LBL-22191
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DE87 009167

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March 1987

*This was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

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Introduction

The injection system for the the LBL 1-2 GeV Synchrotron Radiation Source is designed to provide an electron beam of 400 mA at 1.5 GeV to the storage ring in a filling time of less than 5 minutes. An alternate mode of operation requires that 7.6 mA be delivered to one, or a few, rf bunches in the storage ring. To accomplish these tasks, a high-intensity electron gun, a 50 MeV electron linac, and a 1.5 GeV booster synchrotron are used. The booster has a repetition rate of 1 Hz with a maximum current of 20 mA; the linac can cycle up to 10 Hz, with a 100 ns pulse of 125 mA (for the 400 mA storage ring requirement), or a single 15 ps bunch of 1.3×10^{10} (for the single storage ring bunch mode). For booster injection, an emittance of 1.1×10^{-8} πm-rad and a rms momentum spread of 0.4% or less is needed. As the linac requirements are similar to those of the recently completed injector for the Stanford Linear Collider (SLC) [1], a similar design philosophy will be used. Figure 1 shows a plan of the injection linac and booster injection system.

Requirements

In Table I are summarized the performance requirements for the injector complex--electron gun, linac and booster. In the single-bunch mode, the goal is to load the storage ring with 7.6 mA in a single rf bucket; if several such bunches are loaded sequentially it becomes a "few-bunch" mode. The "multibunch mode," on the other hand, requires a current of 400 mA, with approximately 250 consecutive rf buckets in the storage ring filled, out of a total of 328. The gap is maintained for the purpose of avoiding ion trapping [2]. Table II shows the electron intensities expected, from the gun to the storage ring.

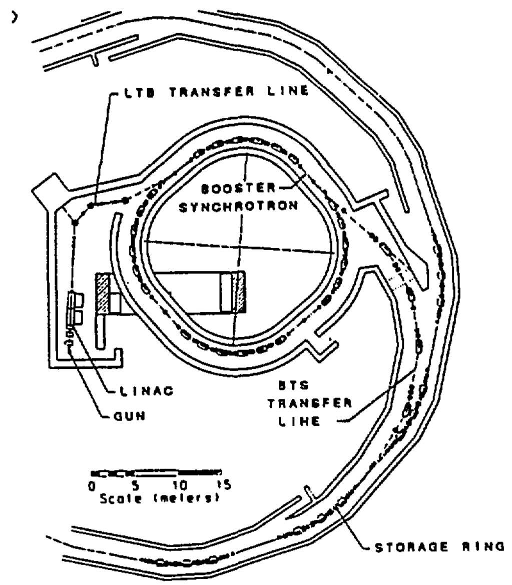

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Fig. 1. Injection System Layout.

TABLE I. Performance Requirements of Injector

ELECTRON GUN		
Single bunch mode		
Current	[A]	2.4
Pulse length	[ns]	2.5
Multibunch mode		
Current	[A]	1.0
Pulse length	[ns]	100
LINAC		
Energy	[MeV]	50
Repetition rate (max.)	[Hz]	10
Radiofrequency	[MHz]	2997.924
Single bunch mode		
Intensity		1.3×10^{10}
Bunch length (rms)	[ps]	15
Multi-bunch mode		
Average current	[mA]	125
Pulse length	[ns]	100
Emittance (rms)	[π m-rad]	1.1×10^{-8}
Momentum spread (rms)	[%]	0.4
BOOSTER RING		
Injection energy	[MeV]	50
Nominal peak energy	[GeV]	1.5
Cycle rate	[Hz]	1
Single bunch mode		
Circulating current	[mA]	3.2
No. of stored electrons		5.0×10^{9}
Multibunch mode		
Circulating current	[mA]	20
No. of stored electrons		3.2×10^{10}
Beam properties at 1.5 GeV		
Natural rms emittance	[π m-rad]	1.4×10^{-7}
Energy spread, rms		6.3×10^{-4}
Bunch length, rms	[mm]	30.5

Electron Gun and Subharmonic Buncher

An electron gun capable of producing 2.4 A in a 2.5 ns pulse is required in the few-bunch mode. For the multibunch mode 1 A is sufficient, but the gun must be capable of operation at 167 MHz. In both modes of operation, the intention is to use a subharmonic buncher, operating at one-eighteenth the 3 GHz linac frequency, in order to collect as much charge as possible for acceleration in the linac while preserving a small energy spread. The source will be pulsed in the multibunch mode, to minimize the out-of-phase electron component, which would be lost in the acceleration process and simply add to the radiation background of the injector facility. This subharmonic bunching, and its relation to the booster acceleration at 500 MHz, is illustrated schematically in Fig. 2. The gun used will be similar to the injector for the SLC [3], and two

*This work is supported by the Office of Basic Energy Sciences of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

TABLE II. Intensities and Transmission for Electrons[a)]

	SINGLE BUNCH MODE		MULTI-BUNCH MODE	
	I (A)	N_e (10^{10})	I (mA)	N_e (10^{10})
Gun current	2.4	3.7	1000	26.6
Subharmonic buncher exit	-	2.6	292	18.6
S-band buncher exit	-	1.9	218	13.9
Linac exit	140	1.3	147	9.3
Accepted into booster	3.2	0.5	23	3.7
Extracted from booster	2.6	0.4	18	3.0
Storage ring accepted	0.5	0.2	3.4	1.5

a) Current values given are peak values for the gun and linac, and average values for the booster and storage ring.

subharmonic buncher cavities will be used, as this has been found to result in more efficient bunching action [4].

Linac Design

Although most electron linacs have been constructed as traveling wave (TW), disk-loaded waveguide, it is often suggested that a standing wave (SW) structure might have some advantages, so this type of operation was evaluated to see if it might be suitable for our requirements.

In theory, a standing wave structure operated with π phase advance per cell can have a shunt impedance twice that of the same structure operated in the traveling wave manner. This is because the forward and backward waves add to give twice the accelerating gradient. With other than 0 or π phase advance, the backward wave will have random phase to the particles being accelerated, and will not, on the average, contribute to energy gain. The standing wave structure requires that we address some special problems: matching the impedance of the power supply to the load is difficult, some means must be adopted to handle reflected power to prevent damage to the klystron, and mode separation can become inconventiently small for a structure with π phase advance per cell.

There are ways of getting around each of these problems, as has been pointed out by Miller [5]. He concludes that for electron linacs with pulse lengths comparable to the risetime, standing wave structures may be superior to traveling wave structures, but for linacs with pulse length short compared to the natural time constant $t_f = 2Q\tau/\omega$, there is little to recommend SW over TW.

For our case, with $Q = 1.4\times10^4$, $\omega/2\pi = 3$ GHz, and an attenuation parameter $\tau = 0.27$, the natural time constant of the linac is about 400 ns. The longest pulse expected (for the multibunch mode) can be taken as 150 ns.

Because the beam pulse is short relative to the natural time constant, a disk-loaded waveguide operated in the TW mode is the appropriate choice. The linac is short (4 m), and has a low duty factor, so rf power is not likely to be a major consideration. On the other hand, compensation for beam loading will be very important, in order to achieve low energy spread, and this can be accomplished as well, or better, with a TW as with a SW structure. Finally, the SW structure would be more expensive to fabricate while offering no compensating advantages.

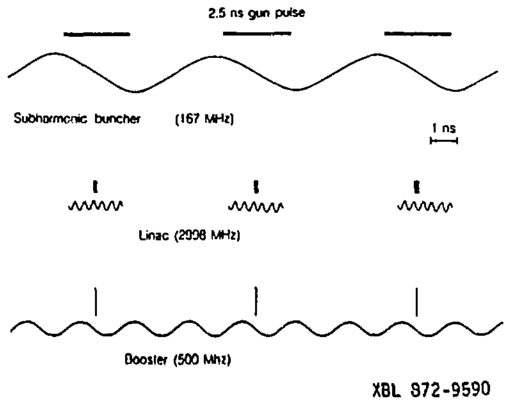

Fig. 2. Relation of beam bunches to rf in the subharmonic buncher, linac, and booster.

The linac frequency will be 2997.9 MHz, 6 times the booster frequency. It will be possible to phase-lock the rf for the bunchers, linac and booster in order to improve booster acceptance. Although one 35 MHz klystron would be sufficient to drive the linac, the tube would be driven close to its rated power; the options of using either two klystrons, or possibly one klystron with SLED [6], are therefore being considered.

Linac to Booster and Booster to Storage Ring Transport

The linac to booster (LTB) line, in addition to transporting the beam for injection to the booster, incorporates means for analyzing and tuning the linac beam to achieve desired transverse emittance matching and energy spread. A switching magnet will be used to divert the beam into a diagnostic line leading to a shielded beam dump; for this tuning the linac will be run at a higher rate (10 Hz) than the usual 1 Hz used for booster injection. Beyond the switching magnet, a dispersive section in the LTB line includes momentum-defining slits. The line contains a sufficient number of quadrupoles to permit phase space matching. Instrumentation is included in both the LTB and diagnostic line for measuring beam intensity, position, and transverse and longitudinal spread.

Transport from the booster to the storage ring (BTS line) is at 1.5 GeV. Diagnostic instrumentation used is similar to that used in the LTB line. At injection into the storage ring, four bump magnets are used to displace the local orbit toward the injection septum.

Booster Synchrotron

The booster is used to accelerate the 50 MeV beam from the linac to the nominal storage ring operating energy of 1.5 GeV. The cycle rate of the booster is 1 Hz. A faster rate would speed the filling operation, but may be ruled out by cost considerations. The natural (uncoupled) rms emittance of the booster is about 1.4×10^{-7} πm-rad at 1.5 GeV.

The booster lattice is a FODO structure with missing dipoles to provide utility straight sections for injection, extraction, and rf cavities. The choice of this structure over several other possibilities was dictated by its flexibility and simplicity. One quadrant of the lattice is shown in Fig. 3. Two sextupole families, SF and SD, are used to correct the chromaticity throughout the acceleration cycle, as the risetime of the head-tail instability is sufficiently short to cause problems otherwise.

Both for injection into, and extraction from, the booster, full aperture kicker magnets are used. The revolution time is 250 ns, and the beam occupies about 100 ns of this. Thus, about 150 ns is available for the injection kicker fall time, and the extraction kicker risetime.

Time spent in the booster is short, and at higher energies radiation damping will minimize the effect of instabilities. Thus, if such problems were encountered, it would probably be near injection energy. The program ZAP [7] has been used to assess the effect of the common instabilities in this energy regime. The single-bunch current limit imposed by the longitudinal microwave instability is about 13 mA; the required current is one-quarter of this. As mentioned above, the chromaticity-dependent head-tail modes could be a problem, and this is taken care of with two sextupole families. Coupled-bunch instabilities might also require correction, as growth times on the order of milliseconds are calculated. This will be done by introducing mode damping in the booster rf acceleration cavity. Finally, intrabeam scattering (IBS) can cause emittance growth. An equilibrium emittance value of 1×10^{-8} πm-rad has been calculated, taking into account IBS, quantum fluctuations, and radiation damping; since this is essentially the same as the emittance provided from the linac, no significant growth is expected.

Calculations were done to show the beam emittance behavior during acceleration in the booster, with results shown in Figs. 4a-4c. Acceleration time was taken as 438 ms. The transverse emittance (Fig. 4a) is damped adiabatically at low energies, with radiation damping becoming important only at higher energies. Above about 750 MeV, quantum fluctuations become the dominant effect. Longitudinal behavior is shown in Fig. 4b, where rf voltage is taken as 250 kV. Rate of energy gain is low, so required rf voltage is determined almost entirely by radiation loss. Momentum spread is taken as 4×10^{-3}, to include the effect of some injection mismatching. At intermediate energies, the bunch area is damped by radiation loss; but at energies above 750 MeV the quantum fluctuations cause an increase in bunch area. In Fig. 4c, relative momentum spread is plotted. Initially this damps adiabatically, but then slowly increases above 750 MeV.

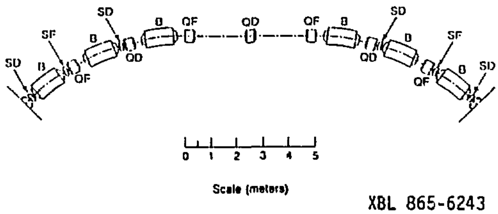

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Fig. 3. Magnets in one quadrant of booster. B, bending magnet; QF, QD, quadrupoles; SF, SD, sextupoles.

Acknowledgments

In the linac design we are receiving considerable assistance from staff at SLAC, particularly from H. Hoag for the linac structure and driver, and from R. Miller for the beam dynamics aspects.

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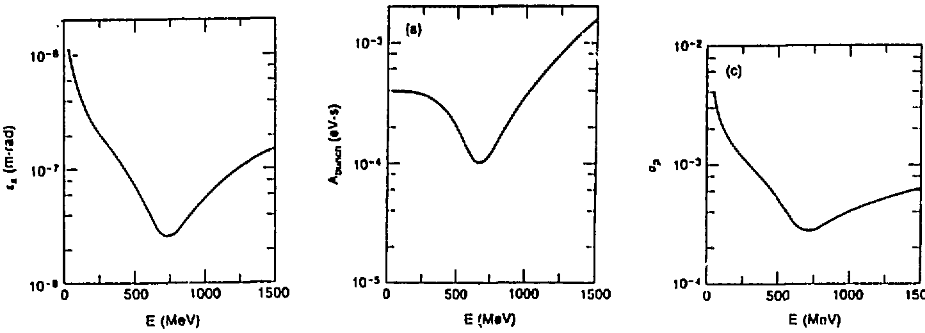

(a) XBL 865-6244 (b) XBL 865-6238 (c) XBL 865-6240

Fig. 4. Evolution of booster parameters during the ramp. (a) Transverse emittance, (b) longitudinal bunch area, and (c) relative momentum spread.