MODIFICATION OF THE ALS BOOSTER SYNCHROTRON FOR AN EXPERIMENT ON OPTICAL STOCHASTIC COOLING *

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Abstract

Modifications to the Booster synchrotron of the Advance Light Source of the Lawrence Berkeley National Laboratory have been made in preparation for a test of the Optical Stochastic Cooling in a single pass beam line, planned for installation in the extraction area of the synchrotron. Electron beam acceleration to 650 MeV, synchrotron radiation cooling at 650 MeV, and deceleration to 200 MeV have been demonstrated. Measurements have been made of the beam horizontal and vertical emittances and beam energy spread in the beam extracted from the synchrotron at 200 MeV and 250 MeV and compared with computer simulation results.

1 INTRODUCTION

The work that we are going to describe in this paper was done in preparation for a test of the optical stochastic cooling scheme[1],[2] in a single pass beam line[3]. We propose to build a new beam line in the extraction area of the ALS Booster synchrotron, where we will include a bypass lattice similar to the lattice that could be used in the cooling insertion in a storage ring. The design of this beam line is being presented in an accompanying paper at this conference[4]. The ALS Booster synchrotron will provide electrons for the test beam line. It is idle all the time between injection cycles into the ALS and, thus, is available as a source of electrons for a new beam line. The layout of the experimental area, showing several Booster synchrotron magnets, the existing beam transport line from the synchrotron to the ALS, and a schematic of a proposed new beamline, is shown in Fig. (1).

For an experimental test of the optical stochastic cooling we need a beam energy of only 200–250 MeV.[1] But there are specific requirements for the quality of the beam. Simulations performed in[4] show that the relative beam energy spread $\sigma_e < 10^{-3}$, the horizontal emittance $\epsilon_x < 1.5\times10^{-7}$ m·rad, and the vertical emittance $\epsilon_y < 6\times10^{-8}$ m·rad are required for a successeful test. In order to reach the desired beam quality, we did a number of modifications to the Booster that we describe in this paper. We also did computer modeling of the beam characteristics in the Booster in the modified mode of operation and measured their actual performance. All of these results are described in the paper.

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[1]The lower energies are preferable for this experiment since the electron radiation in the visible part of spectra is used.

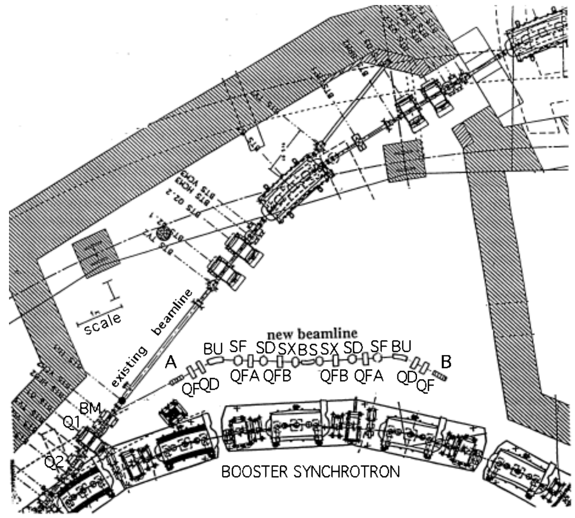

Figure 1: The layout of the extraction area of the ALS Booster synchrotron showing several Booster synchrotron magnets, the existing beam transport line and a schematic of a proposed new beamline.

2 MODIFICATIONS TO THE BOOSTER

In order to get a good quality beam extracted from the Booster at the energy 200–250 MeV, we modify the energy ramp profile. Namely, we ramp the Booster beam energy up from 50 MeV to ∼650 MeV, allowing the beam time to stay at this energy, and then ramp the beam energy down to ∼200 MeV. The goal of this proceedure is to cool the beam emittance and energy spread by using synchrotron radiation damping at the energy of 650 MeV.

The modification to the energy ramp was accomplished by selecting a particular output current ramp shape of the bend magnet power supply. An arbitrary wave form generator was used to provide an input voltage to the bend magnet power supply that resulted in the desired shape of the output current. The quadrupole, sextupole and steering magnet power supplies just follow the bend magnet ramp. To ensure no losses of the beam current in the modified ramp, special attention was paid to a smooth transition from the up ramp to the flat top and from the flat top to the down ramp. However, some extra variations to the output current at the flat top were intentionally induced. The control system interprets any period of level ramp that exceeds 25 ms as the end of the ramp and resets tables used to control the RF ramp profile and to correct tracking of focusing magnets with the bend magnet. In order to avoid this, we simulated some activity at the flat top by inserting just enough slope in the field. Figure (2) shows the oscillograms of the waveform shape of the bend magnet power supply output current, amplitude of the RF voltage and the beam current.

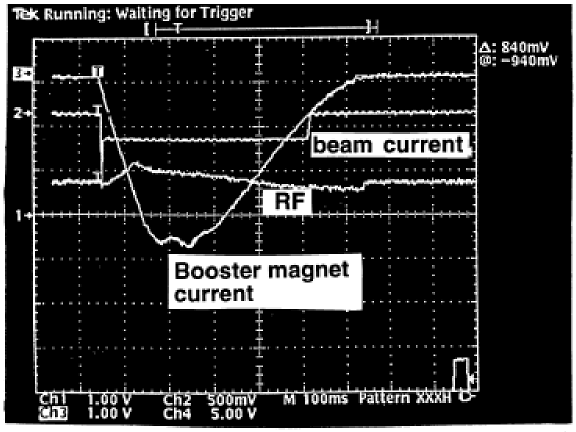

Figure 2: The oscillograms of the wave form shape of the bend magnet power supply output current, amplitude of the RF voltage and the beam current.

Booster extraction energy is controlled by a 'gauss clock'. It processes the output of a pickup coil in one of the bend magnets and triggers many of the functions in the Booster. Extraction is triggered when the field reaches a value corresponding to the desired energy. Initial efforts to use this system to track the down ramp result in unacceptable energy jitter. We decided that we would continue to use it for the up ramp functions, but would base extraction timing on the measurement of the output of the precision transductor that measured bend magnet current. The timing system was modified to begin the extraction cycle when the current fell through the setpoint of a precision comparator.

All modification were made in a such way that typically it takes approximately 10 minutes to switch from the default mode of operation to the modified ramp.

3 COMPUTER MODELING

The electron cooling process in the ALS Booster synchrotron being considered in the present paper includes effects due to the adiabatic damping, intrabeam scattering, and microwave instability, in addition to the synchrotron radiation damping, and the quantum fluctuation excitations. The electron energy varies as shown in Fig. (3a) from 50 MeV at injection, to about 650 MeV at the flat top where electrons are cooled for about 180 msec (or 330 msec), and decelerated to below 200 MeV. Damping time of betatron oscillations, τ_d, at 650 MeV is ∼120 ms; damping time of synchrotron oscillations is twise as short. Figure (3b) shows how the calculated vertical emittances corresponding to the two configurations, as in Fig. (3a), vary with energy during the accelerating and the decelerating phases. (The horizontal emittance and the energy spread behave similarly). The flat top of 330 msec is long enough for horizontal emittance to cool to the minimum possible emittance at 650 MeV, but not for the vertical emittance. A flat top of about 500 msec is required for the vertical emittance to reach the minimum emittance (this configuration is not shown in Fig. 3a).

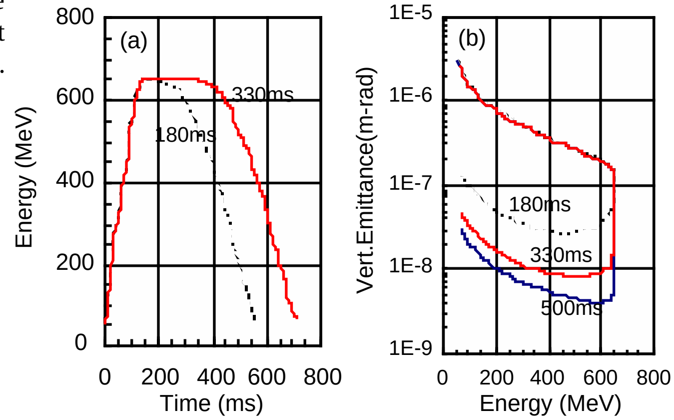

Figure 3: (a) shows the two ramping configurations where the dotted line represents a 180 msec flat top ramp and the solid line a 330 msec flat top configuration, (b) shows how the calculated vertical emittances corresponding to the two configurations as in (a) vary with energy during the accelerating phase (upper part of the curves) and the decelerating phase (lower part of the curves).

The plots in Fig. (3b) and other numerical results presented below were obtained by using the computer program described in[5]. This program was purposely written to consider the evolution of the beam energy spread and the beam emittances in electron synchrotrons and storage rings under the influence of the various effects listed in the beginning of this section. The calculations were made for initial beam parameters taken to be equal to those measured after electron beam acceleration in the 50 MeV injector linac: (i) injected beam intensity of ~ 2 mA (this is above the microwave instability threshold for beam energies up to 1 GeV); (ii) the normalized rms beam transverse emittance of 1.5×10^{-4} m·rad for both horizontal and vertical planes; (iii) the energy spread of 1% and bunch length of 4.5 mm. Initial longitudinal and transverse beam parameters usually are not perfectly matched to the booster acceptance, resulting in transient oscillations which eventually damp in a few damping times at the flat top. In present simulations these oscillations are ignored because, practically, they do not affect final results. Additionally, the coupling coefficient was used as a parameter for fitting the measured horizontal and vertical emittances with the model, and a good fit was obtained at ∼10% coupling.

Numerically, we studied the relative importance of the intra-beam scattering (IBS) and the microwave instability (MWI) in the booster by comparing the following computer simulations for 330 msec flat top ramp configuration: (i) zero intensity; (ii) 2 mA beam with IBS included, but not MWI; (iii) 2 mA beam with IBS and MWI included. The results are summarized in Table 1.

Table 1 shows that when IBS was added to the model the normalized horizontal emittance was increased by 25%

Table 1: Summary of the three computer simulations. Energy spread and normalized horizontal and vertical emittances are listed as the electrons are cooled at 650 MeV and decelerated to 350, 300, 250, and 200 MeV.

0 mA	$\sigma_{\Delta_E/E}$	ϵ_H m·rad	ϵ_V m·rad
350	2.9E-4	2.95E-5	6.86E-6
300	3.1E-4	2.88E-5	6.78E-6
250	3.4E-4	2.84E-5	6.70E-6
200	4.0E-4	2.81E-5	6.64E-6
2 mA+IBS			
350	3.4E-4	3.44E-5	7.07E-6
300	3.7E-4	3.44E-5	6.96E-6
250	4.3E-4	3.47E-5	6.89E-6
200	5.1E-4	3.52E-5	6.83E-6
2 mA+IBS+MWI			
350	7.7E-4	3.10E-5	6.93E-6
300	8.4E-4	3.05E-5	6.84E-6
250	9.4E-4	3.03E-5	6.75E-6
200	11.0E-4	3.02E-5	6.72E-6

and beam energy spread by 30% at 250 MeV point. When MWI was also included, then IBS became weak as a result of more than 100% increase of the beam energy spread due to the MWI. The vertical emittance is not fully damped and so mostly affected by the flat top length.

4 EXPERIMENTAL RESULTS

With the first energy ramping configuration (180 msec flat top) beam parameters were measured at two energy points 250 MeV and 213 MeV. With the second energy ramping configuration (330 msec flat top) beam parameters were measured only at 250 MeV. Measurements of the beam parameters were performed with a quadrupole scan, i.e., by extracting the beam from the booster and observing the variation of the beam profile at the beam profile monitor as a function of the strength of the quadrupole located upstream of the monitor.

As a bench mark test of the measurement technique we measured the beam parameters for the normal mode of operation with beam extracted at 1.5 GeV. The measurement results and comparison with the calculated values for four experimental configurations are summarized in Table 2.

Our measured values are systematically larger than those calculated. Possible sources of discrepancy are the thermal diffusion of images on the scintillator used as the beam profile monitor and deviations of the beta and dispersion functions from their theoretical values. It is likely that our measurements overestimate real emittances, but, taken even as they are measured, the beam emittances and the beam energy spread satisfy a requirement of the beam quality needed for a test of Optical Stochastic Cooling.

Table 2: Measured and calculated beam parameters for the four experimental configurations described in the text.

	Measured	Calculated
Energy 213 MeV, flat top time 180 ms		
ϵ_H, [m·rad]	$1.6 \times 10^{-7} \pm 26\%$ [a]	0.9×10^{-7}
ϵ_V, [m·rad]	$9 \times 10^{-8} \pm 20\%$	4.8×10^{-8}
$\sigma_{\Delta E/E}$	$1.5 \times 10^{-3} \pm 26\%$	1.1×10^{-3}
Energy 250 MeV, flat top time 180 ms		
ϵ_H, [m·rad]	$1.25 \times 10^{-7} \pm 22\%$	0.8×10^{-7}
ϵ_V, [m·rad]	$6 \times 10^{-8} \pm 10\%$	4.1×10^{-8}
$\sigma_{\Delta E/E}$	$\leq 7 \times 10^{-4}$ [b]	9.3×10^{-4}
Energy 250 MeV, flat top time 330 ms		
ϵ_H, [m·rad]	$1.1 \times 10^{-7} \pm 18\%$	6.2×10^{-7}
ϵ_V, [m·rad]	$6 \times 10^{-8} \pm 12\%$	1.4×10^{-8}
$\sigma_{\Delta E/E}$	$\leq 7 \times 10^{-4}$	1.1×10^{-3}
Energy 1.5 GeV		
ϵ_H, [m·rad]	$2.5 \times 10^{-7} \pm 20\%$	1.6×10^{-7}
ϵ_V, [m·rad]	$2 \times 10^{-8} \pm 12\%$	1.5×10^{-8}
$\sigma_{\Delta E/E}$	7×10^{-4}	6.4×10^{-4}

[a] Statistical error.

[b] Measurements were not sensitive to the beam energy spread below this value.

5 CONCLUSION

Modifications to the ALS Booster synchrotron were done in order to reduce emittance and energy spread in the beam extracted from this accelerator at low energy. Then, actual measurements were performed and the horizontal beam emittance of 1.1×10^{-7} m·rad , vertical beam emittance of 6×10^{-8} m·rad, and relative beam energy spread of 7×10^{-4} were found. A computer model produced similar results. Our conclusion is that this accelerator can provide a beam of the required quality for an experiment on Optical Stochastic Cooling in the new beam line.

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6 REFERENCES

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