INJECTION SYSTEM FOR THE CANADIAN LIGHT SOURCE

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Abstract

The full energy injection system for the Canadian Light Source is made up of a 250 MeV linac, a low energy transfer line, a 2.9 GeV booster synchrotron and a high energy transfer line. The system has routinely provided up to 30 mA peak current in a 136 ns pulse train to the CLS storage ring injection point since September 2003. By May, 2004, injection efficiencies up to 75% have been achieved at accumulation rates of up to 3.5 mA/sec. The injection timing system allows a variety of fill patterns.

OVERVIEW

Linac, ECS and Low Energy Transfer

The CLS injection system (Fig. 1) uses a thermionic electron gun and 6 section travelling-wave linac operating at 2856 MHz. The low-emittance electron gun consists of a 220 kV accelerating column followed by a single S-band prebuncher cavity and bunching acceleration section that is able to produce high peak currents. A system of fast deflection plates (video deflectors) is used to adjust the pulse width over a range of about 10 to 2000 ns. Nominally, the gun is operated at the very conservative level of 100 mA over a pulse length of 136 ns. Of the 100 mA, about 65 to 70 mA is bunched and accepted for further acceleration.

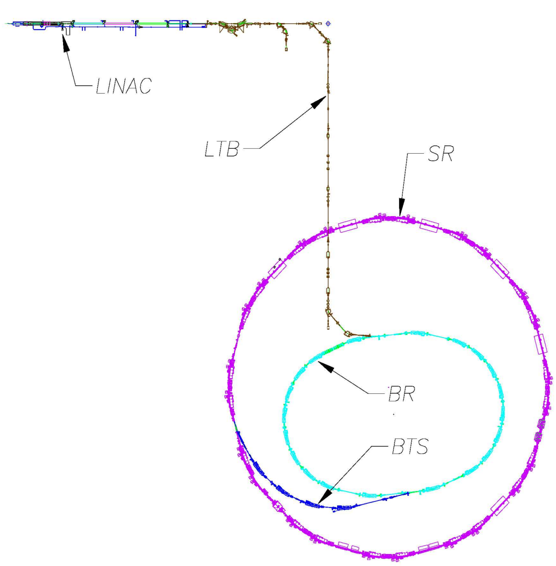

Figure 1: CLS Layout.

The linear accelerator consists of 3 SLAC and 3 Varian sections that are capable of delivering high beam current at an energy of 250 MeV. The 78 m linac-to-booster (LTB) line transports the beam from the below-ground linac to the new CLS building. Two vertical chicanes elevate the beam 6.582 m to the injection point of the booster [1]. Beam loss is minimized by the use of an energy compression system (ECS) located at the start of the LTB line. The ECS decreases the energy spread of the beam by an order of magnitude to a value of ~0.1%. Optimum setups result in over 60 mA of beam reaching the injection point of the booster.

Full Energy Booster

A full energy, 2.9 GeV booster ring (BR) was chosen for the CLS to facilitate greater orbit stability in the light source. The booster ring operates at 1 Hz at an RF frequency of 500 MHz, unsynchronized with the 2856 MHz linac. The resulting RF phase space mismatch results in significant beam loss at or near the injection energy. Optimum tuning results in extracted currents of up to 12 mA average (30 mA peak current contained in 68 bunches) current at 2.9 GeV. Typical operation ranges from 6 to 10 mA average current. A full description of the CLS booster is given in reference 2.

Booster to Storage Ring Transfer

The booster-to-storage ring transfer line (BTS) not only transports the electron beam from the booster ring extraction point to the injection point of the storage ring, but is optically constrained to transform the Twiss parameters of the booster to those required by the light source. The transfer line also incorporates a great deal of tuning flexibility in order to customize the beam parameters at the injection point should it be advantageous to run with a non-matched beam in order to maximize the injection efficiency.

The BTS [3] consists of 4 D-Bend-F cells using 18 degree dipoles identical to those used in the booster ring. The booster extraction and storage ring injection points are equipped with similar 7.62 degree thin septum magnets running with opposite polarities. An 8.38 degree thick septum, is located just upstream from the storage ring thin injection septum.

In addition to the 8 quads utilized in the bending cells, a quadrupole focussing doublet is used just downstream from the booster extraction point to control the β-functions as they evolve from the booster. The tuning of the BTS must be such that the maximum excursions of the β functions, especially β_x, and the dispersion function η_x, are not excessive. The former dominates the horizontal beam size, while the latter determines the energy-acceptance window. With 10 quads, each on separate supplies, a number of different tuning options exist. Operation at one of these configurations has been demonstrated to result in nearly full transmission to the storage ring injection point.

Storage Ring Injection

Injection into the CLS storage ring (SR) is complicated by the very compact nature of the lattice. In the CLS, a single straight section is too short to contain all of the injection hardware required to displace the orbit and inject the beam at the full storage energy. The injection “bump” is accomplished over three consecutive straight sections, encompassing two bend regions and all of the associated magnetic elements [4].

The CLS injection bump (Fig. 2) consists of 4 half-sine kickers that are energized over a 6 turn period (3.42 µs). The advantage of using a 4-kicker system is that, to some extent, this gives freedom to independently adjust the position and angle of the stored beam at the injection point. This was especially important during the commissioning phase to allow for a large amount of adjustment flexibility when the orbit position and machine functions were either unknown or not operating at the design values.

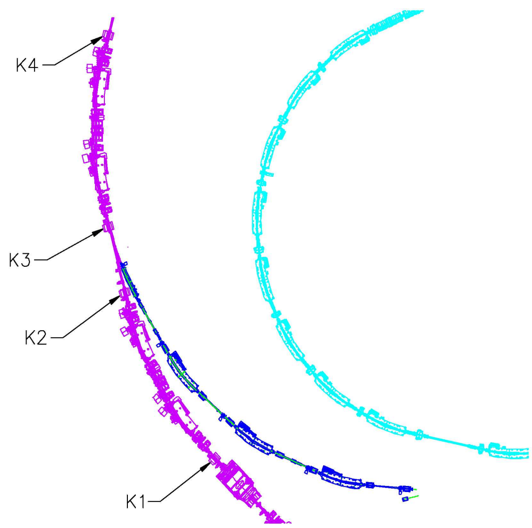

Figure 2: SR injection area layout.

TIMING SYSTEM

The CLS uses a timing system to adjust the firing time of the linac so that injection into specified storage ring bunches is accomplished [5]. The storage ring and booster ring have harmonic numbers of 285 and 171 respectively. The least common multiple is 855, resulting in an alignment of storage ring and booster ring buckets every 1710 nsec. This results in a booster-storage ring coincident frequency of 584.8 kHz, which is used to synchronize all critical frequencies for proper injection. Slower signals such as the ramping of the booster ring magnets are not synchronized. To ensure stable linac operation, all gun, modulator, and RF triggers are shifted together with the video deflectors used to determine the pulse width.

The timing system operation has been verified operationally. As an example, Fig. 3 shows a complex storage ring fill pattern as displayed on an oscilloscope. The trace displays a series of pulses spelling "C" "L" "S" in Morse code.

Figure 3: "C" (-.-.) "L" (.-..) "S" (…) storage ring injection profile.

STORAGE RING INJECTION DETAILS

The additional magnetic elements located internal to the 4 kicker injection bump have two major effects on the injection process. The focusing elements (quadrupoles) result in a beam kick for all particles not traveling through their central axes. The sextupole elements result in an amplitude-dependent injection bump. Thus, the nominal injection bump (Fig. 4) that is formulated to obtain a -15 mm horizontal offset at the injection point with no perturbation to the beam orbit in the rest of the lattice will not close as its amplitude is altered. Such a configuration will ultimately result in slight residual horizontal oscillations of the stored beam about the closed orbit after the injection cycle is completed.

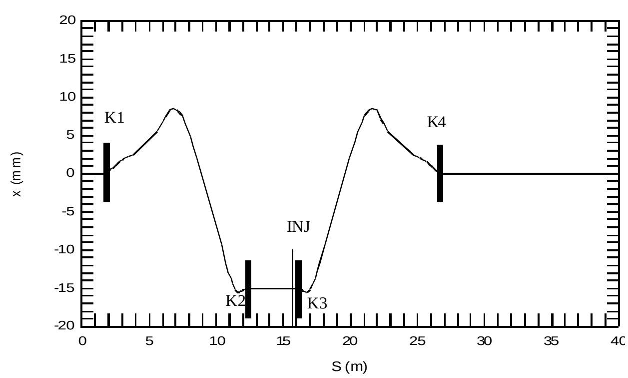

Figure 4: Four kicker horizontal bump.

The nominal injection coordinates for the injected beam are centred at -26 mm and parallel to the storage ring axis (0.0 mrad). Once the beam has travelled one turn around the ring, the decreasing amplitude of the bump and the horizontal tune of the ring work together to allow the beam to clear the septum as shown in Fig. 5. After the kickers have fully cycled, residual phase space oscillations will be damped and the injected beam will join the stored beam. Movement of the injected beam closer to the septum or increasing the offset of the stored beam to a value greater than -15 mm will result in a decrease of the resulting oscillations. However, this may result in greater losses to the injected or stored beam. Ultimately, operational experience determines the amplitude of the bump and the coordinates of the injected beam. Model based "scans" of the injection coordinates and storage ring bump are used to optimize injection efficiency. Effects on the stored beam are monitored by firing the injection kickers and looking for any decreases in the storage ring beam lifetimes.

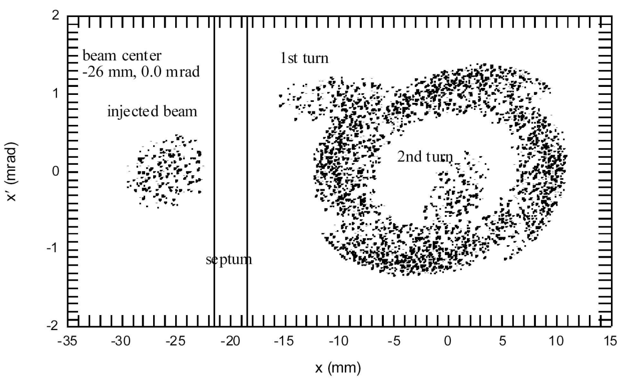

Figure 5: Evolution of the injected beam at the injection point for a 2 σ beam.

OPERATING EXPERIENCE

Commissioning [6] of the storage ring involved establishing a proper injection into the storage ring. The first major injection hurdle was to have the beam remain in the machine for more than 3 turns. At this time the injected beam has persisted through the downward ramp of the kickers. Once the beam was stored for a full injection cycle, the kickers were adjusted to allow for beam accumulation. At this point it was very important to verify the timing of the kicker pulses. Much time and effort was spent to verify that the stored beam was traversing the kickers at the proper times, taking into account all cable lengths and the beam flight time between kicker locations. Amplitude adjustments to the kickers successfully permitted the incoming beam to be injected while allowing the stored beam to pass the next activation of the kickers. The kicker settings often resulted in a trade off between injection efficiency and loss of the stored beam. Stored beam losses were observed as a change in the stored current as measured on a parametric current transformer (PCT) signal which is commonly displayed in the control room. One other important diagnostic used in this tuning was a Cherenkov beam-loss monitor [7] located at the injection septum. By minimizing the spill seen on this monitor, the kickers could be adjusted to ensure that the stored beam was not deflected far enough to intercept the septum.

Next followed the labour intensive task of iteratively applying corrections to the orbit [8] and re-optimizing the injection. This was more easily accomplished when the vertical orbit was corrected and the beam position was held fixed near the injection point. Maintaining the injection during horizontal orbit correction was more complicated since the horizontal quadrupole kicks in the injection area changed with each correction. As well, as the beam was slowly worked towards the axis, the overall path length would decrease enough so that injection could no longer be established without an increase to the ring's RF frequency. On some occasions, progress was very slow when a more extensive orbit correction was done on the stored beam. In this case, the injection was re-established using more aggressive tuning.

Once the injection was established on a fully corrected orbit, the sextupoles were turned on with only minor effects. At this point, the tunes could be adjusted and injection re-established with only minimal effort. Operational experience has shown that a capture efficiency of between 20 and 30 % is easily achieved without any special tuning. Detailed scans of the injection coordinates and adjustments to the kicker bump can be helpful in increasing this figure. What seems to be most crucial are adjustments to the longitudinal dynamics. This includes both RF phase adjustments and energy matching the storage ring to the booster.

Optimizing the storage ring injection at the proper operating tunes on a corrected orbit was done during one shift on May 23, 2004. Detailed adjustments of the storage ring RF phase was critical in achieving injection efficiencies greater than 75%. On a test run, the storage ring was filled to greater than 60 mA in 23 seconds, with some injection cycles adding more than 3.5 mA/sec.

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See also: http://www.lightsource.ca/