COMMISSIONING RESULTS FROM THE INJECTION SYSTEM FOR THE AUSTRALIAN SYNCHROTRON PROJECT

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Abstract

Danfysik has built a full-energy turn-key injection system for the Australian Synchrotron. Presently the commissioning is being finalized. The system consists of a 100 MeV linac, a low-energy transfer beamline, a full-energy booster and a high energy transfer beamline. The booster synchrotron delivers a 3-GeV beam with an emittance of less than 30 nm. The lattice is designed to have many cells with combined-function magnets (dipole, quadrupole and sextupole fields) in order to reach this very small emittance. The current in single- and multi-bunch mode will be in excess of 0.5 and 5 mA, respectively. The repetition frequency is 1 Hz. Results from the ongoing commissioning of the system will be presented together with its performance.

INJECTION SYSTEM

The main parameters of the booster synchrotron for the Australian Synchrotron Project (ASP) injection system [1, 2] are given in table 1, and the layout of the whole system is shown in figure 1.

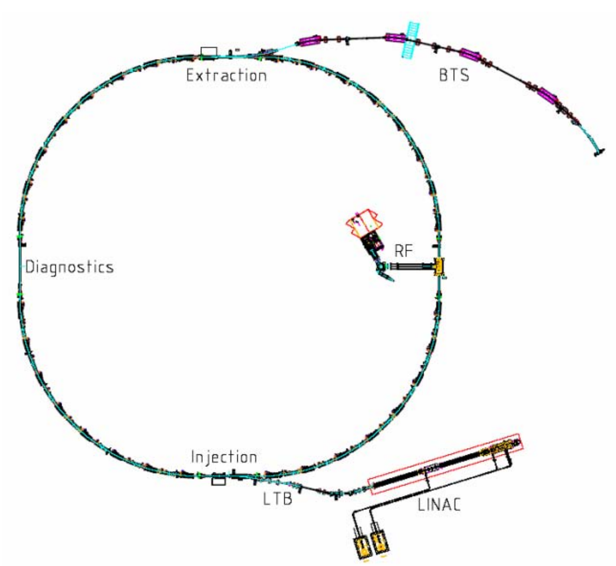

Figure 1: Planar view of the injection system for ASP.

The pre-injector is a 100-MeV linac delivered as a turn-key system from ACCEL. It can operate in either single bunch mode or multi-bunch mode (150 ns). A beamline (LTB) transports and matches the beam to the injection point of the booster. The beam is injected with a pulsed septum magnet and a kicker placed ¼ of a betatron wavelength downstream of the septum magnet. The 1 Hz synchrotron accelerates the beam to a maximum of 3 GeV. The beam is extracted by means of a slow bump, an extraction kicker and a pulsed septum magnet. A transfer beamline, BTS, transports and matches the beam to the injection point in the storage ring. Independent matching of dispersion and betatron amplitude can be made.

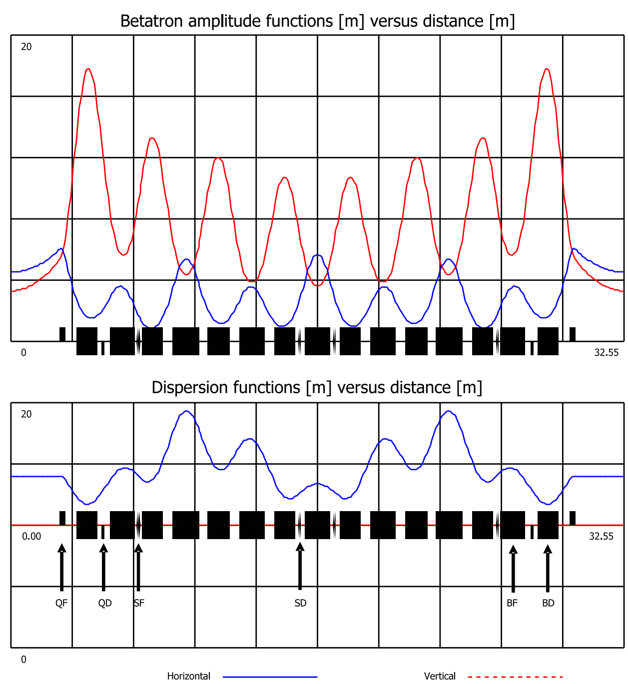

Figure 2: Betatron functions of the lattice.

STATUS

Presently the commissioning of the injection system is in its final stage with many of the acceptance criteria already fulfilled. Utilizing the slow bump, single-turn extraction from the booster has been achieved with no measurable losses, and the extracted beam has successfully been injected into the storage ring. The injection system is currently being used for the storage ring commissioning. Table 1 shows the status of the main parameters.

Table 1: Status of the main parameters

General parameters			
		Design	**Preliminary results**
Energy	E [GeV]	3.0 GeV	3.0 GeV
Emittance	$\varepsilon_H/\varepsilon_V$ [nm]	33/3.3	< 30/1.8

Current in single-/multi-bunch mode	I [mA]	> 0.5/5	0.25/4
Circumference	L [m]	130.2	130.2
Repetition frequency	[Hz]	1	1
Lattice parameters			
Horizontal tune	Q_H	9.2	9.18 – 9.26[a]
Vertical tune	Q_V	3.25	3.12 – 3.21[a]
Natural horizontal chromaticity	$\frac{dQ_H}{d(\Delta p/p)}$	-8.83	N/A[b]
Natural vertical chromaticity	$\frac{dQ_V}{d(\Delta p/p)}$	-11.50	N/A[b]
RF parameters			
RF frequency	f_{RF} [MHz]	499.654	499.654
Harmonic number	H	217	217
RF voltage	V [MV]	1.2	1.2

[a]The tunes drift during the ramp
[b]These measurements have not yet been done

COMBINED-FUNCTION MAGNETS

The main bending magnets of the booster are combined-function (cf) magnets having a dipole, quadrupole, and sextupole field. The horizontal and vertical tunes and chromaticities are mainly determined by these combined-function magnets to (9.20, 3.25) and (1, 1), respectively. Using the trim quadrupoles (QF and QD) and sextupoles (SF and SD), the tunes can be adjusted in the ranges (9.05-9.45, 3.05-3.45) and the chromaticities in the range (0-2, 0-2). In each quadrant of the booster are 7 pairs of horizontally defocusing (BD) and horizontally focusing (BF) cf magnets and a single centrally placed BD cf magnet. Each of the 7 pairs is placed on a common girder (see figure 3).

Figure 3: BD and BF magnets placed on a common girder

During commissioning the horizontal and vertical tunes were measured at 3 GeV. From comparison with the model and assuming no uncertainty in QD and QF quadrupole strength measurements, the combined-function magnets' quadrupole strengths were estimated. The findings are listed in table 2 together with the design values and the averages measured during the factory acceptance test.

Table 2: Combined-function magnets' quadrupole strengths

		BD	BF
Design value	k_{design} [m^{-2}]	0.6698	-0.8260
Factory acceptance test			
Average values	k_{fat} [m^{-2}]	0.6665	-0.8268
Deviation from design		-0.5%	0.1%
Tune measurements			
Estimated values	k_{tune} [m^{-2}]	0.6603	-0.8312
Deviation from design		-1.4%	0.6%
Deviation from FAT		-0.9%	0.5%

EMITTANCE

The transverse emittances were measured using a synchrotron light monitor in the booster. Neglecting the energy spread, the horizontal and vertical emittances were found at 3 GeV to be less than 30 nm and 1.8 nm, respectively. Figure 4 shows the synchrotron light spot from the 3 GeV electron beam. The 1σ beam size is 213 μm horizontally and 129 μm vertically.

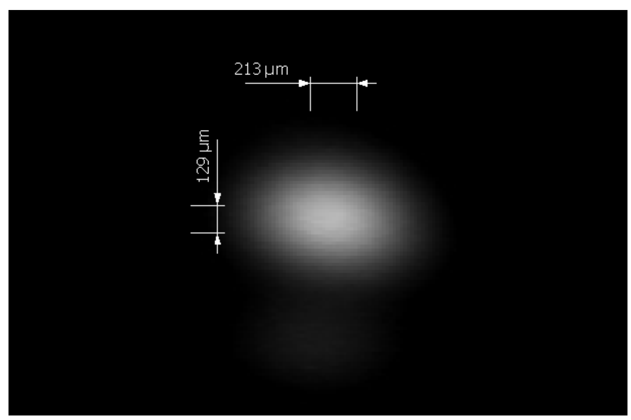

Figure 4: The 3 GeV synchrotron light spot on the synchrotron light monitor CCD. The 1σ beam size is indicated.

TUNES

The tuning quadrupoles, QD and QF, were used to find the tune working point at injection, which gave the lowest losses and was reasonably close to the design working point of (9.2, 3.25). During the energy ramp, the relative strengths of the different magnet families (BD, BF, QD, and QF) were adjusted at seven points from injection to extraction. The main parameter that was optimized on was losses, and no effort was made to keep the tunes strictly constant.

Figure 5 shows the change of tunes during the energy ramp. The beam is injected in the right most point and extracted in the left most point. Resonances up to 4th order are shown. The points are not equidistant in time. The first three points are measured at 10, 20 (100 MeV), and 50 ms (110 MeV) after injection.

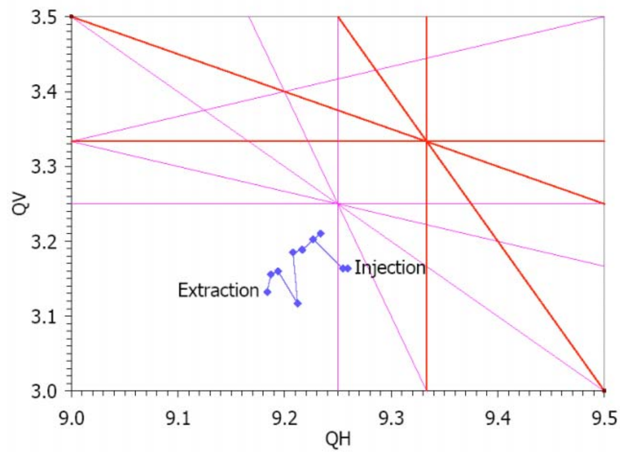

Figure 5: The tune in the booster synchrotron during the energy ramp.

The first horizontal corrector magnet was used to apply a 1.28 mrad kick to the beam at 3 GeV. Figure 6 shows the measured horizontal difference orbit overlaid the theoretical prediction. The orbit suggests the integer part of the horizontal tune is 9 as designed. A good correspondence between the model and lattice is seen.

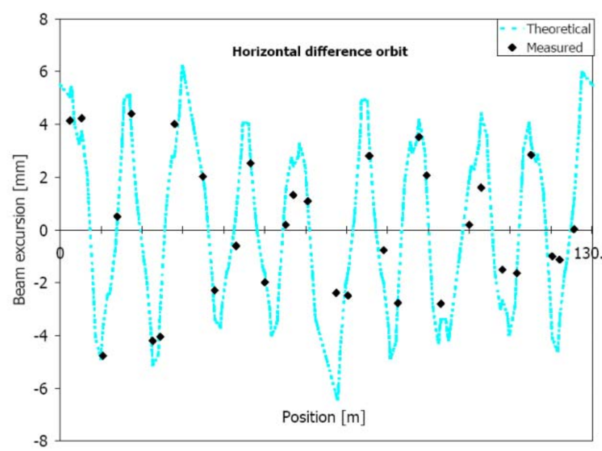

Figure 6: A horizontal difference orbit at 3 GeV.

BEAM CURRENT

Presently 4 mA of circulating beam current has been obtained in multi-bunch mode. Figure 7 shows the current during the energy ramp. The red trace shows the beam energy; the blue trace shows the beam current in the booster (negative scale). The figure predates extraction, and the beam is lost during ramp down.

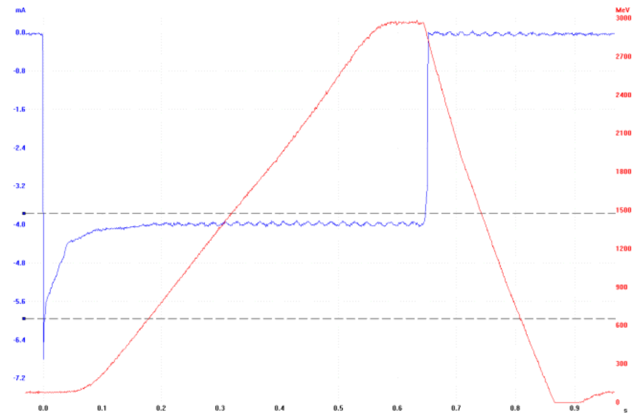

Figure 7: Circulating beam current (negative scale) during energy ramping (multi-bunch mode).

BEAM LOSSES

Beam losses occur shortly after injection and at the early start of the ramp. Virtually no losses are seen at beam energies above 115 MeV.

It was found that a linear ramp yielded the best result in terms of beam losses. Running the correction sextupoles DC reduced the initial losses significantly; ramping the sextupoles gave no additional improvement.

Though the beam is injected on a 4th order resonance, investigations showed that this could not explain the initial losses. Several injection tune points were investigated in the process.

The losses are associated with the initial ramp to 115 MeV. Careful shaping of this part of the ramping curve did not yield smaller losses.

Reducing the energy defining slit opening in the LTB reduced the fractional beam loss, suggesting a variance between the booster energy and transverse acceptance and the linac emittance and energy spread.

OUTLOOK

The injection system is presently being used successfully in commissioning of the ASP storage ring, with most of the acceptance criteria fulfilled.

The main issue to be addressed in the remaining injection system commissioning is the beam current (nominally 5 mA accelerated), and understanding and optimizing the initial beam losses in the booster from around 7 mA to 4 mA.

REFERENCES

[1] S.P. Møller et al, “Status for the injection system for the Australian Synchrotron Project (including combined-function magnets)”, THPKF024, PAC’05.

[2] M. Georgsson et al, “A State-of-the-art 3 GeV Booster for ASP”, TPPE054, EPAC ’04.