Title
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Author
Jackson, A.

Publication Date
1995-09-18

LBL-37742
UC-410

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

Presented at Synchrotron Radiation Instrumentation 1995,
Argonne, IL, October 17–20, 1995, and to be published in
the Proceedings

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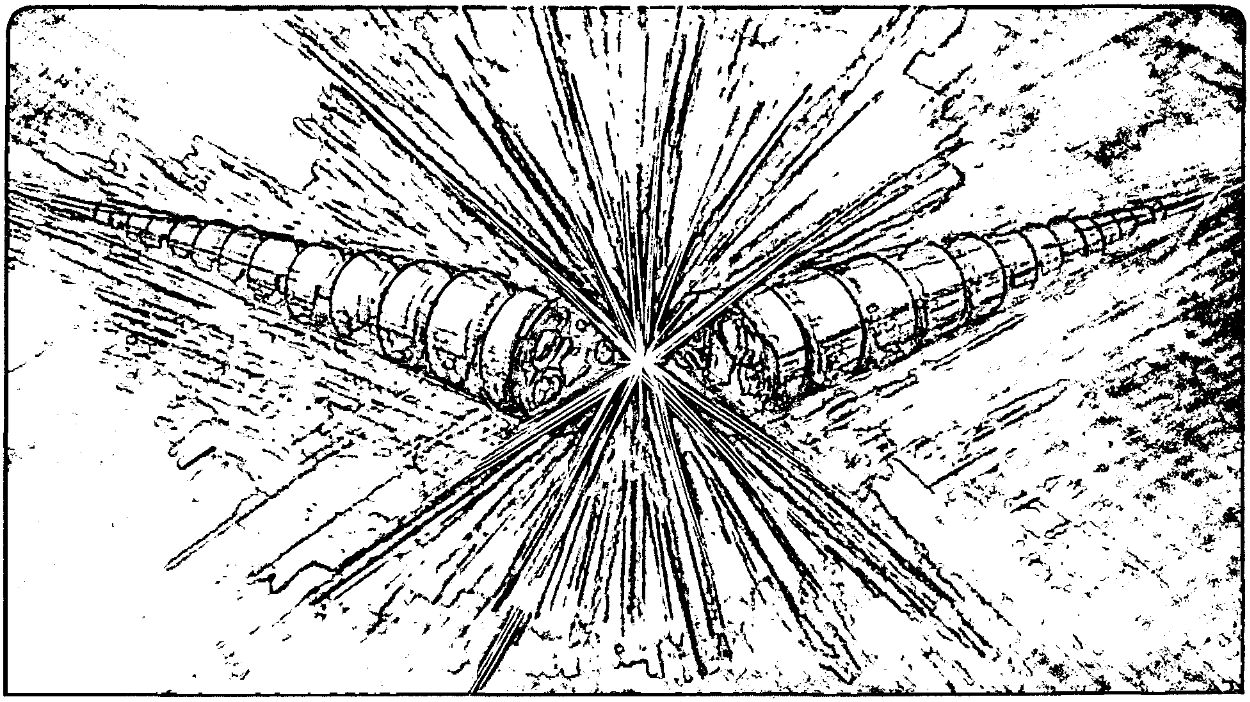

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL-37742

OPERATIONAL EXPERIENCES AT THE ADVANCED LIGHT SOURCE*

A. Jackson

Advanced Light Source
Accelerator and Fusion Research Division
Lawrence Berkeley National Laboratory
University of California
Berkeley, CA 94720

September 25, 1995

Paper Presented at the National Conference on Synchrotron Radiation Instrumentation 1995, October 17–20, 1995, Argonne National Laboratory

***This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098**

Operational experience at the Advanced Light Source

Alan Jackson
Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720

October 18, 1995

The Advanced Light Source (ALS) has been operational for users since October 1993 when white light from a bend magnet was delivered to the Center for X-Ray Optic's (CXRO) x-ray microprobe end-station. Since then, the ALS has installed and commissioned three undulators and their beamlines (including monochromators and post-monochromator focusing optics), and eight bend magnet beamlines, including one dedicated to machine diagnostics. Apart from one serious outage, when scheduled beam was not available to users for 17 days, the ALS has enjoyed remarkable operating statistics, with typically 95% of scheduled beam-time delivered to the users. Beam quality has also been very good. With a vertical emittance measured at 0.06 nm-rad, the electron beam is kept stable to about one-tenth of it's transverse dimensions, in the face of changing error fields in the insertion devices (as their main fields are varied), temperature variations and floor vibration. The longitudinal motion of the beam, which leads to an increase in the electron beam energy spread, and thence, to a degradation of the undulator spectra, has recently been brought under control by the addition of an innovative feedback system. This paper focuses on those aspects of electron beam stability that we find most affect the ALS users: beam size and position, and energy spread.

1. INTRODUCTION

Currently, the ALS has three undulators, four undulator-based beamlines and eight bend-magnet beamlines in operation, as indicated in TABLE I.

As well as running in the nominal 1.5 GeV multibunch mode, where the starting current is 400 mA, the ALS has also operated at 1.0 and 1.9 GeV, and with just two equally spaced bunches (starting current 20 mA/bunch) at all three energies. In multibunch mode the beam lifetime was typically 12 hours at 400 mA, and in two bunch mode this is reduced to about 2 hours at 20 mA/bunch due to the increase in Touschek scattering.

During normal operations the beam availability was typically 95%, as shown in Fig. 1. However, in April 1995 a problem occurred that kept the storage ring off the air for 17 days. The cause was eventually tracked down to a broken "finger" in the rf liner of a bellows assembly. The cause of the failure is still not known, but a new bellows assembly armed with diagnostic devices (E- and B-field rf probes and a viewing port for an infrared camera), was installed in the storage ring during the September/October shutdown.

From the earliest days of operation beam stability was a major concern of ALS users and, as is usual, a controversy developed as to whether the source (the electron beam) or something in the beamline was moving. The correct answer was not found until the end of 1994, after two new diagnostics were added to the storage ring. The first of these diagnostics was a new electron beam position monitor with a resolution of better than 1 micron and a frequency response from dc to a few hundred Hertz[1]. One of the first sets of data to be recorded using the new monitor is shown in Fig. 2. For the first time we were able to distinguish coherent beam jitter at the level of a few microns, and cyclic motion with periods of minutes, which in one case was correlated with temperature variations in the low-conductivity water (LCW) cooling system. The second diagnostic was a bend-magnet beamline (BL 3.1), dedicated to accelerator studies that gives a high resolution image of the electron beam with unity magnification[2]. In the remainder of this paper, we discuss the information on beam stability gathered from these and other diagnostics.

Table 1. Beamlines at the ALS.

Beamline	Source	Research	Energy Range
3.1	Bend magnet	Electron bean diagnostics	200–280 eV
6.1.2	Bend magnet	High-resolution zone-plate microscopy	250–600 eV
6.3.1	Bend magnet	Calibration and standards, EUV optics testing	500 eV–4 keV
6.3.2	Bend magnet	Calibration and standards, EUV optics testing	50–1000 eV
7.0.1	U5 undulator	Surface and mateials science, spectromicroscopy	60–1000 eV
8.0	U5 undulator	Surface and materials science	70–1200 eV
9.0.1	U8 undulator	Atomic and molecular science	20–310 eV
9.0.2	U8 undulator	Chemical dynamics	5–30 eV
9.3.1	Bend magnet	Atomic and molecular science, materials science	700 eV–6 keV
9.3.2	Bend magnet	Chemical and materials science	30–1500 eV
10.3.1	Bend magnet	Fluorescence x-ray microprobe	3–12 keV
10.3.2	Bend magnet	Deep-etch x-ray lithography (LIGA), surface analysis (TXRF)	3–12 keV

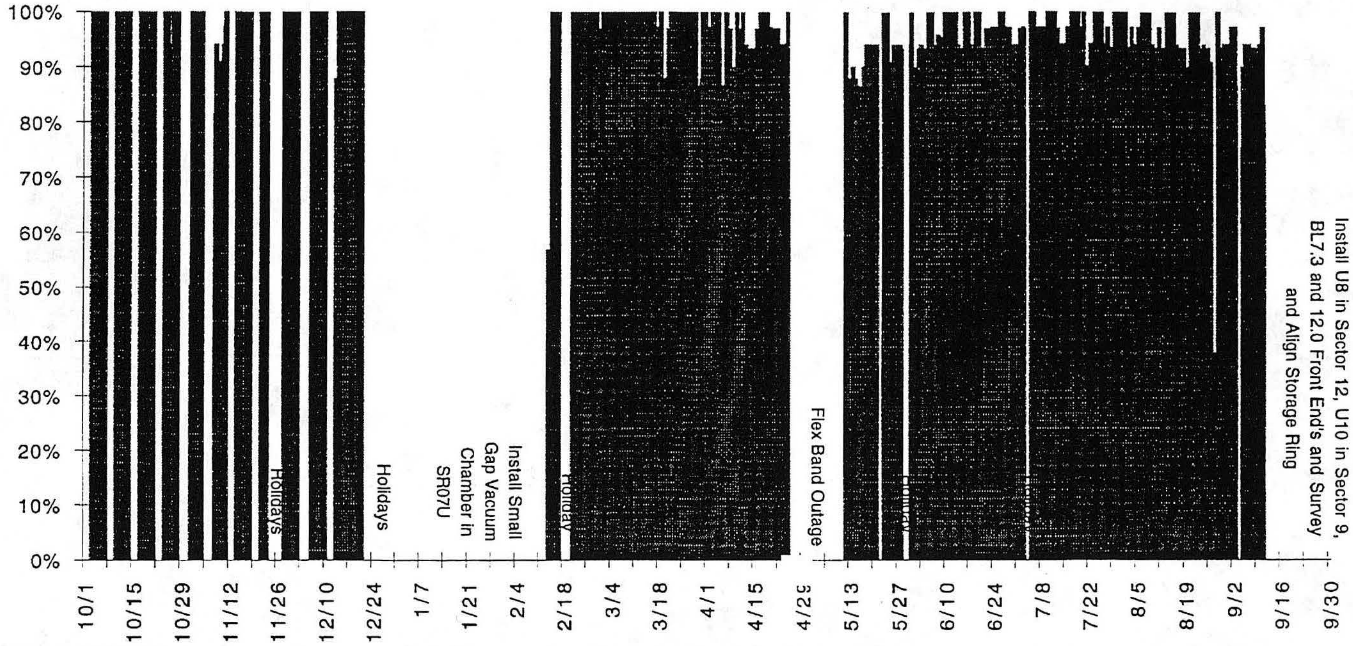

FIG. 1. FY'95 Operations. Beam availability as a fraction of scheduled beam time.

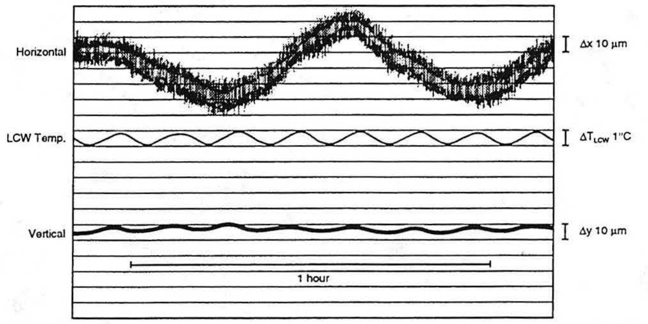

FIG 2. Electron beam motion measured in straight section 4, and LCW temperature. A strong correlation is seen between the vertical beam motion and the LCW temperature.

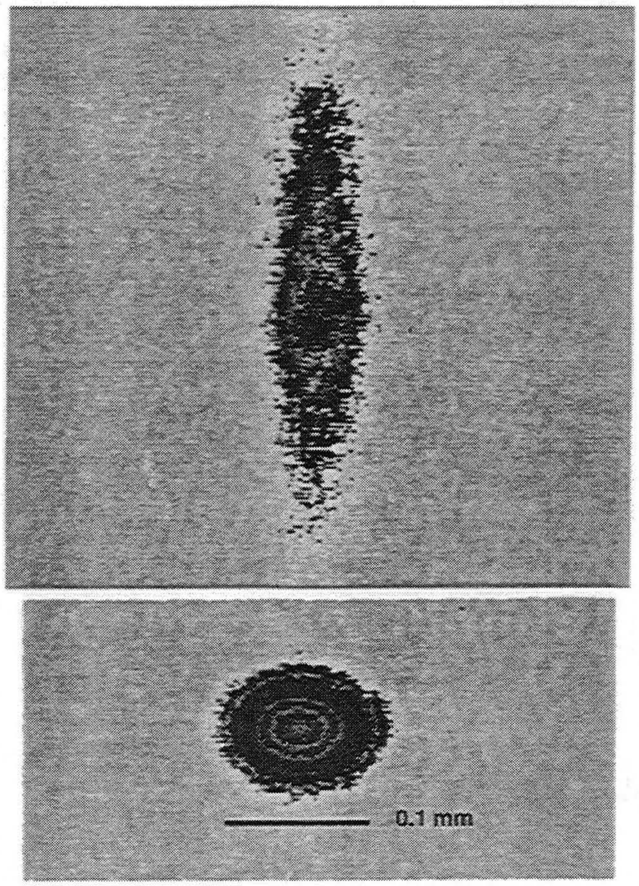

FIG 3. Vertical beam blow-up caused by the transverse coupled-bunch instability. The lower picture shows the instability suppressed by feedback.

2. COUPLED-BUNCH INSTABILITIES

The fastest beam motion in the ALS electron beam results from interactions between the 320 electron bunches in the form of so-called coupled-bunch instabilities. These beam oscillations occur at sub-harmonics of the synchrotron and betatron frequencies and are seen by the users at frequencies of tens to hundreds of kilo-Hertz, i.e., far too fast for most experiments to notice. The result of these instabilities, as far as the user is concerned, is a reduction in photon beam brightness, particularly from undulators.

Transverse coupled-bunch instabilities lead directly to an increase in the transverse emittances. The instability is mediated through the impedance of the vacuum vessel, which in the case of the ALS is larger in the vertical plane because of the narrow vertical gaps in the undulator vacuum vessels. Fig. 3 shows the increase in vertical beam size observed in BL 3.1 when the vertical coupled-bunch instability is active.

The longitudinal coupled-bunch instability generates a beam energy oscillation and, through phase mixing, leads to an increase in the energy spread. In the ALS we observe the relative energy spread, σ_E/E, increase from it's expected value of 8 x 10^{-4} to 3.2 x 10^{-3}, i.e., an increase of a factor of 4. For bend-magnet beamlines, this manifests itself in an increase in the horizontal beam-size through the equation

$$\sigma_X = \mathrm{sqrt}[\beta\varepsilon + (\eta\ \sigma_E/E)^2]$$

where σ is the beam-size, β is the amplitude function, ε is the beam emittance, and η is the dispersion function (which is finite at all the bend magnet source points).

For undulator beamlines the result is spectral line-width broadening:

$$\delta\lambda/\lambda = 2\sigma_E/E.$$

In the U5 devices (which have 89 periods) the natural line-width is 0.48% RMS, to be compared with line broadening due to energy oscillations of 0.64%.

The solution to coupled-bunch instabilities is feedback. In the ALS this has been implemented through a novel system that observes the motion of each bunch individually, on a turn-by-turn basis, and gives an appropriate feedback kick through special broad band electrodes. The systems are described in detail in references 3 and 4.

With all feedback systems operational the ALS beam parameters have been measured to be:

$$\sigma_X = 4 \times 10^{-9} \text{ m-rad}$$
$$\sigma_y \leq 1 \times 10^{-10} \text{ m-rad}$$
$$\sigma_E/E = 8 \times 10^{-4}$$

3. BEAM JITTER

Beam jitter is that motion of the beam that can be observed with the naked eye (or other instrumentation!), i.e., motion that has frequencies from a few to a few tens of Hertz. It is particularly worrisome to the experimenters since this period is in the range of typical instrument integration times and therefore it contributes directly to "noisy" data. The main causes of beam jitter are floor vibration and acoustic "noise" in cooling water circuits from air bubbles and turbulence. In the ALS the dominant perturbation is floor motion transmitted to the storage ring magnets at a frequency of around 14 Hz, through a torsional mode of the ALS girder/magnet assembly. The electron beam motion, measured at the end of a straight section (see Fig. 2), is 20 μm peak-to peak in the horizontal plane and 4 μm peak-to-peak in the vertical (to be compared with beam sizes at this point of 220 μm RMS x 25 μm RMS). The resulting increases in beam emittances are negligible.

Beam motion at harmonics of the electrical power system (as has been observed at other facilities), is at least an order of magnitude smaller than the effects described above.

4. BEAM DRIFT

Beam drift describes the motion of the electron beam measured in seconds through hours (or the length of a typical fill) – times that are usually much longer than experimental integrating times. At the ALS its causes are associated with undulator gap changes, and temperature changes in large mass systems such as air temperature and the temperature of water cooling systems.

Each of the undulators has an unwanted dipole component that varies with its gap setting. This causes a shift in beam position manifesting itself as a closed wave around the storage ring with an amplitude of up to ± 0.6 mm (from each undulator), in both the horizontal and vertical planes. Such motion is intolerable to most experiments. The solution is to use two corrector magnets in each plane at the ends of the undulators to compensate for the undulator dipole field. The settings of the correctors are determined by minimizing the orbit distortions seen at a series of gap settings, then using these values in a lookup table that is continuously scanned and interpolated by the computer control system as the undulator gaps are changed. Fig. 4 shows the currents required in the four corrector magnets necessary to compensate the dipole field in the BL 7.0 undulator. Note that the corrector strengths are not symmetric (indicating that the error fields are not uniformly distributed along the undulator), and that they are not monotonic (indicating a complex mechanism in the generation of these fields). Using this compensation method the beam motion has been reduced to below 10 μm for all settings of the three undulators. This value is limited by the accuracy of the beam position (BPM) monitoring system, and will be improved as more accurate BPMs are installed in the storage ring straight sections.

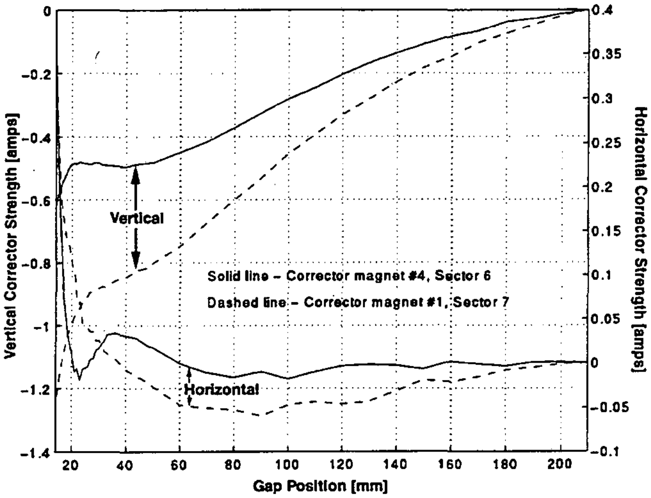

Fig. 4. Corrector-magnet currents required to compensate for the steering effects of the BL 7.0 undulator.

Other beam drifts have been measured with three distinct cyclic periods:

The first, with a period of two minutes, has been correlated with temperature variations of ± 0.3° C in the self-contained RF cavity cooling water system. Improved control has led to temperature regulation of better than ± 0.05° C in the system, and at this level the effects on user beam are negligible.

The second has a period of 10 to 15 minutes and is caused by temperature variations in the LCW system, as indicated in Fig. 2. We found that ± 0.5° C variations in this system resulted in electron beam motion of ± 2 μm vertically. However, although the periodicity of photon beam motion observed in the beamline was well correlated with the electron beam motion, the magnitude of the effect was much greater than could be explained by the electron beam motion, indicating that the main problem was the effect of the LCW on beamline optical components. The solution to this problem was either to replace the beamline cooling systems with local stand-alone systems, or to better regulate the temperature of the LCW system. After extensive monitoring of the LCW system, the cause of its temperature variations was traced to air-fans in the cooling towers that are used to control the water basin temperature by varying the evaporation rates! This is about as far away as one can get from the control usually exercised by accelerator physicists. However, once the source of the problem was found, a relatively simple (and inexpensive) solution was implemented, resulting in temperature regulation at a level better than ± 0.1° C over a typical fill of 6 hours, and the effects on beamline performance are now negligible.

The third kind of drift has a period of 45 - 60 minutes. We have not yet found good correlation with any specific temperature variations, but there is some evidence that this motion is caused by variations in the regulated air temperature. This aspect of beam motion is still under investigation.

5. SUMMARY

In its two year life as a user facility the ALS has achieved a remarkable operations record, providing high quality beams of undulator and bend-magnet radiation to the user community, with exceptional efficiency. Users on undulator beamlines have the freedom to tune the radiation spectrum as they wish without affecting other users, and short-term beam position has been reduced to an acceptable level, measured at a small fraction of the beam size..

In the immediate future, the main priority in the development of the facility is to add to the complement of insertion devices and beamlines—one more undulator will be installed this year and another in May 1996—and to improve the stability of the source still further to meet the ever more demanding requirements of synchrotron radiation-driven science.

ACKNOWLEDGMENTS

Contributions to the work described in this paper have come from many people at the Advanced Light Source Center, in particular the members of the Accelerator Group, and the Instrumentation and Controls Sections of the Engineering Group. The coupled-bunch feedback systems were built and commissioned as a collaboration between the ALS, the LBL Center for Beam Physics, and the SLAC Feedback Group.

This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Material Sciences Division of the U. S. Department of Energy under Contract No. DE-AC03-76SF00098.

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LAWRENCE BERKELEY NATIONAL LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL & ELECTRONIC INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720