BEAM DYNAMICS ASPECTS OF THE ASP BOOSTER

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Abstract

Some beam dynamics aspects of the 3 GeV booster synchrotron designed and produced by Danfysik A/S for the Australian Synchrotron Project are presented. The booster synchrotron, based on a lattice with combined-function magnets, will have a very small emittance of around 30 nm. The dynamical aperture (admittance) of the booster has been investigated with tracking, and results for different tunes and chromaticities will be presented. Also the reduction in admittance caused by alignment errors of the magnets will be discussed.

INTRODUCTION

DANFYSIK A/S is in the process of building the full-energy booster synchrotron for the Australian Synchrotron Project. The Booster will accelerate a beam from the injection energy of 100 MeV to a maximum energy 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 has a 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 to reach a very small emittance of around 30 nm. A small emittance is beneficial, in particular for top-up operation. The status of the project is summarized in [1].

Table 1: Main parameters of the ASP booster synchrotron

General parameters		
Energy	E [GeV]	3.0
Dipole field	B [T]	0.44/1.25
Curvature radius	ρ [m]	22.6/7.99
Circumference	L [m]	130.2
Revolution time	T [ns]	434
Injected emittance	ε [nmrad]	<250
Lattice parameters		
Horizontal tune	Q_x	9.2
Vertical tune	Q_y	3.25
Horizontal chromaticity	$\Delta Q_x/d(\Delta p/p)$	-8.83
Vertical chromaticity	$\Delta Q_y/d(\Delta p/p)$	-11.50

The parameters of the ASP booster synchrotron relevant for the present paper are given in table 1. A more comprehensive list of parameters can be found in [2].

MAGNET MISALIGNMENT AND CLOSED ORBIT DISTORTIONS

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The 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. The betatron functions are shown in fig. 1 together with the location of the magnetic elements. Using the trim quadrupoles (QF and QD) and sextupoles (XH and XV), 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 there are 7 pairs of horizontally defocusing (BD) and focusing (BF) cf magnets and a single centrally placed BD cf magnet; see figure 1. Each of the 7 pairs is placed on a common girder.

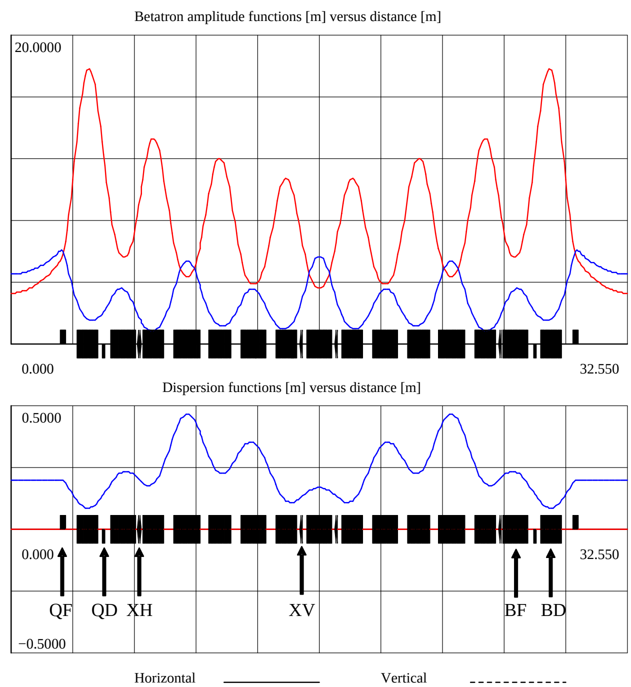

Figure 1: Betatron functions of the lattice.

Alignment errors

Magnetic field and alignment errors lead to closed-orbit deviations. The alignment errors used in this analysis are for the quadrupoles 0.2 mm horizontal and 0.15 mm vertical random displacements, and for the cf magnet girders 0.5 mm longitudinal and 0.15 mm transverse random errors, all RMS. The relative field errors for the dipoles are expected to be no larger than $3{\cdot}10^{-4}$ horizontally and $1{\cdot}10^{-3}$ vertically, corresponding to an RMS angle error of 0.15 and 0.05 mrad, respectively.

When misaligned, the quadrupole field in the cf magnet will give rise to a dipole kick. As each pair of BD and BF magnets are mounted on a common girder, the relative

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alignment error between a BD and a BF magnet in a pair is expected to be much smaller than the alignment error of the individual girders, and this latter error is hence neglected. With this approximation, and as the betatron wavelength is much larger than the length of a BD-BF pair, and assuming a perfect alignment of the BD and BF relative to each other, the total kick angle for the pair can be obtained by adding the individual kick angles.

Using the data from table 2, the kick angle for a BD-BF pair is 0.052 mrad, while the kick angle for the single BD magnet is 0.115 mrad.

Table 2: Parameters of the combined-function magnets

Name of magnet	**BD**	**BF**
Num. of magnets	32	28
Magnetic field [T]	0.0418 – 1.2529	0.0148 – 0.4436
Bend angle [°]	8.250	3.429
Arc length [m]	1.150	1.350
Radius of curvature [m]	7.9867	22.5602
$-dB_z/dx$ [T/m]	6.6977	-8.2559
d^2B_z/dx [T/m^2]	49.2477	-35.4062
Vacuum chamber inner dimension [mm^2]	40×24	

Closed orbit correction

Correction dipoles are mandatory for satisfactory operation of the booster. In total, 24 horizontal and 12 vertical corrector magnets will be installed. In each of the four arcs there will be 8 beam position monitors, giving a total of 32 BPM's.

Closed-orbit deviations have been estimated with the program WinAgile [3] using the above error values. For the cf magnets, the girder angle errors have been added in quadrature to the angles stemming from dipole field errors. As this is done on a per dipole basis rather than per pair basis, the closed-orbit deviations will be overestimated, and this should compensate for the single BD being assigned less than half of its misalignment kick angle, giving a reasonable estimate for the closed-orbit deviations.

For a sample of 100 closed orbits the uncorrected maximal and RMS horizontal orbit excursions are 9.0 mm and 1.6 mm, respectively. Using the correctors this can be reduced to 1.8 mm and 0.3 mm. Likewise the vertical correctors can reduce the vertical orbit excursions from 9.4 mm to 1.0 mm (maximal) and from 1.6 mm to 0.2 mm RMS.

ADMITTANCE AS FUNCTION OF TUNE

Also for the studies of dynamical admittance, we have used WinAgile. First, the horizontal and vertical admittance is found as a function of tune with the tuning sextupoles turned off. No difference in admittance was observed for chromaticities in the range 0-2 for perfectly aligned magnets.

Ignoring misalignment errors

The dynamical admittance is found in the following way. First, a map of a full revolution in the machine was generated. A beam of 1500 particles was generated with a Gaussian distribution. The emittance of the generated beam was chosen so that about 80% of the beam is lost. The particle loss converges after a few hundred turns, and the tracking is stopped after 500 turns.

In figure 2 is shown the emittance of the remaining particles as function of horizontal and vertical tune. As can be seen the choice of tunes (QH, QV) = (9.2, 3.25) leaves ample space for the beam. Although the lower left part of the figure appears to allow for a larger beam, it obviously does not take into account the proximity to the integer resonance, which will have an extended influence, when magnet misalignments are included.

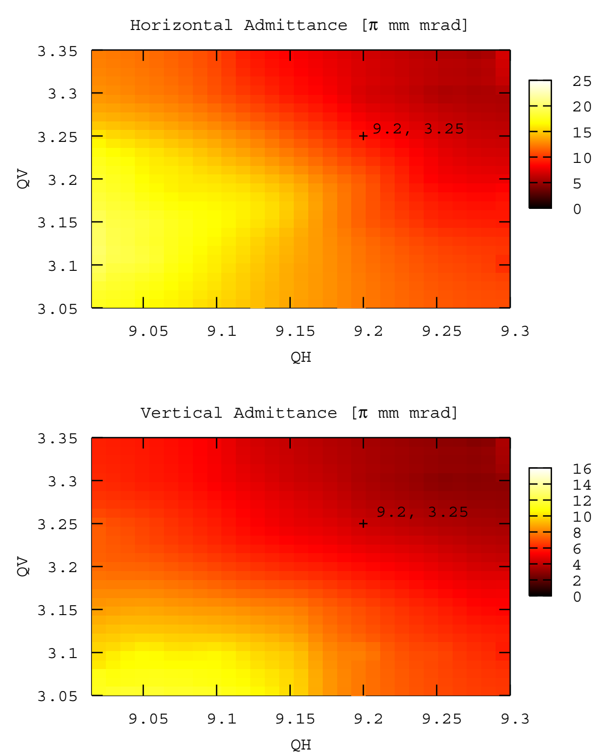

Figure 2: Horizontal and vertical admittances.

Including misalignment errors

When dipole kicks from closed orbit distortions are included, tracking through each element in the lattice has to be carried out. Due to the very large computation time needed to carry out such an investigation, only a qualitative survey has been done at this time. From this investigation several conclusions can be drawn.

Blow-up of the horizontal and vertical emittances is observed due the sextupole fields of the cf magnets. These are strongly increasing with the size of the closed-orbit excursions.

Vertical orbit excursions are much more severe than horizontal as only vertical excursions lead to beam emittance blow-up. For the large horizontal maximal excursion of 9.0 mm and zero (or small) vertical excursions, there is no emittance blow-up in either direction. For the large vertical maximal excursion of 9.1 mm and no horizontal excursions, the coupling between the horizontal and vertical planes results in a slight horizontal emittance blow-up in addition to the vertical blow-up leading to losses.

The beam emittance blow-up for two different closed orbits is shown in figure 3. The first orbit has a maximal horizontal and vertical excursion of 3.5 mm and 9.1 mm, respectively, and the other has 5.1 mm and 3.0 mm. The injected beam initially has the nominal injection emittance. The emittance measurement is stopped when fewer than 25 particles remain. The lifetime of the beams appears from figure 4.

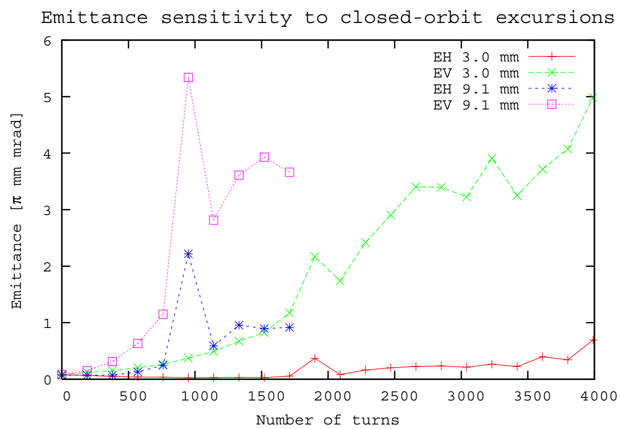

Figure 3: Horizontal and vertical emittances as a function of the number of turns for two beams with different closed orbits. The legend refers to horizontal or vertical emittance and to the maximal vertical excursion of the closed orbit.

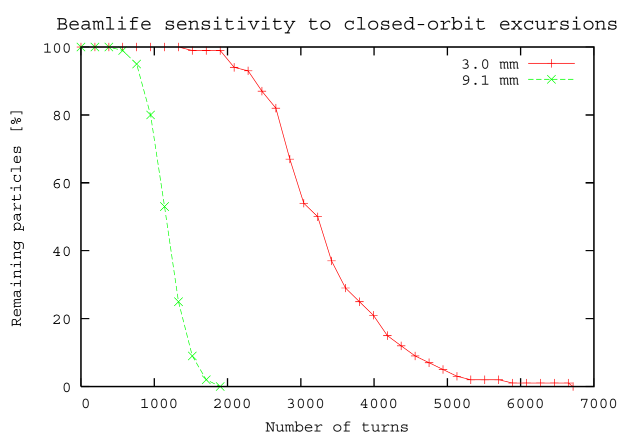

Figure 4: The fraction of remaining particles as a function of the number of turns for two beams with different closed orbits. The legend refers to the maximal vertical excursion of the closed orbit.

As was expected, the beam is unstable in the proximity of the integer resonances. At (QH, QV) = (9.02, 3.13), which had high admittance without alignment errors, the beam is lost within a couple of hundred turns. Moving to (9.09, 3.12) radically increases the number of stable turns. In fact the lifetime of the beam at this tune point is much longer than at the nominal tunes (9.20, 3.25) used for the above simulations. The sensitivity of the beam lifetime to the tunes is shown in figure 5 for a beam with an initial emittance 10 times the injection emittance and a maximal closed-orbit excursion of 3.5 mm horizontally and 9.1 mm vertically. It is evident that there is a great difference between the possible beam lifetimes within the tuning range.

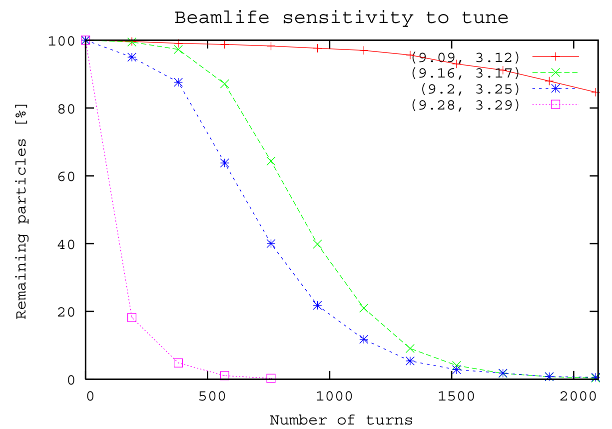

Figure 5: The fraction of remaining particles as a function of the number of turns for selected tunes (QH, QV).

OUTLOOK

Further investigations are planned to asses the importance of closed-orbit correction. Of particular interest is the maximal horizontal and vertical excursions possible for which there will be no significant emittance blow-up and hence no beamloss for the nominal injection emittance after say tens of thousands of turns.

The commissioning of the booster will take place in several steps. The first is to circulate the injected beam one full turn. The second and third step is storage of the beam at injection energy without and with RF. The above analysis shows, that this should be possible without any corrections of the closed orbit. Step 4 is to perform closed-orbit correction at injection energy in order to obtain a long lifetime. In step 5 the beam is ramped to full energy, and in step 6 the orbit of the accelerated beam is corrected followed by extraction of the beam. The characterization of the beam will be done in the seventh and final step.

REFERENCES

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

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

[3] P. Bryant, http://bryant.home.cern.ch/bryant/