Commissioning the SSRL Injector*

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Abstract

Some results from the commissioning of the SSRL injector [1] for SPEAR are described.

I. PRE-INJECTOR

A. Microwave Gun

The microwave gun is fed with a 2.5 μsec RF pulse (2856 MHz), which produces a 2 MeV electron pulse with a peak current of around 650 mAmps. The pre-injector is described in [2]. In order to obtain the optimum electron beam, in both intensity, energy and energy spread, careful attention must be paid to the Gun Cathode heater, which controls the intensity of the electron beam and thus the beam loading in the RF Gun. The balance between input RF power and beam intensity is monitored by observing the RF power reflected from the Gun.

B. Alpha Magnet

The 281 degree Alpha magnet shortens the individual micro-bunches and a movable scraper, placed inside the magnet, allows the low energy tail of the beam to be removed before it reaches the Linac. The beam intensities before and after the alpha magnet are measured on two identical current toroids [3]. The beam energy profile is measured from the incremental change in beam current as the scraper is moved through the beam. Then the scraper is positioned to remove the low energy tail of the beam, reducing the beam intensity by around 30%.

C. Fast Chopper

Since only a single bunch is accelerated on each Booster cycle, a fast chopper [4], consisting of two permanent magnets and a vertical kicker, lets only three 2856 MHz bunches into the Linac. The beam is steered so that the rising edge of the chopper pulse scans the beam vertically across a horizontal slit. The fast rise time of the chopper pulse allows only three pre-injector bunches into the Linac. Figure 1. This vertical steering through the chopper is very delicate as incorrect steering here allows secondary particles and scattered beam into the Linac. See section II. 2 10^9 electrons/pulse in three bunches are injected into the Linac.

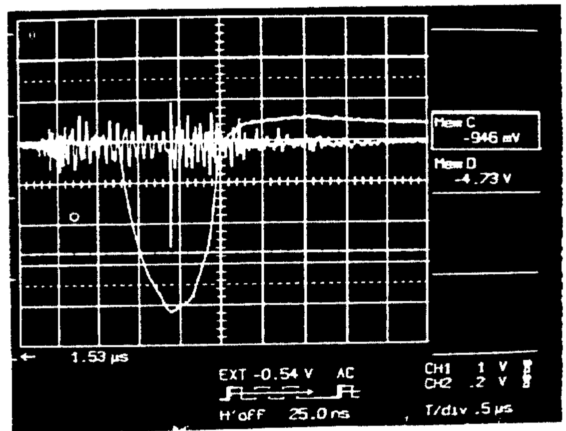

Figure 1
Pre-injector beam before and after the Chopper

II. LINAC

The Linac has three accelerating sections [5] and operates at 2856 MHz, with a 10 Hz repetition rate. The Klystron for accelerating section 2 also supplies the RF drive for the microwave gun and the other Klystrons.

When accelerating the beam from the pre-injector, the phase of the RF in each accelerating section and the gun have to be optimised so that the bunches always travel on the peak of the accelerating wave all three sections. These phases are optimised by maximizing the beam energy and minimizing the energy spread, as measured in the high dispersion region after the first bending magnet in the Linac to Booster transport line. Here both beam position monitors and a luminescent screen are used for beam observation. The nominal Linac beam energy is between 120 and 130 MeV, with an energy spread given by: $\sigma = 0.25\%$.

Two current toroids monitor the beam intensity at the beginning and end of the Linac. Once the Linac is operating correctly, 100% transmission efficiency is routinely achieved. These toroids have been absolutely calibrated using a Faraday Cup at the end of the Linac. When the Injector is operating, the beam in the Booster must not exceed 3 10^{10} electrons/sec. Therefore, if the integrated current read by these toroids exceeds 3 10^9 electrons/pulse, the beam is shut off [6]. So unwanted particles must not enter the Linac. See section IC.

III. LINAC TO BOOSTER (LTB) TRANSPORT LINE

The LTB transport line transports the 125 MeV beam from the Linac to the Booster. It consists of three main bending magnets and 6 quadrupoles. Corrector magnets and trim coils on the bending magnets and quadrupoles are used for fine steeing. The beam position and intensity in the line are monitored using 5 Beam Position Monitors (BPM). As well as beam position the summed signals from all 4 individual BPM buttons are very useful for measuring beam intensity. Once the beam is well centered throughout the LTB line, 100% transmission is routinely achieved.

IV. BOOSTER OPERATION

A. Injection and Acceleration

Injection into the Booster uses a horizontal septum magnet and a horizontal kicker [7]. Early in the commissioning large position fluctuations at injection into the Booster made injection very difficult. They are caused by energy changes in the Linac beam due to small changes in the output of the Variable Voltage Transformer, which supplies high voltage to the three Linac Modulators. Modifications

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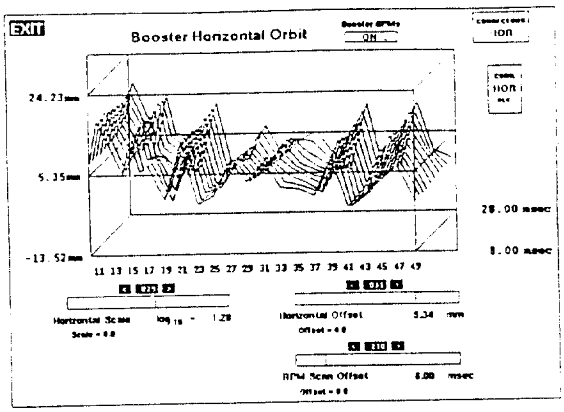

Figure 2
Evolution of the horizontal closed orbit over 20 msecs of acceleration

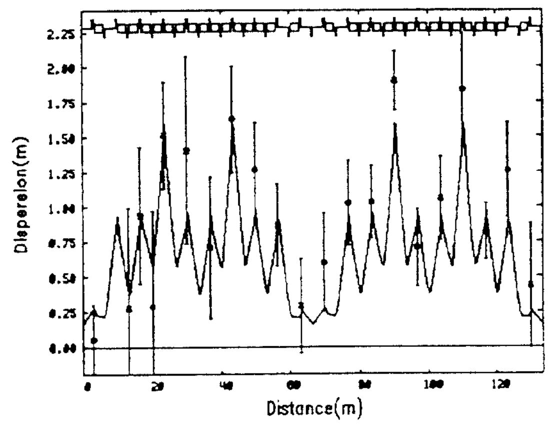

Figure 3
Dispersion function, the solid line is the theoretical curve

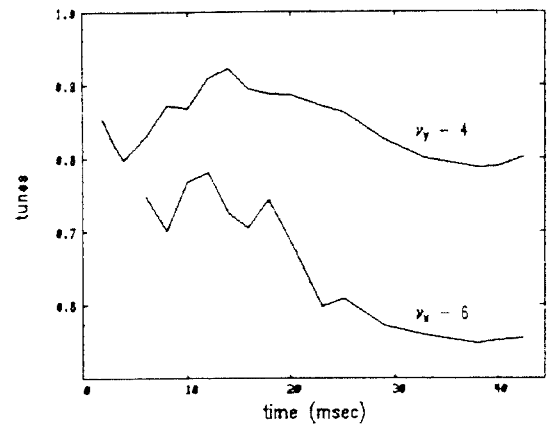

Figure 4
ν_x and ν_y during the acceleration. The design values were 6.25 and 4.18. Note the large change in ν_x shown here was part of a deliberate machine experiment

to the VVT are in progress, but a software feedback system [8], which monitors a BPM in a high dispersion region of the LTB line and corrects the Linac RF power to maintain constant beam energy, has greatly reduced the impact of this problem.

The Booster bending magnets and quadrupoles are part of a single 10 Hz resonant or "White" circuit [9]. The oscillating current passes from a small negative current to around −500 Amps peak value, which corresponds to an energy of 2.3 GeV. Injection occurs at about 27 Amps, and is triggered at a particular main magnet field level set for the incoming beam energy [10]. Accurate control of this field level is essential for reliable injection into the Booster. This trigger is also synchronised to the Booster RF frequency to ensure RF capture of the beam. In the early days of commissioning the Booster, DC injection, using a constant main field setting, was established first. However, since the remanent fields are completely different when ramping, DC injection is no longer used.

The beam intensity in the Booster is measured on a sensitive capacitive longitudinal pick-up [3]. The captured beam intensity was found to be very sensitive to the horizontal orbit and the QF and QD settings at injection. Now a typical ramp shows no losses, except for a 10-20% during the first few turns after injection. To reduce this initial loss the matching of the beam from the LTB line into the Booster still needs some study. The Booster RF [5] system runs at 358 MHz to match exactly that of SPEAR, and all three 2856 MHz Linac bunches are injected into a single RF bucket. The RF voltage is ramped during acceleration according the relation:

RF Gap Voltage $\propto E^4 - dE/dt$, (E=beam energy)

B. Closed Orbits

Initially obtaining a first turn around the Booster required steering around the ring BPM by BPM. Now that the Booster orbit is better understood, injection RF capture and acceleration can usually be established in a few minutes. The closed orbits in the Booster are measured every 2 msec through the 45 msec ramp. Figure 2 [11]. Over the first 8 msec of the acceleration the distortion shrinks as the remanent field effects from different magnets wash out. The orbit then stays constant until around 4 msec before ejection, when the distortion increases slightly as the pulsed ejection septum magnet comes on. The large residual horizontal orbit distortion, is due to many small quadrupole misaligments and not a single large error. Short of a complete re-alignment this is proving very difficult to correct, and predictions for correction by moving single quadrupoles are shown in Table 1. The dispersion

Table 1
Horizontal orbit correction for displacement of different quadrupoles

Quad	Disp. (mm)	Initial rms orbit error	Final rms orbit error	ν_x
Q16	2.50	7.82	1.95	6.96
Q13	0.47	7.82	2.29	6.97
Q19	0.88	7.82	2.38	6.92
Q19	2.05	5.81	3.86	6.55
Q16	7.13	5.81	4.26	6.55
Q16	1.76	5.81	4.40	6.55

function around the Booster has been measured by analyzing the horizontal orbit as a function of RF frequency, Figure 3

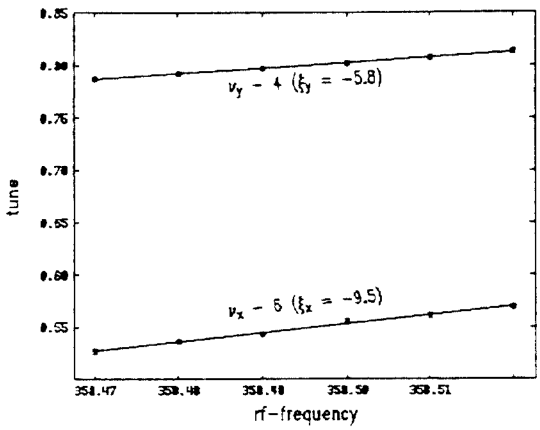

Figure 5

ν_x and ν_y vs. RF Frequency. This gives ξ_x = -9.1(-9.3) and ξ_y = -5.5(-6.5). Design values are given in brackets.

C. Betatron Tunes

Variation of horizontal and vertical tunes have been measured during the acceleration. Figure 4. Tunes are controlled by trim windings on the QF and QD quadrupoles. fed by a function generator [12], which is programmed for the required tune corrections. The beam is excited in both planes simultaneously using a pair of striplines driven at a variable frequency in the range 0-2 MHz. The beam response is observed, via a similar pair of strip lines, on a spectrum analyser, externally triggered to take data at a particular time in the acceleration. As the frequency is swept across the horizontal or vertical betatron sidebands a strong response is seen. By measuring the tunes at a fixed point in the ramp as a function of RF frequency, Figure 5, the chromaticities have been measured. The Booster has sextupoles, but they have not been powered, and there are no plans to use them. Horizontal tunes were also measured by observing the response of the beam after a single horizontal kick. No evidence was found that the horizontal tune varied measurably with the amplitude of the initial kick. It was not possible to observe any vertical excitation in this way, which suggests that horizontal/vertical coupling is small.

V. Booster to SPEAR (BTS) transport line

A horizontal kicker [7] and a vertical pulsed septum [13] eject the beam at the peak of the magnetic cycle into the BTS transport line. Due to the close proximity of the ejection line to both the Booster and the injection line, powering the BTS magnets perturbs the beam at injection in the Booster. These effects are corrected using two vertical dipole correctors in the Booster and two vertical steering magnets at the end of the LTB injection line. This line is matched to give the same injected beam parameters at SPEAR injection as the SLAC Linac. Three luminescent screens and 6 BPM's are routinely used for monitoring beam stability, position and transmission efficiency.

VI. Conclusions

In conclusion the SSRL injector has been commissioned and already fills SPEAR at rates which are comparable to those obtained using the SLAC Linac. Table 2 shows the design goals for the Injector, the best achieved performance levels, and routine performance levels.

Table 2
Injector performance: Intensity in 10^{10} electrons/sec

	Design	Best	Routine
Linac	2.00	2.50	2.00
Booster Inj.	2.00	1.60	1.10
Booster Acc.	1.25	1.50	0.70
Booster Ej.	0.60	1.00	0.60
SPEAR Inj.	0.15	0.22	0.15[1]

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[1] This corresponds to an accumulation rate of 20 mAmps/minute