1. ALS ACCELERATOR PHYSICS

Reported by David Robin, Group Leader

Late in 1997 the Advanced Light Source, a major user facility that had been designed, built, and operated under the leadership of AFRD, became a division of the Laboratory in its own right. AFRD maintains an extensive and formally defined relationship with the ALS, providing it with accelerator physics support both for day-to-day running and for enhancements. Development of user systems such as beamlines, the management and enhancement of the scientific program, support of the users, and (as of 1999) operation of the machine are among the responsibilities of the ALS Division.

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The mission of the ALS is to support the users in doing outstanding science. To achieve the goals of this mission, the ALS Accelerator Physics Group plays several important roles. The first is to make certain that the ALS *provides high-quality beam in a reliable manner* to users. The second is to strive to understand and continually *improve the performance* of the facility, keeping it at the forefront of synchrotron radiation sources. The third role is to *ensure that machine upgrades are implemented smoothly* with minimal adverse impact to users. The fourth is to *study potential upgrades* to the facility that will enhance the capabilities and capacities of the ALS. Finally, the accelerator physics group *supports other accelerator projects* both inside and out of the laboratory as well as non-accelerator projects at the ALS.

This past year, significant gains were realized in understanding the ALS storage ring and improving its performance. Additionally, a lot of effort was directed at future projects and upgrades of the facility, particularly for the generation of femtosecond x-rays, brightness increases, and far-infrared radiation.

Machine Upgrades

With regard to our first role—providing high-quality beam in a reliable manner to users— the ALS realized several improvements in operation as compared with the previous year. This was the first full year of operation with higher-order-mode (HOM) dampers in the RF system and vertical dispersion wave.

HOM Dampers

Installation of HOM dampers in the main and third harmonic cavities reduced the thresholds of couple bunch instabilities. Prior to the installation of the dampers, the driving terms of the HOMs were sufficiently large that if the beam were longitudinally unstable, it would be impossible to restabilize at large currents. A loss in longitudinal lock required approximately half an hour of downtime, during which the beam energy

was ramped down to the injection energy, the current scraped down, longitudinal lock recaptured, beam current refilled, and the beam energy ramped back to user energy. Loss of longitudinal lock was one of the major causes of beam loss for users. The HOMs damped the modes to such a level that the coupled bunch feedback systems could recapture longitudinal lock at full beam current. This meant that a loss in longitudinal lock did not result in a loss of beam time.

Vertical Beam Size Control

Another improvement in operation was in the manner that was used to control the vertical beam size. Prior to this year, the beam size was controlled by exciting a coupling resonance. This year the beam size was controlled by correcting the coupling and then using a vertical dispersion wave. This had several advantages. The first was that the vertical beam size was much less sensitive to changes in the coupling distribution in the ring. One important consequence of the reduced sensitivity was that, this past year. there was far less variation in the vertical beam size resulting from motion of the Elliptically Polarizing Undulators.

New Diagnostic Beamline

For the last two years a project has been ongoing to build a second ALS beamline, BL 7.2, completely dedicated to beam diagnostics. BL 7.2 was installed in August 2003 and successfully commissioned in September 2003. The design of the beamline is optimized for the simultaneous measurement of the momentum spread and emittance of the ALS beam in combination with the existing diagnostic beamline, BL 3.1. Before the operation of BL 7.2, the momentum spread, a fundamental parameter in a storage ring, was not directly measurable at the ALS. The analysis of the experimental error of the emittance-momentum spread measurement allowed the definition of the system parameters and the obtained requirements found the ideal match with a simple and reliable system based on an x-ray pinhole system. BL 7.2 also includes a second port for the visible and the infrared portion of the synchrotron radiation (SR) as well as an x-ray beam position monitor system. The design of the beamline is based on two similar diagnostic beamlines at BESSY II in Germany. This approach allowed a significant saving in time, cost and engineering effort.

Coherent IR as a Femtoslicing Diagnostic

This year a lot of work went into investigation of infrared radiation in the storage ring. One of the interesting outcomes was the generation of enhanced radiation during the femtosecond slicing experiment. When the femtosecond laser modulates the stored beam, a longitudinal density modulation was created that enhanced the emission of coherent infrared radiation. This radiation, which was measured at the infrared beamline, was used as an effective diagnostic for the femtosecond experiment. This diagnostic had many advantages compared to other diagnostics used to adjust and optimize the laser beam interaction. It is a sensitive, continuous, nondestructive diagnostic of the effectiveness of the slicing and was fundamental for the users of the femtoslicing beamline.

Planned Near-Term Upgrades

In May 2004, there is a plan to install additional dampers in the third-harmonic cavities. The goal of these dampers is to make the beam passively stable (no feedback systems required) at full beam current. If successful this will have several important advantages. First, the feedback systems themselves limit operation. They are not able to damp the beam over the full range of third harmonic cavity settings. In particular it is not possible to stably go to the maximum bunch lengthening mode. In addition, the beam should be more stable, as the feedback systems themselves introduce some beam noise.

During the same shutdown, a new wiggler, a W11, will be installed, replacing an older W16 wiggler. This new wiggler has two functions. If will be a source of hard x-ray radiation for three protein crystallography beamlines. In addition it will serve as the modulator for the femtosecond slicing experiment. The big advantage of W11 is the ability to serve both the femtosecond and protein crystallography communities simultaneously. This was not possible with W16.

There are also plans to install an in-vacuum undulator in the storage ring to act as the radiator for the femtoslicing experiment. This will be the first in-vacuum device installed in the storage ring and the vacuum gap is 5 mm. This is significantly smaller than the present minimum gap of 8.9mm. There was concern that this may impact the performance of the storage ring – primarily the lifetime and injection efficiency. The effect of the smaller gap on the performance of the ALS has been extensively modeled. In addition measurements have been performed using vertical scrapers to simulate the effect of the gaps. We found that with the vertical dispersion wave, the effect on the smaller gaps was not significant up to about 5 mm. This was not the case when the beam size was controlled by linear coupling, where the lifetime was strongly a function of the vertical gap size.

Future Upgrades

This past year a lot of thought has gone into upgrades for the facility. This was prompted by a Basic Energy Sciences Advisory Committee (BESAC) subcommittee's "Workshop on 20-Year Basic Energy Sciences Facilities Roadmap" that was held on February 22-24, 2003. The ALS presented plans at the workshop for upgrades of the storage ring as well as a new storage ring dedicated to far infrared radiation. The storage ring upgrades consisted of improvements in brightness.

The first step was to increase the time-averaged current by a factor of three. The plan was to go to a quasi-continuous injection scheme and increase current to 750 mA. In addition the brightness would be increased by operating with smaller vertical gaps. This would also increase the range of undulator radiation to higher energies. In addition the plan called for the replacement of the older full-length planar insertion devices by two half-length insertion devices with chicanes. This would increase the

capacity and productivity of the facility by having more "application specific" beamlines. The idea was the plan could be gradually implemented in typical annual shutdowns with minimal disruption for users.

The short-term upgrade plan is to operate with top-off injection at 500 mA. The idea behind top-off injection is to inject quasi-continuously in order to keep the beam current nearly constant. Top-off at 500 mA would double the time-averaged current. To operate with top-off injection, the booster injector energy has to be increased from 1.5 GeV to 1.9 GeV. Also, top-off operation requires that the beamline shutters remain open during injection. We have received some initial money this past year, which is being used to refine the scope of the top-off upgrade. The effort this year is concentrated in three areas.

1. A major part of the work is a study of the key injection components that must be upgraded.
2. A series of experiments were performed with various user groups to identify issues with top-off. Of particular concern was the injection process. which would perturb the beam current and beam orbit. We identified a few types of experiments (particularly microscopes with short integration times) where injection was not transparent, and we found gating schemes to mitigate the problem.
3. Finally, we are studying plans for modifications of the radiation protection system.

By the end of this year the scope of the upgrade will be well defined. The plan is to complete the upgrade by the end of FY07.

CIRCE: An LDRD Project Exploring a Far-IR Source

A new source for far infrared radiation was presented at the BESAC 20-year facilities workshop. This source, named CIRCE (for Coherent Infrared Center) would be a 66 m circumference ring located on top of the ALS booster synchrotron shielding tunnel and using the existing ALS injector.

CIRCE would be optimized for the generation of far infrared radiation, using a scheme where the new 66-m storage ring would be designed to take advantage of the synchrotron radiation to shape the pulse, providing stable far infrared radiation at a flux many orders of magnitude higher than conventional sources.

The idea was experimentally verified at BESSY-II. The effect of the synchrotron radiation impedance on the bunch distribution was first investigated by Murphy et al., and in the past two years scientists at LBNL and BESSY were able to expand upon the theory to quantitatively explain the BESSY results. The theory was used to design CIRCE to be fully optimized for the generation of far infrared radiation. These studies, together with engineering studies, were funded with strategic LDRD funds.

The BESAC subcommittee recommended that the DOE organize a national workshop to explore the scientific advantages of research with terahertz radiation at user facilities. This workshop was held in February 2004, sponsored by DOE (Office of Basic Energy Sciences), the National Institutes of Health, and the National Science Foundation. The CIRCE parameters were presented. The report of that workshop has not yet been released; its outcome will impact how aggressively we pursue the CIRCE proposal.

Non-ALS Accelerator Projects

In its final role, the group was effective in supporting non-ALS accelerator physics projects at the Laboratory. The group continues to be involved in the electron optics design of an aberration-corrected photoemission microscope (called PEEM-III), which is being built at the ALS. Several members of the group played major roles in LUX (see Chapter 2), primarily through injector and lattice studies. Members of the group helped with the understanding and optimization of the PEP-II storage ring optics. The group was involved in helping SSRL with the commissioning of the SPEAR-III storage ring. And, with LDRD funds, one of the group members worked on the design and feasibility of a neutral molecular storage ring to store and cool molecules that have a dipole moment.

Finally this past year the group was fortunate to have as a long-term visitor Prof. Harald Rose from Darmstadt Technical University, who is the world expert on charged particle optics for electron microscopes. The group already has extensive expertise with charged particle optics applied to accelerator physics and some experience with electron microscopes. With Prof. Rose's help, the intention is to broaden our expertise in charged particle optics to allow us to study problems in electron microscopy, streak cameras, spectrometers, and so on. His visit was funded on a regular LDRD. During the year Prof. Rose gave a lecture series on charged particle optics, particularly concentrating on Eikonal methods, that was attended by members of AFRD, ALS, Engineering and the Material Sciences Division.

Featured Publications

To give a fuller perspective on our activities, we chose the publications that best represent our accomplishments from the past year in support of the ALS. Clicking the link will bring up a copy, in PDF format, of the best form available to us.

J. M. Byrd, M. C. Martin, W. R. McKinney, D. V. Munson, H. Nishimura, D. S. Robin , F.Sannibale, R.D. Schlueter, W. G. Thur, J. Y. Jung, and W. Wan, "CIRCE: A Ring-based Source of Coherent Synchrotron Radiation," in *Proceedings* of the 2003 Synchrotron Radiation Instrumentation Conference (August 25-29, 2003, San Francisco, California), American Institute of Physics Conference Proceedings Vol. 75, No. 1.

W. Wan, J. Feng, H. A. Padmore and D. S. Robin, "Simulation of a mirror corrector for PEEM3," in *Proceedings* of the Sixth International Conference on Charged Particle Optics (Greenbelt, Maryland, October 21-25, 2003), *Nuclear Instruments and Methods in Physics Research* Section A, Volume 519, Nos. 1-2 (Feb. 2004), pp. 222-229.

Y.K. Wu, D.S. Robin, E. Forest, R. Schlueter, S. Andres, J. Feng, H.A. Padmore, D.H. Wei, "Design and analysis of beam separator magnets for 3rd generation aberration compensated PEEMs," in *Proceedings* of the Sixth International Conference on Charged Particle Optics (Greenbelt, Maryland, October 21-25, 2003), *Nuclear Instruments and Methods in Physics Research* Section A, Volume 519, Nos. 1-2 (Feb. 2004), pp. 230-241.

F. Sannibale, J. M. Byrd, A. Loftsdottir, M. C. Martin, M. Venturini (LBNL), "A model for producing stable, broadband terahertz coherent synchrotron radiation in storage rings," in *Proceedings* of the 2003 Particle Accelerator Conference (May 12-16, Portland, Oregon) .

Y. K. Wu, E. Forest, and D. S. Robin, "Explicit symplectic integrator for s-dependent static magnetic field," *Physical Review E* 68, 046502 (2003).

C. Steier, D. Robin, A. Wolski (LBNL), "Coupling correction and beam dynamics at ultralow vertical emittance in the ALS," in *Proceedings* of the 2003 Particle Accelerator Conference (May 12-16, Portland, Oregon).

Hiroshi Nishimura, Glen Lambertson, Juris G. Kalnins, and Harvey Gould, "Feasibility of a synchrotron storage ring for neutral polar molecules," *Review of Scientific Instruments*, 2003, Vol. 74, No. 7, pp. 3271-3278 (2003).

D. Robin (LBNL), "Superbend Upgrade at the Advanced Light Source," in *Proceedings* of the 2003 Particle Accelerator Conference (May 12-16, Portland, Oregon).

C. Steier, L. Nadolski, H. Nishimura, D. Robin, W. Wan, A. Zholents (LBNL), "Accelerator physics challenges of the fs-slicing upgrade at the ALS," in *Proceedings* of the 2003 Particle Accelerator Conference (May 12-16, Portland, Oregon).

D. Robin, C. Steier, W. Wan, A. Wolski (LBNL), "Impact of narrow gap undulators on the Advanced Light Source," in *Proceedings* of the 2003 Particle Accelerator Conference (May 12-16, Portland, Oregon).

Full Publications List

Publications from fiscal 2003 to date are listed here, organized by level of scholarly review.

Refereed Literature

Y. K. Wu, E. Forest, and D. S. Robin, "Explicit symplectic integrator for s-dependent static magnetic field," *Physical Review E* 68, 046502 (2003).

T. Houck and S. Lidia, "Beam dynamics experiments to study the suppression of transverse instabilities," *Physical Review Special Topics-Accelerators and Beams* 030101 (2003).

Hiroshi Nishimura, Glen Lambertson, Juris G. Kalnins, and Harvey Gould, "Feasibility of a synchrotron storage ring for neutral polar molecules," *Review of Scientific Instruments*, 2003, Vol. 74, No. 7, pp. 3271-3278 (2003).

H. Rose (LBNL), "Five-dimensional Hamiltonian-Jacobi approach to relativistic quantum mechanics," in *Advances In Imaging And Electron Physics* vol. 132, Academic Press (in press).

W. Wan, J. Feng, H. A. Padmore and D. S. Robin, "Simulation of a mirror corrector for PEEM3," *Nuclear Instruments and Methods in Physics Research* Section A 516, Feb. 2004.

Y.K. Wu, D.S. Robin, E. Forest, R. Schlueter, S. Andres, J. Feng, H.A. Padmore, D.H. Wei, "Design and analysis of beam separator magnets for 3rd generation aberration compensated PEEMs," *Nuclear Instruments and Methods in Physics Research* Section A 516, Feb. 2004.

J. M. Byrd, M. C. Martin, W. R. McKinney, D. V. Munson, H. Nishimura, D. S. Robin , F.Sannibale, R.D. Schlueter, W. G. Thur, J. Y. Jung, and W. Wan, "CIRCE: A Ring-based Source of Coherent Synchrotron Radiation," in *Proceedings* of the 2003 Synchrotron Radiation Instrumentation Conference (Amer. Inst. of Physics, in press).

J. Feng, A.A. MacDowell, R. Duarte, A. Doran, N. Kelez, M. Marcus, D. Munson, H. Padmore, K. Petermann, S. Raoux, D. Robin, A. Scholl, R.S chlueter, P. Schmid, J. Stöhr, W. Wan (LBNL), D.H. Wei (SRRC), Y.Wu (Duke), and E. Forest (KEK), "An Aberration Corrected Photoemission Electron Microscope at the Advanced Light Source," in *Proceedings* of the 2003 Synchrotron Radiation Instrumentation Conference (Amer. Inst. of Physics, in press).

F. Sannibale, J. M. Byrd, A. Loftsdottir, M. C. Martin, M. Venturini, "Fundamentals of Coherent Synchrotron Radiation in Storage Rings," in *Proceedings* of the 2003 Synchrotron Radiation Instrumentation Conference (Amer. Inst. of Physics, in press).

J. M. Byrd, M. C. Martin, W. R. McKinney, D. V. Munson, H. Nishimura, D. S. Robin , F. Sannibale, R.D. Schlueter, W. G. Thur, J. Y. Jung, and W. Wan (LBNL), "CIRCE: A Dedicated Storage Ring for Coherent THz Synchrotron Radiation," *Infrared Physics & Technology* (in press).

T. Scarvie et al. (LBNL), "Noise reduction efforts for the ALS infrared beamlines," *Infrared Physics & Technology* (in press).

Conference Proceedings and Other Unrefereed Publications

All are in* Proceedings *of the 2003 Particle Accelerator Conference (Portland, Oregon, May 12-16: http://accelconf.web.cern.ch/accelconf/p03/INDEX.HTM).

"Superbend Upgrade at the Advanced Light Source," D. Robin (LBNL).

"A recirculating linac-based facility for ultrafast x-ray science," J. Corlett, W.A. Barletta, S. De Santis, L. Doolittle, W. Fawley, M.A. Green, P. Heimann, S. Leone, D. Li, S.M. Lidia, A. Ratti, K. Robinson, R. Schoenlein, J. Staples, W. Wan, R.P. Wells, A. Wolski, A. Zholents (LBNL), M. Placidi (CERN), W. Pirkl (Consultant), S.-H. Wang (Indiana University), F. Parmigiani (Sincrotrone Trieste), R.A. Rimmer (Thomas Jefferson National Accelerator Facility).

"An injector for the proposed Berkeley Ultrafast X-Ray Light Source," S.M. Lidia, J. Corlett, J. Pusina, J. Staples, A. Zholents (LBNL).

"Emittance compensation studies of photoinjector beams with angular momentum," S.M. Lidia (LBNL).

"The LBNL Femtosource 10 kHz photoinjector ," J. Staples, S.M. Lidia, S. Virostek (LBNL), R.A. Rimmer (Thomas Jefferson National Accelerator Facility).

"Angular momentum measurement of the FNPL electron beam," Y. Sun, K.-J. Kim (University of Chicago), K. Desler, D. Edwards, H. Edwards, M. Hüening, P. Piot, J. Santucci (FNAL), S.-H. Wang (Indiana University), S.M. Lidia (LBNL), N. Barov, D. Mihalcea (Northern Illinois University), R. Tikhoplav (University of Rochester).

"Flat beam production in low energy injectors," S.-H. Wang (Indiana University), J. Corlett, S.M. Lidia, J. Staples, A. Zholents (LBNL).

"Recent improvements to the ASTRA particle tracking code," S.M. Lidia (LBNL), K. Floettmann (DESY), P. Piot (FNAL).

"Commissioning results of the fast orbit feedback at the ALS," C. Steier , A. Biocca, E. Domning, S. Jacobson, G. Portmann, T. Scarvie, E. Williams (LBNL).

"Coupling correction and beam dynamics at ultralow vertical emittance in the ALS," C. Steier, D. Robin, A. Wolski (LBNL).

"ID Modeling at the ALS," Weishi Wan, Hiroshi Nishimura, David Robin, Christoph Steier (LBNL), Ying Wu (Duke).

"Impact of narrow gap undulators on the Advanced Light Source," D. Robin, C. Steier, W. Wan, A. Wolski (LBNL).

"Noise reduction efforts for the infrared beamline at the Advanced Light Source," Tom Scarvie, Nord Andresen, Ken Baptiste, John Byrd, Mike Chin (LBNL).

"Single-particle beam dynamics in BOOMERANG," A. Jackson and H. Nishimura (LBNL.

"Cross platform SCA component using C++ Builder and Kylix," H. Nishimura, C. Timossi and J. L. McDonald (LBNL).

"Lattices for milli-eV neutral molecules," H. Nishimura, H. Gould, J. Kalnins, G. Lambertson (LBNL).

"Accelerator physics challenges of the fs-slicing upgrade at the ALS," C. Steier, L. Nadolski, H. Nishimura, D. Robin, W. Wan, A. Zholents (LBNL).

"A model for producing stable, broadband terahertz coherent synchrotron radiation in storage rings," F. Sannibale, J. M. Byrd, A. Loftsdottir, M. C. Martin, M. Venturini (LBNL).