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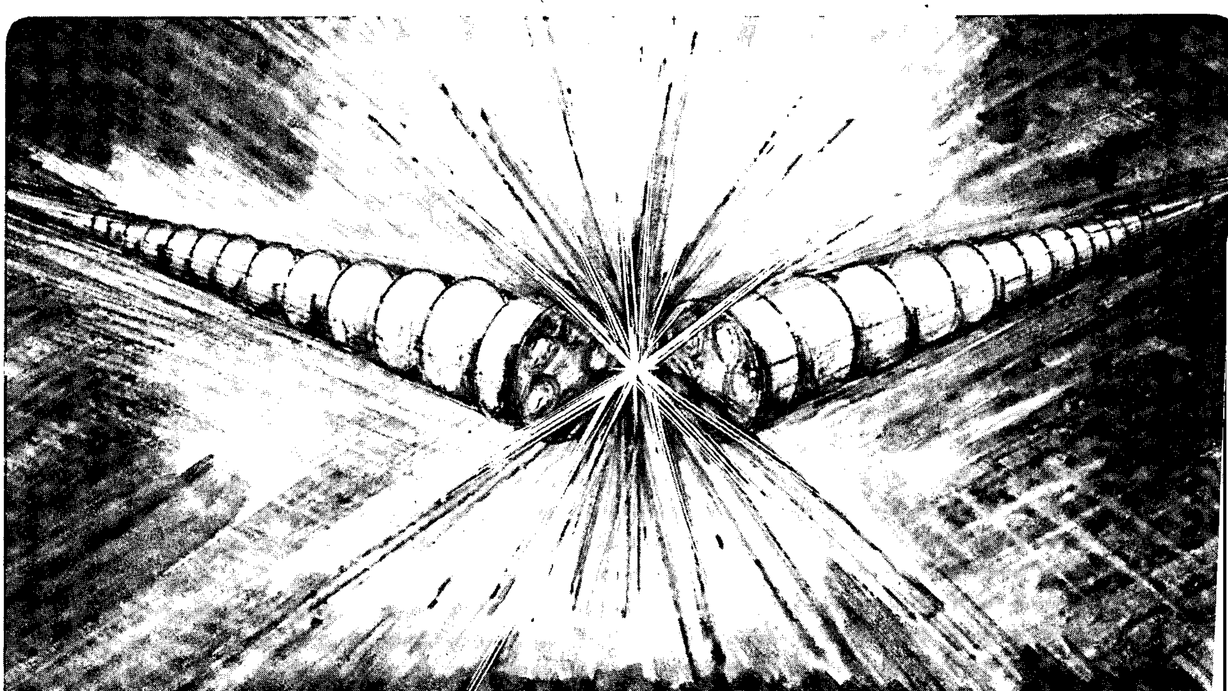

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PERFORMANCE OF THE ALS INJECTION SYSTEM

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Performance of the ALS Injection System*

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Abstract

We started commissioning the Advanced Light Source (ALS) storage ring on January 11, 1993. The stored beam reached 60 mA on March 24, 1993 and 407 mA on April 9, 1993. The fast pace of storage ring commissioning can be attributed partially to the robust injection system. In this paper we describe the operating characteristics of the ALS injection system.

I. INTRODUCTION

The ALS injection system [1] consists of an electron gun, a 50 MeV linear accelerator, a 1.5 MeV booster synchrotron and three beam transfer lines (GTL, LTB, and BTS), as shown in Figure 1. Accelerator installation began with the beneficial occupancy of Building 6 in January, 1990. Linac [2] reached the design energy of 50 MeV in December, 1990 and the design current of 125 mA in November, 1991. Booster installation [3] was finished in May, 1991 and the booster rf system in December, 1991. The booster reached the design energy of 1.5 GeV in January, 1992 and design current of 15 mA in February, 1992. Full energy beam was extracted from the booster in April, 1992. The injection system has been running reliably since September, 1992, after some technical problems associated with the magnet power supplies were corrected. The BTS beam transfer line was installed on January 11, 1993 and the beam was successfully transferred to the storage ring on the first day.

The filling time to 460 mA measured on April 30, 1993, was about 14 minutes. That was without any optimization. We expect a significant improvement in filling time as we reduce the linac energy spread and the storage ring injection efficiency. The repetition rate of the injection system is 1 Hz.

II. GUN AND GTL BEAM TRANSFER LINE

The 120 keV electron gun has a triode geometry. An rf voltage with a frequency of 125 MHz (synchronous with the 500 MHz storage ring rf system) and an amplitude of 0 - 70 Volt is applied between the cathode and the grid. The rf voltage is biased up to 30 V dc to produce shorter pulses. We recently upgraded the gun electronics to add the single-bunch-mode capability and reduce the gun timing jitter. Pulse duration is now about 2 nsec fwhm and number of electrons is ≤ 3 nC/bunch. Electron gun current is monitored with a wall current monitor.

Bunchers consists of a 125 MHz subharmonic buncher, a 500 MHz subharmonic buncher, and a 3 GHz traveling wave buncher. We tune the amplitudes and phases of the bunchers carefully while monitoring the bunch shape using LEP buttons at the 25 MeV point. We do not have fast enough beam diagnostics to directly measure the bunch length at this time. Computer simulations show that the total bunching factor should be about 50 at the optimum condition. The linac can be characterized as a high peak-current, low duty-factor machine.

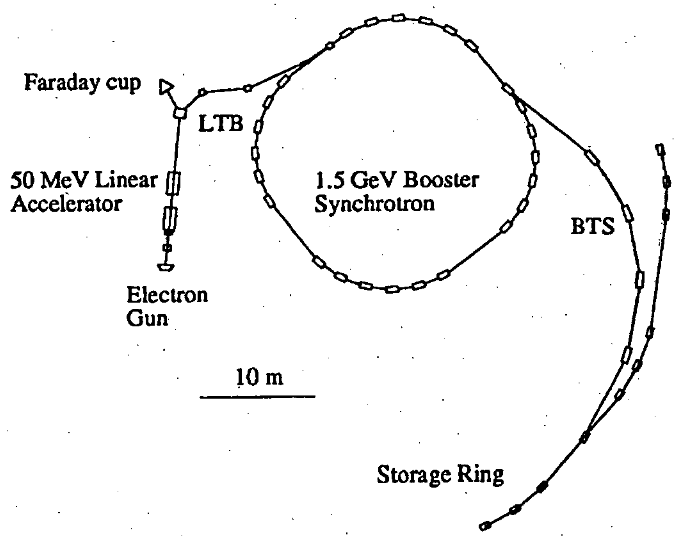

Figure 1. ALS Injector

We monitored the beam size and shape in the LTB line just after the first bending magnet, where energy dispersion is large. If the bunching system is tuned well, we can see well-separated individual bunches on the screen.

III. LINAC

The linac consists of two 2-meter, 3-GHz, disk-loaded waveguides with a constant-impedance structure for the 2p/3 mode [4]. Beam parameters at the linac exit, measured for optimized operating conditions, are summarized in Table 1.

Table 1.

Charge	0.8 nC/bunch
Energy spread (dE/E)	
single bunch	0.2%
multi-bunch	0.6%/bunch
Beam Emittance [5] (ss')	
Vertical	3.2×10^{-7} m-rad
Horizontal	3.3×10^{-7} m-rad

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A computer simulation [6] and a beam loading consideration in the waveguides indicate that beam loss should most likely occur before the electrons reach the first wave guide. The measured emittances agree well with the simulations.

Large energy spread in multi-bunch mode is caused by beam loading in the wave guides. A beam loading compensation scheme using the fast-phase-switching technique was tested successfully [2]. Because the booster energy acceptance is ± 1%, only 4 linac bunches can be accepted to the booster at a time without beam loading compensation. This mode of operation has been good enough for the storage ring commissioning so far. We expect to use the beam loading compensation scheme more routinely in the future.

IV. LTB BEAM TRANSFER LINE AND BOOSTER INJECTION

Beam matching from the 50 MeV linear accelerator to the booster and steering are done in the LTB beam transfer line for a maximum beam capture in the booster. Injection to the booster is via a fast kicker magnet utilizing the well-established single-turn, on-axis injection technique. The injection kicker magnet has a 100 nsec flat top (< ± 0.5%), with a fall time of about 150 nsec. The flat top time window is long enough to inject 13 linac bunches into the booster. Booster orbit time is 250 nsec. Beam transfer efficiency from linac to booster is typically about 75%. Most of the beam loss occurs during the first 200 msec after injection.

A peaking coil installed in one of the booster dipole magnets triggers the electron gun, linac, and the injection kicker magnet. The peaking coil also triggers a Gauss clock, which then starts to generate a series of pulses at given dipole field intervals. The Gauss clock is used to trigger and moderate other booster instrumentations such as rf ramping and beam position monitors.

V. BOOSTER SYNCHROTRON

The booster consists of 24 dipole- and 32 quadrupole-magnets in a missing-magnet FODO-lattice configuration with a super periodicity of 4. The booster lattice parameters and the operating point are summarized in Table 2.

Dipole magnets are connected in series to a SCR-switched power supply and run freely at a repetition rate of 1 Hz. Acceleration to 1.5 GeV in the booster takes 0.34 seconds. The focusing (defocusing) quadrupoles are connected in series to a power supply which tracks the excitation current of the dipole magnet. The core nonlinearities such as remnant magnetic fields at low fields and core saturation at high fields cause large tune-shifts during acceleration. Tune-shifts make machine operations very susceptible to resonant beam losses during the first 100 msec of the ramping. We were able to correct the tune-shift to < 0.02 by applying programmable correction voltages to the quadrupole power supplies at certain Gauss clock intervals.

Spontaneous betatron oscillations were observed during the first 1 msec after injection. We can excite horizontal betatron oscillations using the extraction kicker magnet at any time 50 msec after injection. Tunes were measured by (1) analyzing the beam position monitor signals in the Fast-Analog-to-Digital (FAD) [7] mode, or (2) using a Tektronics 3052 spectrum analyzer. In the FAD mode BPMs provide beam-position information for 1024 turns. The Tektronics 3052 spectrum analyzer can provide, for example, a 100 msec record of spectra in 200 msec steps.

Table 2. Booster Lattice Parameters

Circumference [m]		75
Revolution Frequency [MHz]		3.997
Betatron Tune	Horizontal Vertical	5.80 2.79
Synchrotron Freq (kHz)	injection extraction	256 44
Momentum Compaction		0.046
Chromaticity	Horizontal Vertical	-8.31 -4.69
Quadrupole *kL* [1/m]	Focusing Defocusing	0.787 0.471
Sextupole *kL* [1/m^2]	Focusing Defocusing	0.867 0.989
Radiation Loss at 1.5 GeV [keV/turn]		112
Natural Energy Spread at 1.5 GeV [%]		0.064
Radiation Damping at 1.5 GeV [msec]	Horizontal Vertical Energy	6.68 6.72 3.37

for quadrupoles $k = (dB/dx) / [Br]$
for sextupoles $k = (d^2B/dx^2) / 2 [Br]$

Ramping the rf amplitude was programmed by specifying the rf amplitude values at Gauss clock intervals. Under the best condition the synchrotron frequency was 256 kHz at injection and 44 kHz at extraction. Many higher order synchrotron harmonics were observed under this condition, which may mean quadrupole and sextupole modes were present.

The booster has 20 sextupole-magnets for chromaticity corrections and 32 corrector-magnets for orbit corrections. Sextupole- and corrector-magnet power supplies are designed to track the dipole field in a way similar to the way the quadrupole fields do. Sextupoles have not been necessary for and have had no effects on booster operations so far. We expect that sextupoles may be necessary in the future, when the booster current is higher (which may induce some instabilities).

Orbit correction was successful in improving the capture efficiency [7]. The booster circumference is about 5 mm larger than designed and closed orbit is distorted to the first order by the dispersion function [8].

VI. BOOSTER EXTRACTION AND BTS TRANSFER LINE

When the beam is accelerated to the extraction energy, the following sequence of events occurs. Three extraction bump magnets are turned on to form a 10 mm local bump near the extraction septum magnet. The bump is slow enough for the extraction kicker magnet to wait up to 82 msec for the correct storage ring rf bucket to line up with the booster rf bucket. We can thus program the storage ring fill pattern by programming the kicker timing.

We measured the beam emittance of the extracted beam by measuring the horizontal and vertical beam sizes in the BTS line where the beta functions are known. The results are: $e_x = 2.5 \times 10^{-7}$ m and $e_y = 0.1 \times 10^{-7}$ m rms unnormalized. The measurements agree with the theory very well.

VII. INSTRUMENTATION AND CONTROL

The accelerator instrumentation [9], [10] played the roles of our eyes and ears in commissioning and operating the accelerator. We had adequate accelerator instrumentation in most parts of the accelerator. The cost of the instrumentation is small compared with other costs and was well worth it for the saved time and effort during commissioning. We felt that we could have used more diagnostics such as BPMs and steering magnets in the GTL line. More diagnostics at the linac exit such as total charge monitors and high speed diagnostics are becoming commercially available. This will make further commissioning more enjoyable. ALS accelerator instrumentation is summarized in Table 3.

Table 3. Summary of ALS accelerator instrumentation.

	GTL	Linac	LTB	Booster	BTS
WCM	1	-	-	-	1
Faraday cup	-	-	1	-	-
DCCT	-	-	-	1	-
Scintillator	2	2	6	5	7
BPM (buttons)	2	1	-	32	-
BPM (TWE's)	-	1	7	3	6

Scintillators were used for focussing and steering of the beam in the linac and in the beam transfer lines. They are also used for calibrating magnets using the electron beam as a probe.

Because of their non-destructiveness of the beam and the high speed with which data can be processed, various types of beam position monitors are extensively used throughout the ALS accelerator system. Fast and simultaneous measurements of the beam positions and the relative intensities at different locations in the accelerator are very important for tuning and feedback stabilizing of accelerators. BPM's were used for tuning the beam transfer lines, injection and first-turn studies in the booster synchrotron and the storage ring, tune measurements, closed orbit measurement and correction, feedback stabilization, etc. A BPM system consists of an array of beam pickup electrodes, a set of high-quality coaxial cables, a bin of processing electronics, and a controlling computer. Careful preparation and testing of the hardware and software were necessary for each of these applications.

The BPMs were an indispensable part of our instrumentation, and we have learned a great deal during our commissioning about how to use them and interpret the data properly.

The booster is controlled by the ALS control system. It utilizes the intelligent local controllers (ILC's) which are highly distributed and centrally connected to collector micro-modules via fiber optical links. Operator interface is via a number of personal computers (six 486/PC's at present) using mostly commercially available software and development tools. Applications have been developed jointly by the ALS control systems group and the accelerator systems group.

VIII. ACKNOWLEDGMENTS

Material presented in this paper is the result of a cooperative work performed by the ALS project team and the Accelerator Systems Group. I want to thank Mr. Alan Jackson for his leadership and encouragement. Many helpful discussions with Center for Beam Physics staff at the Lawrence Berkeley Laboratory are gratefully acknowledged.

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