

SPEAR3 Project

The SPEAR3 Upgrade Project, jointly funded by the DOE/BES and the NIH, was completed on time and within budget. The project completely replaced the 30-year-old SPEAR electron storage ring originally designed for colliding beam physics with a modern, low-emittance, high current machine. The old machine was removed, a new stable concrete floor was poured, and new magnets, vacuum chambers, rf system, power supplies, beam instrumentation and controls were installed in a notably short 7-month shut-down period that ended in mid-November, 2004.

Beam commissioning began in early December and first beam was stored several days later. Machine operation development and performance optimization continued until early March, when first beam was delivered to users. Accelerator physicists and engineers from several domestic and international light sources participated in the commissioning effort. The beam current during the first phase of SPEAR3 operation is limited to 100 mA while beam lines are being upgraded for higher current operation, scheduled to begin in FY2006. The 3-GeV SPEAR3 light source operating at 500 mA will produce X-ray beams having 1 to 2 orders of magnitude higher brightness than the old machine, enabling enhanced X-ray science capabilities comparable to those for other 3rd generation synchrotron radiation sources.

Progress in FY2004

Accelerator Improvements

The accelerator improvements in FY2004, and the plan for FY2005 and FY2006, reflect the advent of operation of the new SPEAR3 storage ring at 100 mA in FYs 2004 and 2005 and the migration to higher current operation in FY2006 and beyond. The SPEAR3 accelerator program in 2004 was aimed at the high performance of the facility until it would be replaced by SPEAR3, and at the same time prepare the ground for the SPEAR3 operation. The injector underwent a program of improvements that made it more robust and reliable in view of the more demanding SPEAR3 requirements. Such improvements led to a considerably more reliable operation during the user run.

Injector – Work continued in FY2004 to improve the reliability and operation of injector at 3 GeV. A system that digitizes and records the beam injected and ramped in the booster was completed. The White circuit cell tune monitoring system will be based on the technology used for this system.

Turn-Turn Beam Position Monitors (BPMs) – Commissioning of the turn-turn BPM system continued in FY2004. The data acquisition software residing in EPICS IOCs was been completed and tested. Work continued on software for continuous high-bandwidth data acquisition. Digital receiver modules were tested and sent back to the manufacturer for firmware upgrades.

Synchrotron Light Monitor (SLM) – The design and fabrication of the cold finger and M₀ mirror vacuum chamber assemblies and the first phase radiation shielding was completed and these components were installed in the ring tunnel. The rough vacuum components and optical elements for the optics room were also completed and installed. The system will be connected to the SPEAR vacuum chamber in the FY2005 shutdown and commissioned at the beginning of the FY2006 user run. Work was done on the BL2 X-ray pinhole camera to provide a beam profile image in the SPEAR control room.

Beam Scrapers – Low-impedance horizontal and vertical beam scraper modules for the SPEAR3 vacuum chamber were designed, fabricated and installed. The scrapers will enable studies of beam size, lifetime, injection apertures, and minimum apertures for future insertion devices.

500 mA Shielding – Additional localized shielding in the ring tunnel needed for higher current injection and 500-mA stored beam operation was installed during the ring shutdown period in August and September 2004.

LION Development – Significant progress was made in developing processing electronics for the Long Ion Chamber (LION) system required for the Beam Containment System before the injection beam

current limit can be raised to that commensurate with 500-mA operation. The processing system is relatively complex, requiring extremely sensitive detection electronics having a large dynamic range that is capable of extracting a small injected beam signal out of a large background signal associated with the stored beam. The LION system is scheduled for completion in FY2005.

High-Current SPEAR Tests – SSRL received authorization from the DOE Site Office to conduct 3 special 8-h shifts of SPEAR operation with currents above the official safety envelope value of 100 mA. These high-current test shifts took place on swing shifts with the experimental floor cleared of non-radiation workers. The main purpose of these tests was to determine if multi-bunch beam instabilities will be encountered at higher current operation, in which case a program to implement a costly multi-bunch feedback system would have to be launched. Other potential problems, primarily excessive component heating, are also of concern.

The current reached in these tests was limited to 225 mA by the power rating of some absorbers in a legacy insertion device chamber. This current was reached and a comprehensive search revealed no apparent beam instabilities. The temperature of absorbers near unused dipole beam line exit ports increased significantly, but it was later determined that this heating is tolerable and could be reduced if desired with the simple addition of cooling tubes near the exit ports.

Orbit Control – Work began on the implementation of fast orbit feedback based on the combination of multiplexed and turn-turn BPMs. The development of high speed data transmission and processing hardware, real-time control programs, system application programs and additional orbit monitoring and control hardware needed for fast orbit feedback commenced.

Control System and Application Programs – Work is continued through FY2004 to extend and refine the functionality of the control system by adding more sophisticated control and application programs. Programs have been developed for automatic bucket-filling, TSP flashing, accumulated beam monitoring, temperature monitoring from over 600 thermocouples, Orbit Interlock steering verification, kicker bump compensation, orbit feedback with photon beam position monitors, and many more. A new program was added for booster current monitoring.

SPEAR3 Performance and Lattice Upgrades – The accelerator physics and engineering groups continued to study and tune the SPEAR3 accelerator to maximize its performance and stability. Vertical coupling was reduced to the order of 0.1%, producing brighter beams for users. The compensation of skew quadrupole gradients introduced by the BL 5 Elliptically Polarizing Undulator (EPU) was studied and the design of a correction scheme was proposed.

A major study was conducted to identify potential lattice modifications that will enable smaller gap insertion devices (IDs), including the in-vacuum undulator proposed for the new BL 12. The “double waist chicane” optics, which accommodates two small-gap IDs in the east long straight section and reduces the vertical beam size in the four matching cell straight sections (one of which will accommodate the BL13 EPU), was selected and studied in detail. A successful configuration having good dynamic aperture was found and approved for implementation by an external review committee.

Gun Test Facility – Important progress was made in understanding the sources of excessive electron beam emittance from a high-charge photo-cathode gun to be used for the LCLS. Slice emittance measurements determined that most of the increase in projected emittance over slice emittance is due to beam slice offsets and not phase space misalignments, as previously thought. This indicated the presence of a time dependent kick that significantly increases the projected emittance in photocathode rf guns. This discovery sets the path for reducing the projected emittance by determining the source of the time-dependent kick and eliminating it, the next major goal for the GTF.

A scheme to shape the rf pulse driving the gun to reduce the thermal load was tested on the GTF gun. The work will aid in reducing the thermal load for the LCLS rf gun which operates at 120 Hz and with 12 times the load of the GTF gun.

Anticipated Progress in FY2005

Accelerator Improvements

Injector – Work to improve the reliability and operation of injector at 3 GeV is continuing in FY2005. The low level rf control system has been tuned to maximize booster ramping efficiency for all bucket timings. Work to characterize gun and linac beam instabilities and to implement a feedback circuit to stabilize the booster White Circuit has begun as part of the work required to implement top-up injection (see below). The Accelerator Physics and Engineering groups will continue to study injector performance and limitations and formulate improvement plans.

Turn-Turn Beam Position Monitors (BPMs) – Commissioning of the turn-turn BPM system is continuing in FY2005. The primary remaining effort for the turn-turn BPM processor project includes verification of signal quality, power levels, timing, noise rejection, signal integrity, and completion of the data communication and software systems. Test tone couplers have been installed around the SPEAR ring and development of test tone processing, which will maintain parallel processing channel gain equalization is in progress. Software tasks include completion of the data acquisition and position-computing programs and integrating the turn-turn BPMs into the orbit feedback system. More digital receiver modules have been sent back to the manufacturer for firmware upgrades.

Synchrotron Light Monitor (SLM) – The work remaining to complete the SLM includes: 1) finalizing the radiation shielding design, obtaining radiation protection system approval from the SLAC Radiation Safety Committee and installing the remaining protection components, and 2) connecting the SLM beam line to the SPEAR vacuum chamber. These activities are scheduled for completion by October 2005, with SLM commissioning at the beginning of the FY2006 user run. Work continues to characterize and improve the BL2 pinhole camera system.

Beam Scrapers – The horizontal and vertical beam scrapers have been commissioned and used to characterize beam lifetime, injection apertures, and minimum apertures for future insertion devices. Studies are continuing to improve radiation shielding for these devices. The scrapers will continue to be a valuable diagnostic for beam size, lifetime and aperture studies.

LION Development – The development of the processing electronics for the Long Ion Chamber (LION) system continues and is anticipated to be complete during the FY2005 user run. Tests are being conducted to determine the optimal location of the LION cables in the SPEAR tunnel, and the processing electronics are being refined for best performance. The LION system must be connected to the Beam Containment System before the injection beam current limit can be raised to that commensurate with 500-mA operation.

Transverse Kickers – Work will begin on the design of horizontal and vertical stripline kickers for the storage ring. The kickers will be used to excite transverse beam oscillations for beam studies, and can be used in a transverse multi-bunch feedback system at higher currents if necessary.

High-Current SPEAR Tests – More high-current test shifts are planned for SPEAR in FY2006 after the remaining shielding for 500-mA operation is installed and the SPEAR3 Final Safety Assessment Document has been revised to raise the operational safety envelope from 105 mA to ~520 mA. The tests will take place with beam lines closed during special machine study shifts beginning in late May, 2005. The main purpose of these tests is to determine if multi-bunch beam instabilities or excessive component heating will be encountered at higher current operation, in which case a mitigation program will have to be initiated and completed before beam current above the problem threshold can be delivered routinely to users.

Orbit Control – Work will continue on the fast orbit feedback system, first by commissioning a system using only the 54 Bergoz averaged-orbit BPMs, then by adding the turn-turn BPMs operating in averaged-orbit mode. The frequency response of each corrector magnet together with its associated

vacuum chamber must be matched with those of all other feedback correctors over a bandwidth of ~100 Hz. The SVD-derived inverse matrix will be optimized for best performance, as will the digital filters used to tailor the system time and frequency responses. Work will continue for the rest of the year to provide an operator interface and data acquisition applications for the new fast orbit feedback system.

Double Waist Chicane Lattice – Tracking studies, frequency map analyses and the consequent optics optimization of the double waist chicane lattice continue in FY2005. Magnet families and properties, power supply requirements and beam performance-related design requirements for the chicane vacuum chambers are all being specified by the Accelerator Physics group. A plan has been initiated to install the principal optics components (quadrupoles and power supplies) without the chicane in the FY2005 shutdown so that the optics can be tested and optimized during the FY2006 run, in advance of the actual BL12 in-vacuum undulator and BL13 Elliptically Polarizing Undulator (EPU) beam line commissionings in FY2007.

Top-Off Injection – The design of the system needed for top-off injection with beam line stoppers open will begin in FY2005. This injection mode, with minimal interruption to users, will enable more frequent beam injection to limit beam current variation, minimizing the variation of thermal power on beam line optical components and improving beam stability for users. Work will begin to implement a booster power supply control system that will permit quick turn-on and off the booster beam to avoid continual operation of the power-consuming booster. Design will begin on an improved booster-to-SPEAR (BTS) transport line that eliminates several vacuum windows that spoil injected beam emittance. An extensive study of beam loss modes will be initiated to determine what radiation safety components will be required to inject beam into SPEAR with open beam line radiation stoppers. Significant changes to the Personnel Protection System, including the Septum Interlock, will be needed to implement the top-off system. This work will enable the first phase of top-off injection - a mode that will maintain beam current constancy in SPEAR to a few percent. A second phase of top-off development that would enable maintaining SPEAR beam current constancy to less than 1% will most likely require large-scale improvements to the electron gun and possibly to the booster. These changes will not commence until FY2007.

SPEAR3 Performance – The accelerator physics and engineering groups will continue to study and tune the SPEAR accelerator to maximize its performance and stability. With high current operation enabled by the new 500 mA shielding, further measurements of bunch instability modes will be conducted and feedback system requirements, if any, will be determined. Studies of the sources and cures of orbit instability will also continue. Work will continue to improve and expand the accelerator computer control system software and to upgrade hardware interface components as needed.

Gun Test Facility – The GTF will continue to operate in FY2005 in support of developments for the LCLS injector group. The emphasis will continue to be on improving electron beam quality especially correcting undesired effects such as the correlated energy spread and time dependent transverse kicks. New diagnostics will be tested and developed such as the electro-optic bunch length monitor. The GTF work group also will study and test rf effects such as multiple gun probes, rf pulse shaping, and timing jitter. Thermal emittance measurements on Cu and Mg cathodes will be performed. Several laser issues such as transverse laser shaping, temporal laser shaping, and stability improvement techniques will be tested. Alternate cathodes can also be installed and tested as needed to determine the maximum obtainable field, evaluate laser cleaning techniques, as well as measuring the cathode quantum efficiency and thermal emittance. The GTF also can be used to test alternate gun designs such as a multi-cell gun optimized for generating polarized electrons. An experiment in ultrafast electron diffraction (UED) is being planned in collaboration with Brown University.

Expected Progress in FY2006

Accelerator Improvements

Injector – In FY2006 the performance capabilities of the injector gun, linac, booster and transport lines will be well understood and the plan for improvements and/or new components needed for top-off injection will be pursued. These include rebuilding the BTS injection line and completing the improved

control of the booster power supply system. Potential large scale and costly upgrades to injector systems, including gun, are scheduled to commence in FY2007.

Turn-Turn Beam Position Monitors (BPMs) – The turn-turn BPM system will be fully commissioned in FY2006 and emphasis will be placed on refining control interface software for improved user friendliness. A decision will be made as to whether more turn-turn BPM processors will be procured.

Synchrotron Light Monitor (SLM) – The SLM will be commissioned at the beginning of the FY2006 user run. Visible and UV light will be brought to the SLM optics table in the SLM room and work will begin to measure beam properties using visible light and simple refractive optics. Beam size, bunch dimensions and multi-bunch stability properties will be measured using a gated CCD camera, streak camera, fast photodiodes and other optical components and instruments. The high-performance UV Cassegrain mirror system will be commissioned to measure small vertical beam size. Work will continue on improving the BL2 pinhole camera system and work will begin to develop a visible light interferometer to measure very small vertical beam size.

Transverse Kickers (and Feedback, if needed) – The fabrication and installation of horizontal and vertical stripline kickers for the storage ring will be completed in FY2006. RF power amplifiers and diagnostic/control circuitry for the kickers will be installed to enable beam dynamics studies. Work will begin on the design of a transverse feedback system using the kickers if high-current studies indicate that such a system is needed for stable high-current operation.

Orbit Control – Work will continue to maximize the performance of the fast orbit feedback system using a combination of the averaged-orbit Bergoz BPM processors and the turn-turn BPM processors operating in averaged-orbit mode. Two new Bergoz BPM processors will be installed in the BL 12 chicane and incorporated into the orbit feedback and orbit interlock systems during the FY2006 shutdown.

Double Waist Chicane Lattice – The double waist chicane lattice, without the chicane itself, will be tested and optimized during the FY2006 user run in preparation for commissioning the actual BL 12 in-vacuum undulator and BL 13 EPU beam lines in FY2007.

500 mA Operation – SPEAR operation at currents higher than 100 mA will continue to be tested throughout the FY2006 user run. Higher current will be delivered to users subject to beam line readiness, multibunch beam stability and operation scheduling that must accommodate beam lines that will not yet be ready for operation above 100 mA.

Top-Off Injection – Components and systems required to implement the first phase of top-off injection with beam stoppers open, as defined in the FY2005 design study, will be implemented and/or revised with the goal of conducting a test run in this mode before the end of the FY2006 user run. While the capability of operating in top-off injection mode will be demonstrated, it is expected that additional time will be needed before the beam line users will be sufficiently prepared to take routine data in this mode. A blanking signal will be provided to each user station that can be used to tag or inhibit data acquisition during the few-millisecond injection transient, but many of the data acquisition systems will need to be modified to make use of this signal. It is also expected that substantial upgrades to the injector gun and possibly to the booster (in FY2007 and FY2008) will be needed to proceed to a second phase of top-off that maintains higher beam current constancy in SPEAR.

SPEAR3 Performance and Controls – The accelerator physics and engineering groups will continue to study and tune the SPEAR3 accelerator to maximize its performance and stability at high current. Studies of the sources and cures of beam instability, including the possibility of needing a transverse feedback system, will also continue. Turn-turn BPMs, scrapers, the SLM and other beam diagnostics will be used for these studies.

Work will continue to improve and expand the accelerator computer control system software and to upgrade hardware interface components as needed. The performance of the orbit feedback system will be

continuously monitored and further developments will be pursued as needed to maximize beam stability for users. In addition, tests of a finite-dispersion version of the double waist chicane lattice will be conducted to see if the horizontal beam emittance can be reduced from 16 nm-rad to ~10 nm-rad without degrading beam performance.

Gun Test Facility – The GTF will continue to support rf laser cathode gun and short pulse instrumentation development for the LCLS in FY2006. An experiment in ultrafast electron diffraction (UED) will be conducted in collaboration with the Brown University. Other uses for the facility will be considered, including using the bright beam to develop a Far IR or THz radiation source. The beam at the GTF can be used to generate high peak power, short pulse THz radiation with the addition of a short wiggler.

Expected Progress in FY2007

Accelerator Improvements

Injector – Funding will be provided to upgrade gun, linac and booster components to improve the control and stability of the injector complex so that a higher level of beam current constancy in SPEAR can be maintained with top-off injection. It is expected that a new electron gun capable of producing 1-2 nC of beam charge per injection cycle will be installed. Injector control, instrumentation and power components will be improved to enable more refined control.

Synchrotron Light Monitor (SLM) – Work will continue to develop the diagnostic capabilities of the SLM using visible and UV synchrotron radiation. The visible light interferometer will be completed, enabling measurement of the 10-micron-level vertical electron beam size.

Transverse Kickers (and Feedback, if needed) – The transverse kicker system will be commissioned for beam dynamics studies. If necessary, work will continue on the design and implementation of a transverse feedback system using these kickers.

Double Waist Chicane Lattice – The double waist chicane, BL 12 and BL 13 components that will be installed in their final locations during the FY2006 shutdown will be commissioned at the beginning of the FY2007 user run. The lattice optics will be tuned for optimal performance.

500 mA Operation – It is expected that routine high-current operation for all users will commence in FY2007. The machine will be operated at as high a current as is possible, up to a maximum of 500 mA, while maintaining beam stability and sufficiently high performance in the beam lines. It is possible that a transverse feedback system might be needed above a certain high-current threshold, and exceeding that threshold will require completion of the feedback system.

Top-Off Injection – Work will begin to implement the second phase of top-off injection which will enable maintaining beam current constancy in SPEAR to less than 1% with minimal impact on user experiments. The success of this implementation will depend on the injector upgrade program discussed above.

SPEAR3 Performance and Controls – The accelerator physics and engineering groups will continue to study and tune the SPEAR3 accelerator to maximize its performance and stability at high current. Work will continue to improve and expand the accelerator computer control system software and to upgrade hardware interface components as needed.

Gun Test Facility – The GTF will continue to support rf laser cathode gun and short pulse instrumentation development for the LCLS in FY2006. An experiment in ultrafast electron diffraction (UED) will be conducted in collaboration with the Brown University. Other uses for the facility will be considered, including using the bright beam to develop a Far IR or THz radiation source.