A STATE-OF-THE-ART 3 GEV BOOSTER FOR ASP

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Abstract

DANFYSIK A/S will build the full-energy booster for the Australian Synchrotron Project. The Booster will accelerate the beam from the injection energy of 100 MeV to a maximum of 3.0 GeV. The Booster shall accelerate either a single bunch or a bunch train of up to 150 ns. The current accelerated to 3 GeV will be in excess of 0.5 and 5 mA for the two modes, respectively. The circumference of the Booster is 130.2 m, and the lattice will have four-fold super-symmetry with four straight sections for RF, injection, special diagnostics and extraction. The lattice is designed to have many cells with combined-function magnets (dipole, quadrupole and sextupole fields) in order to reach a very small emittance of around 30 nm. A small emittance is beneficial, in particular for top-up operation. Details of the lattice design and beam dynamics of the booster will be presented.

LATTICE

The main parameters of the booster synchrotron are given in table 1, the lay-out is shown in fig. 1, and the lattice functions for one-quarter of the booster are shown in fig. 2.

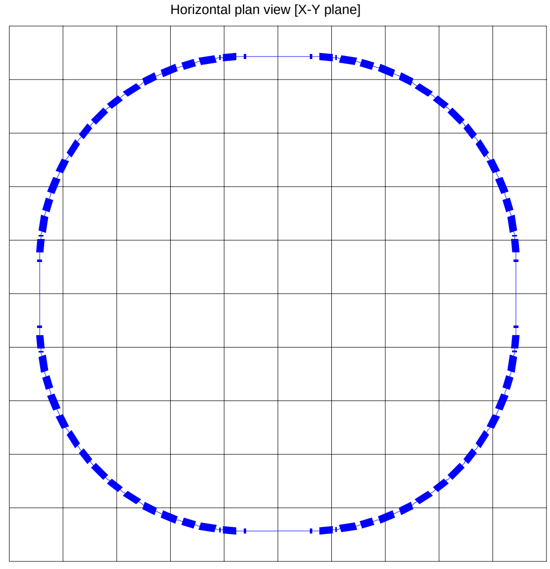

Figure 1. Planar view of booster. Only combined-function and quadrupole magnets are indicated.

The lattice is a FODO lattice with 4 arcs of each 8 horizontally defocusing and 7 focusing combined-function bending magnets, and with 4 straight sections for injection, extraction, RF cavities and diagnostics, and a total circumference of 130.2 m. The lengths of the four straight sections are in excess of 5 m. The lattice will have sextupoles integrated in the combined function magnets correcting the chromaticities to +1 in both planes. The horizontal natural emittance at 3 GeV is 33 nm for horizontal and vertical tunes of 9.25 and 3.20, respectively. Two families of tuning quadrupoles in the lattice allow tuning of the horizontal and vertical tunes in the intervals (9.05-9.45) and (3.05-3.45), respectively.

In order to get a well damped beam in all dimensions, there is a limit to the bending power of the horizontally focusing magnets. Hence the radius of curvature in these magnets is relatively large (22.6 m) as compared to the 7.99 m for the vertically focusing magnets.

The present lattice has a dynamical acceptance in excess of the physical acceptance. The dynamical acceptance is around 40 mm mrad horizontally and 10 mm mrad vertically, when the chromaticities are corrected to the nominal values of +1.

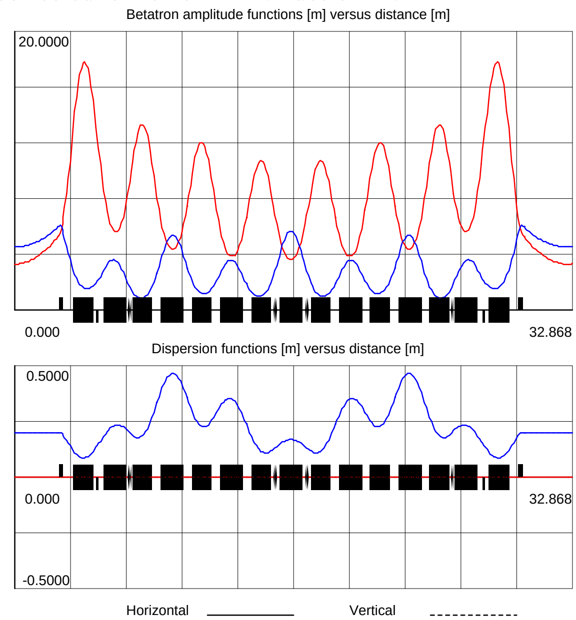

Figure 2. Lattice functions for 1/4 of the ASP Booster. Here also sextupoles are indicated.

CHROMATCITIES AND SEXTUPOLES

In addition to the design of the linear lattice, there is the critical issue about sextupolar fields and chromaticities. Sextupoles are used to decrease the chromaticities to small values in order to reduce the tune spreads, and to positive values to avoid the head-tail instability.

In the present energy regime almost all existing and planned boosters are equipped with sextupoles. Only the CLS booster is operating, very well, with accelerated currents in excess of 15 mA, [1] without sextupoles. We have assessed that in order to have a safe solution for the booster of the ASP, sextupoles are necessary for chromaticity correction. In the present lattice we have chosen to incorporate the main part of the sextupoles in the combined-function magnets, correcting the chromaticities to +1. Two families of tuning sextupoles are included to provide chromaticity changes of ±1 unit.

General Parameters			
Energy	*E* [GeV]	0.10	3.0
Dipole field	*B* [T]	0.015 /0.042	0.44/ 1.25
Radius of curvature	ρ [m]	22.6/7.99	
Current in single-bunch mode	*I* [mA]	>0.5	
Current in multi-bunch train	*I* [mA]	>5	
Charge per bunch in single/multi bunch mode	[nC]	0.22/0.03	
Circumference	*L* [m]	130.2	
Revolution time	*T* [ns]	434	
Injected pulse length	[ns]	2-150	
Max. number of filled bunches		75	
Injected emittance	ε [nm]	<250	
Injected energy spread (rms)		0.5%	
Injected bunch length	[mm]	< 33	
Repetition frequency	[Hz]	1	
Lattice parameters			
Horizontal tune	Q_x	9.2	
Vertical tune	Q_y	3.25	
Horizontal chromaticity	$DQ_x/d(\Delta p/p)$	-8.83	
Vertical chromaticity	$DQ_y/d(\Delta p/p)$	-11.50	
Momentum compaction	α_p	0.0098	
Assumed coupling factor		10%	
Synchrotron Radiation parameters			
Energy loss per turn	U_0 [keV]	0.0009	743
Synchrotron radiation power	*P* [kW]	0	3.7
Natural emittance	ε_x [nm]	0.04	33
Characteristic wavelength	λ_c [Å]	44632	1.65
Characteristic energy	ε_c [keV]	0.0003	7.5
Horizontal damping time	τ_x [ms]	72	2.7
Vertical damping time	τ_y [ms]	93	3.5
Longitudinal damping time	τ_E [ms]	54	2.0
RF parameters			
Damped energy spread	σ_E/E[%]	0.0031	0.094
Damped bunch length	σ_L[mm]	0.3	19
RF frequency	f_{RF} [MHz]	499.654	
Revolution frequency	*f* [MHz]	2.303	
Harmonic number	*H*	217	
RF voltage	*V* [MV]	0.12	1.2
Overvoltage factor	*Q*	∞	1.6
Quantum lifetime	[s]	∞	205
Synchrotron frequency ($\nu=\Omega/2\pi$)	[kHz]	184	100

Eddy-current effects

Fast ramping of the combined-function magnets will induce eddy currents in the vacuum chambers resulting in an induced sextupole component. The induced sextupole component has been estimated according to the "Syphers" formalism in [2] for a 0.7 mm thick vacuum chamber wall, and it has a broad maximum below 0.5 GeV and amounts to k_2 = 0.10m^{-3}. This in turn gives rise to chromaticity changes which are largest in the vertical plane, where it amounts to around 0.5. This can easily be accommodated by the correction sextupoles.

RF

A total RF voltage of 1.2 MV will be provided. This voltage will be produced with a single power source feeding 48 kW into one five-cell cavity of so-called "PETRA" type. In addition, 4 kW has to be delivered into the cavity to compensate synchrotron radiation losses. Finally, the power source should deliver power to losses in the waveguide system, and hence a 75 kW IOT will be used.

INJECTION

One straight section is used for the injection system elements: one 8° injection septum magnet and one fast injection kicker. The injection process is shown in fig. 3. The septum magnet chosen is a pulsed thin septum with a septum thickness of 1.8 mm. The septum blade is placed 20 mm from the central orbit. The septum magnet brings the beam to the septum exit 28.8 mm from the booster axis and 0.583 m upstream from the centre of the straight section. At this point, the beam is inclined towards the booster axis by 25 mrad. The beam crosses the booster axis at the position of the fast injection kicker, whose centre is 1.0 m downstream from the middle of the straight section. The kicker deflects the beam by 1° onto the booster axis, and the fast kicker falls to zero field in less than 250 ns.

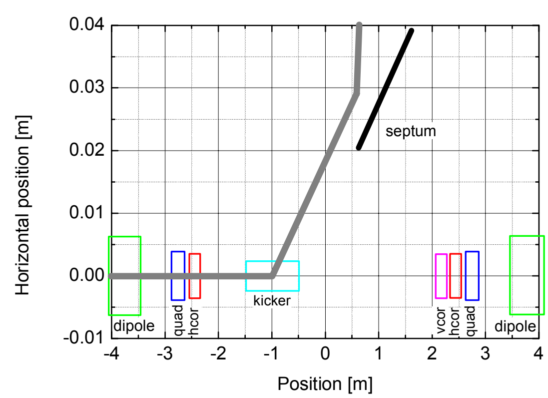

Figure 3. Injection process (electron beam coming in from right)

EXTRACTION

The extraction scheme consists of a fast kicker magnet deflecting the beam into a thin septum magnet deflecting the beam out of the booster to have an angle to the booster axis by 6.86°, assuring the beam stays clear of the downstream combined function magnet.

In order to relax the requirements to the extraction kicker, a local horizontal bump is made. The maximum bump will be 14.5 mm giving a clearance of 3.5 mm (9σ) from the septum blade positioned 18 mm from the axis.

The chosen bumper scheme uses 4 bumpers as indicated on fig. 4. The bump angles are 9.5, 7.9, 8.0 and 11.0 mrad respectively to give the requested bump of 14.5 mm at the entrance to the septum magnet.

The thin septum has a septum blade thickness of 1.5 mm and the septum blade is placed 18 mm from the booster axis. The extraction septum aperture will accommodate around ±16σ both horizontally and vertically at maximum energy. The fast extraction kicker will kick the beam by 5 mrad to a position in the middle of the septum channel at the entrance to the extraction septum magnet of 25.5 mm from the booster axis. From this point the septum magnet will deflect the beam out of the machine. A leak field from the septum magnet of 10 gauss·m will produce a closed orbit distortion of less than 0.5 mm.

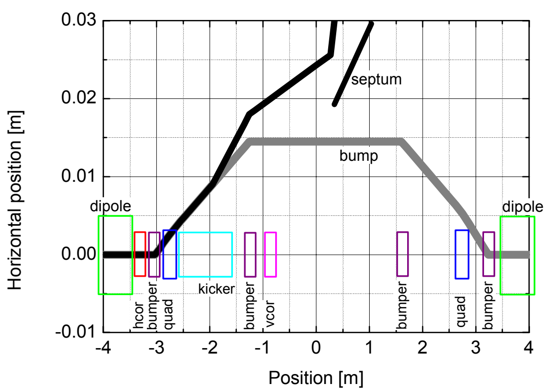

Figure 4. Extraction process (electron beam coming in from left).

MAGNETS AND APERTURES

The aperture requirements to the machine are determined by the beam size and the closed-orbit distortions, which originate from alignment errors and magnetic field errors. The parameters of the combined-function magnets are given in table 2, and figure 5 shows the transverse profile of the horizontally defocusing magnets, BD. With the maximum vertical beta function in the combined-function magnets of 18 m, we get an admittance of 8 mm mrad, corresponding to ±6σ at injection, where the beam emittance is largest. During acceleration the vertical emittance will shrink, first as a result of the acceleration itself and from around 1 GeV due to the synchrotron radiation damping. At a somewhat larger energy, the vertical emittance will increase again since it is finally determined by the horizontal emittance and the coupling to the horizontal plane. The horizontal admittance is significantly larger, around 65 mm mrad.

The requirements to the main combined-function magnets are given in table 2 below. For these magnets the required quality of the quadrupole field of 0.001 corresponds to a tune change of $\delta Q = 0.01\text{-}0.02$.

Table 2 Combined-function magnets

Name of magnet	**BD**	**BF**
Number of magnets	32	28
Max Magnetic field [T]	1.2529	0.4436
Bend angle [°]	8.250	3.429
Arc length [m]	1.150	1.350
Radius of curvature [m]	7.9867	22.5602
Gradient [T/m]	6.6977	-8.2559
Sextupole [T/m^2]	49.2477	-35.4062
Magnet gap [mm]	26	28
Vacuum chamber inner dimensions [mm^2]	40×24	

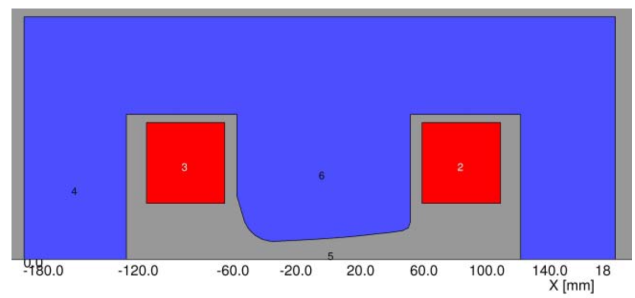

Figure 5. Model of BD magnet

CLOSED ORBIT CORRECTION

The booster will contain 24 horizontal correctors and 12 vertical correctors. We will install 8 BPM's in each arc giving a total of 32 horizontal and vertical BPM's. Different closed-orbit correction procedures will be used including least-squares fit and singular-value decomposition methods.

The chosen number of correctors and BPM's and their positions allows prediction of the performance of the closed-orbit correction system. With the predicted errors, the horizontally/vertically absolute maximum, average and RMS final excursions are 1.76, 0.97, and 0.31 mm /0.74, 0.48 and 0.13 mm, respectively.

CONCLUSIONS

A relatively compact booster with a very small emittance has been designed for the Australian Synchrotron Project. The booster is scheduled to be commissioned around Christmas 2005/2006 with final delivery to performance specifications in April 2006.

REFERENCES

[1] L. Præstegaard et. al., *The Booster for the Canadian Light Source*, in Proc. Part. Acc. Conf., Chicago, 2001, p. 3951.

[2] Chao & Tigner, *Accelerator Physics and Engineering*, World Scientific 1999.