhancement system on JLAB/ERL/FEL drive laser maybe adopted to help mitigate possible "ghost pulses" interference with electron beam operation." *If required, would like to learn more about JLAB's pulse contrast enhancement system.*

Temporal and spatial shaping:

- "Careful and long-term (>8 hours) stability observation is recommended for temporal shaping when using multiple birefringent crystals which are sensitive to environment temperature variation. *These crystals have an influence on the spatial profile due to clipping and wave-front distortions due to inhomogeneity, but this does not change with the environment. Temporal shape changes are not expected due to environmental changes (mostly temperature). Time-shifts due to changes in refractive indices are on the order of femtoseconds for changes of a few degrees Celsius, which is not relevant for LEReC.*
- We have seen significant change over the pulse shape from shapers with the same technique. A thermally stabilized system maybe used and will be very helpful, but also add in great complexity. It is also worth mentioning that some balance may be needed in order to maintain the pulse flatness when transporting the shaped pulse over a long distance through many optics with polarization-dependent reflectivity. Significant modulation on the top of the pulse is expected but may not be a great concern for LEReC operation. *Specification is +/-20% modulation after pulse shaping which has been demonstrated however online measurements are not available.* If available, a fast streak camera should be used and will be a better temporal diagnostic instrument to characterize the shaped pulses." *BNL does not own a streak camera with <ps resolution. An alternative diagnostic approach is under development (reference: presentation by P. Inacker)*
- "In regard to spatial shaping, although there are many options available, we recommend special care be taken when picking up the commercial beam shapers. A carefully designed hard aperture would work just fine under many circumstances (most likely truce for LEReC) while eliminating the headaches from the commercial beam shapers which show very high degree of sensitivity to the beam size and alignment." *Commercial beam shapers cannot provide the versatility and reliability required by the program. The implemented truncated Gaussian with multiple apertures in a filter wheel is the most reliable and versatile solution.*

Optical transport and virtual cathode camera: "The infrastructure and floor foundation for the optical transport seems very good. There are sections of free-space that may need enclosure to minimize interference from surrounding environment. More work is needed on the optical diagnostics on the laser table near the gun chamber, to make the power measurement and observation of laser beam spot on cathode easier if dynamic range of the system can be extended by using combination of motor-controlled variable attenuators. It should be mentioned good attenuation can also be provided electronically by adjustment of the gain on many cameras. The virtue cathode camera is an important tool the accelerator operators will have to rely on for laser beam alignment and electron beam-tuning." *All implemented*.

Off-center on cathode beam operation: "The center of the photo-cathodes is the most vulnerable area that damage happens due to the ion back bombardment. The laser spot on the cathode should be off the center by approximately one beam diameter to keep the active photo-emission area to from the ion damage and for long operation life time. *Implemented late in FY18.* Damaged surface also tends to generate light scattering, raise the pressure in the gun and trip off the gun. The beam exiting the gun chamber shall be properly terminated and shielded. Stray light must be minimized around the windows/viewports." *Improvements (shielding against stray light) underway.*

Other: "A phase detector is recommended to be setup near the optical table near the beam entrance to the gun." *done*

DOE Review (Nov 14-15, 2017)

Executive Summary:

- "Considerable progress has been made with the laser system but it is not quite ready for continuous high power operation. The efficiency of conversion of infrared to green light is noteworthy."
- "A number of issues need to be resolved on schedule, and the size of the team which also has other systems to manage, is a concern."
- "Four of five recommendations from the previous review have been met. Some progress has been made toward the remaining recommendation to carry out long duration operation tests with the laser but has still not been met. The recommendation is reiterated in this review."

Recommendations:

- "Test longitudinal pulse shaping with the original crystal configuration but a larger diameter beam, to facilitate early down-select between options for addressing thermal lensing and related issues. Report outcome of measurements and decision to NP by January 5, 2018. (received)"
- "Perform long-duration (multiple day) operational tests of the drive laser as soon as possible and prior to beam tests. Report progress during monthly phone calls with NP." *Drive laser was running 24/7 starting in FY18. 24/7 operation of entire laser system was not possible (as proof-of-principle) during 2017-2018 shutdown due to LEReC installation work (for which laser transport pipes were removed). During 2018 beam commissioning, 24/7 laser system operation was deferred to after development and installation of Laser MPS (completed May, 2018, high reliability 24/7 operation started immediately thereafter) after which 24/7 beam operation was demonstrated with high reliability.*

Technical status, findings:

- "The laser system was commissioned in a burst mode. Operating at high-power with an optimum drive laser pulse profile was reported to be problematic and attributed to issues with the pulse stretcher (e.g. thermal lensing). A long-duration (multiple day) test of drive laser operation has not been performed since the last review. The IR-to-green conversion in the laser system has demonstrated up to 70% conversion efficiency. There is currently no connection between fire detection in the laser trailer, and laser interlocks"

Technical status, comments:

- "Upgrading the gun beam dump from 10 kW to the full power capacity of the gun plus SRF booster cavity would allow the 'front end' of LEReC to be exercised at full power for extended periods of time; e.g. for cathode lifetime testing, extended test runs of the gun and drive laser systems, etc."
- "The panel supports the installation of a multi-beamlet laser mask for beam diagnostics purposes."
- "The laser system made a lot of progress during last year commissioning at low duty factor but is not quite ready for the high-power CW operation and requires some modifications to make it work. Although the laser system is progressing well, several critical active feedback systems (e.g. laser pointing / positioning stabilization) have yet to be implemented. The measurements on short-term drive laser jitter appear very good on the gun table. There are several options for addressing the photocathode drive laser longitudinal pulse shaper concerns, including a hybrid interferometer/crystal stretcher, ad a larger spot size with temperature stabilized crystals. The project team appears to be confident that these issues will be resolved on schedule. The 70% conversion of infrared laser power to green is commendable and noteworthy performance."

Technical status, recommendations

- "Test longitudinal pulse shaping with the original crystal configuration but a larger diameter beam, to facilitate early down-select between options for addressing thermal lensing and related issues. Report outcome of measurements and decision to NP by January 5, 2018. *done*

Management and ES&H, Comments:

- "Recommendation R1 (Perform long-duration (multiple day) operational tests of the drive laser as soon as possible and prior to beam tests) was partially met (operation during shifts up to 12 hours). A plan was presented for the activities that would permit multi-day laser operation." *Drive laser was running 24/7 starting in FY18. 24/7 operation of entire laser system was not possible (as proof-of-principle) during 2017-2018 shutdown due to LEReC installation work (for which laser transport pipes were removed). During 2018 beam commissioning, 24/7 laser system operation was deferred to after development and installation of Laser MPS (completed May, 2018, high reliability 24/7 operation started immediately thereafter) after which 24/7 beam operation was demonstrated with high reliability.*
- "The panel advises that the team should connect the fire detection system in the trailer to the laser interlock, such that a fire detection event shuts down the laser." *done*

Management and ES&H, recommendations: “Perform long-duration (multiple day) operational tests of the drive laser as soon as possible and prior to beam tests. Report progress during monthly phone calls with NP.” *Drive laser was running 24/7 starting in FY18. 24/7 operation of entire laser system was not possible (as proof-of-principle) during 2017-2018 shutdown due to LEReC installation work (for which laser transport pipes were removed). During 2018 beam commissioning, 24/7 laser system operation was deferred to after development and installation of Laser MPS (completed May, 2018, high reliability 24/7 operation started immediately thereafter) after which 24/7 beam operation was demonstrated with high reliability.*