FINAL COMMISSIONING RESULTS FROM THE INJECTION SYSTEM FOR THE AUSTRALIAN SYNCHROTRON PROJECT

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Abstract

Danfysik has delivered a full-energy turn-key injection system for the Australian Synchrotron. The system consists of a 100 MeV linac, a low-energy transfer beamline, a 130 m circumference 3-GeV booster, and a high energy transfer beamline. The booster lattice was designed to have many cells with combined-function magnets (dipole, quadrupole and sextupole fields) in order to reach a very small emittance. The injection system has been commissioned and shown to deliver a beam with an emittance of less than 30 nm, and currents in single- and multi-bunch mode in excess of 0.5 and 5 mA, respectively, fulfilling the performance specifications. The repetition frequency is 1 Hz. Results from the commissioning of the system will be presented.

INJECTION SYSTEM

The main parameters of the booster synchrotron for the Australian Synchrotron Project (ASP) injection system [1-3] are given in table 1, and the layout of the whole system is shown in figure 1.

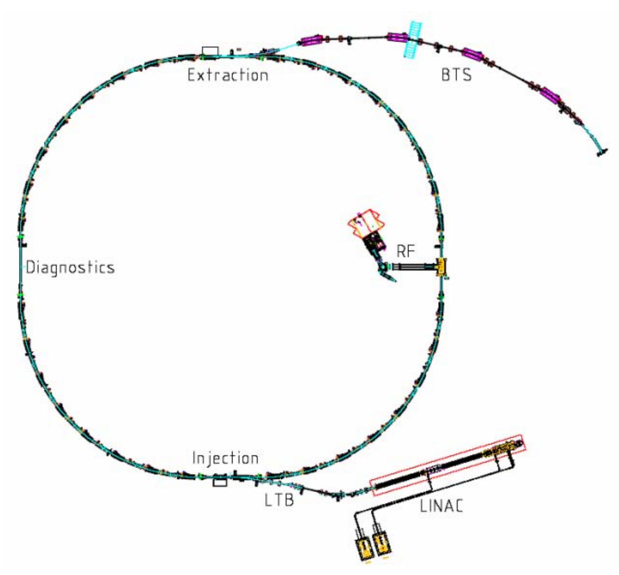

Figure 1: Planar view of the injection system for ASP.

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.

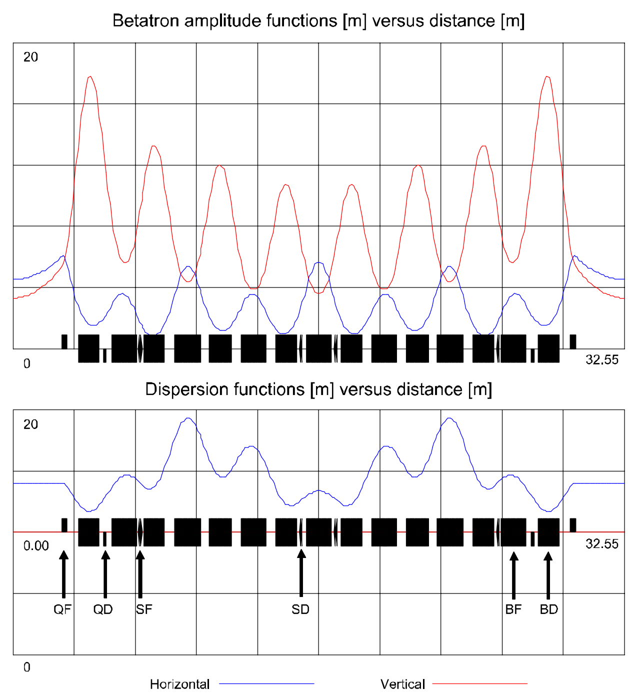

Figure 2: Betatron functions of the lattice.

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 trim quadrupoles (QF and QD) and sextupoles (SF and SD), the tunes and chromaticities can be adjusted in the ranges (9.05-9.45, 3.05-3.45) and (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. The BD family and BF family are on separate power supplies. During commissioning the relative strengths of the BF and BD supplies were varied to optimize the acceleration.

1-4244-0917-9/07/$25.00

COMMISSIONING RESULTS

The commissioning of the injection system was finalized in August 2006. Table 1 shows the main parameters.

Table 1: Main parameters

		Design	Results
Energy	E [GeV]	3.0 GeV	3.0 GeV
Emittance	$\varepsilon_H/\varepsilon_V$ [nm]	33/3.3	< 30/1.8
Current (single-/multi-bunch mode)	I [mA]	> 0.5/5	0.6/6.1
Circumference	L [m]	130.2	130.2
Repetition rate	[Hz]	1	1
Horizontal tune	Q_H	9.2	9.18 – 9.26[a]
Vertical tune	Q_V	3.25	3.12 – 3.21[a]
Horizontal chromaticity	$\frac{dQ_H}{d(\Delta p/p)}$	-8.83	Not measured
Vertical chromaticity	$\frac{dQ_V}{d(\Delta p/p)}$	-11.50	Not measured
Momentum compaction	α_p	0.0098	Not measured
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 are changed during the ramp

Beam Current

An accelerated current of 6.1 mA was obtained in multi-bunch mode. Figure 3 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).

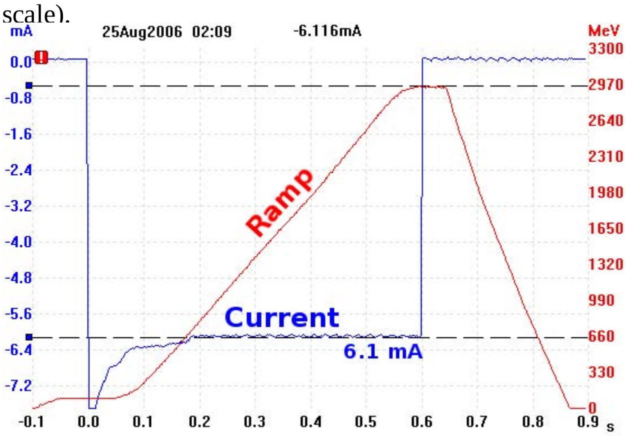

Figure 3: Circulating beam current (negative scale) during energy ramping (multi-bunch mode) .

In single-bunch mode 0.6 mA circulating current at 3 GeV was obtained. For comments on the initial beam losses see [3].

Tunes and Chromaticities

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 losses during the ramp were minimized, and no effort was made to keep the tunes strictly constant.

Figure 4 shows the change of tunes during the energy ramp overlaid a contour plot of the simulated dynamic aperture. 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. The dynamic aperture was investigated using tracking in MAD-X with PTC [4]. Each grey cross in the figure represents a point where tracking was done.

The chromaticities were measured shortly after injection and at 2 GeV. They were found to be between 0.5 and 1.5.

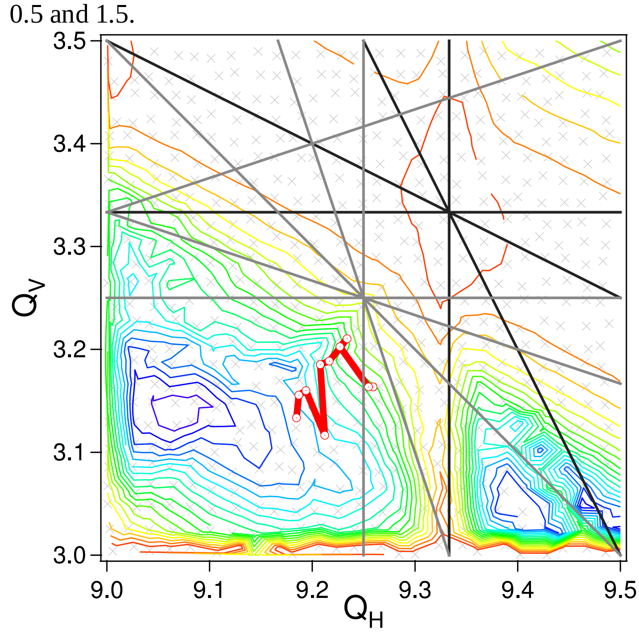

Figure 4: The tune (full red line) in the booster synchrotron during the energy ramp overlaid the simulated dynamic aperture. The black and grey lines are 3rd and 4th order resonances, respectively.

Corrector magnets were used to apply kicks to the beam at 3 GeV. Figures 5 and 6 show the measured horizontal and vertical difference orbits, respectively. Overlaid are the theoretical predictions: the design model and an adapted model. In the adapted model the cf magnets' quadrupole components have been fitted to give the measured tune. The obtained quadrupole components vary during the ramp. The adapted model is on average a much better fit for the data, most visibly for the vertical difference orbit. The causes of the apparent difference in the effective quadrupole component of the cf magnets as well as the breaking of the four-fold symmetry have not yet been fully understood. Likely explanations for the difference in the quadrupole fields are feed-down from the sextupole components on the off-axis beam, and intentional changes in the relative BF-BD strengths during ramping. Misalignment or field errors in one or more elements are possible explanations for the symmetry-breaking. Regardless the cause, the performance of the booster has not been impaired.

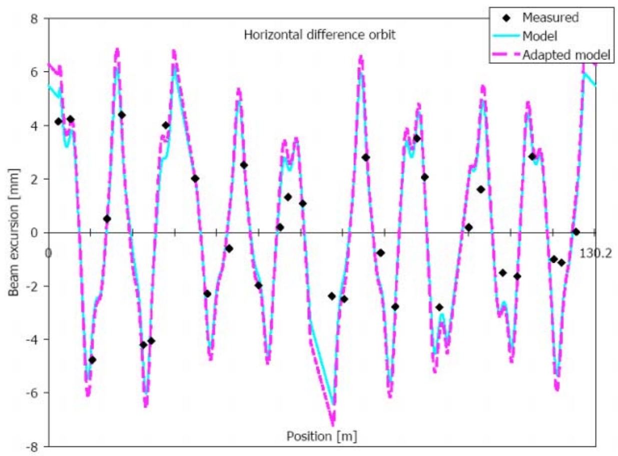

Figure 5: A horizontal difference orbit at 3 GeV.

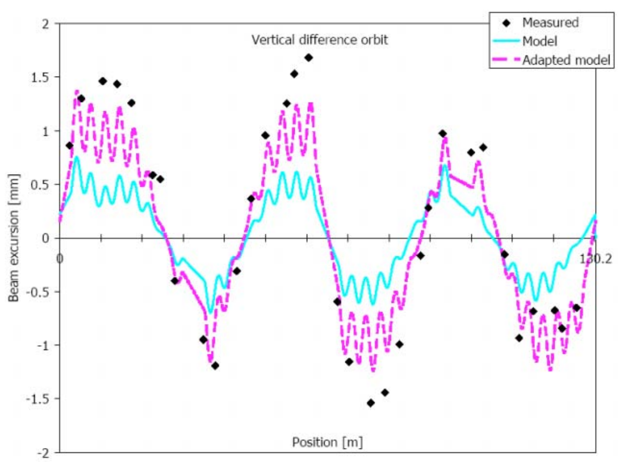

Figure 6: A vertical difference orbit at 3 GeV.

Dispersion Function and Momentum Acceptance

The dispersion function and momentum acceptance was investigated at 100 MeV. Using a separate Master Oscillator, the booster RF frequency was varied while measuring the beam position and maximum circulating current remaining after 1 second. The dispersion function is shown in figure 7 overlaid the design model and an adapted model. As with the difference orbit case the adapted model gives a better average fit but noticeable deviations from the four-fold symmetry exist in the data.

Using the design value for the momentum-compaction, the difference in RF frequency was translated into a momentum deviation. Figure 8 shows the current in the booster after a full second versus the momentum deviation. From this the FWHM momentum acceptance was found to be 2%.

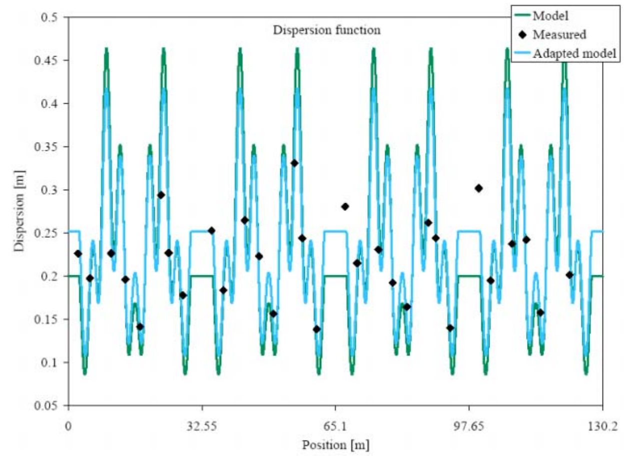

Figure 7: The dispersion function at 100 MeV.

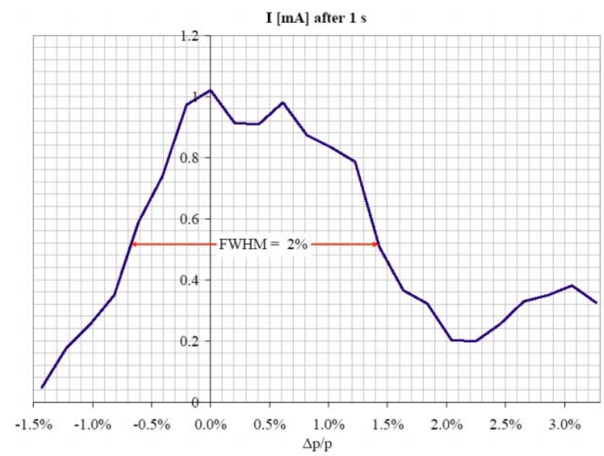

Figure 8: Circulating current after 1 s at 100 MeV.

OUTLOOK

The injection system commissioning was completed in August 2006, with final acceptance for the delivery two months later. The booster design has shown to be sufficiently flexible to compensate the observed differences in the lattice. Presently the injection system is used in the running of the Australian Synchrotron and performing consistently well, with no tuning needed during operation.

REFERENCES

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