Injection and Extraction of the BESSY II Booster and Storage Ring

CH. GEYER, D. KRÄMER, BESSY II Project Team
Rudower Chaussee 5, Gebäude 15.1
D - 12489 Berlin
Germany

Abstract

The layout of the injection and extraction systems of the BESSY II booster and storage ring is presented. A 50 MeV racetrack microtron will be used as preinjector. To inject the beam into the booster it is bent in the horizontal plane by a septum magnet (bending angle 250 mrad). In the multibunch mode the beam is deflected onto the central orbit by a fast kicker ($\alpha_{FastKicker} = 8.7 mrad$).

At full energy (1.9 GeV) the beam is bent with a fast kicker ($\alpha_{Bend} = 2.7 mrad$) into the first extraction septum ($\alpha_{Bend} = 24 mrad$) and finally is extracted by a thick septum ($\alpha_{Bend} = 220 mrad$). Injection into the storage ring is realized by two septum magnets with a deflection angle of 100 mrad and 20 mrad respectively. Four kicker magnets in the straight section generate the required closed orbit displacement of 28 mm.

1 BOOSTER

1.1 Injection

For the injection into the booster synchrotron two alternative solutions were investigated:

- singleturn injection, which is the standard scheme for the multibunch mode. Its advantage is the small number of injection elements: only a septum and one fast kicker are required. The drawbacks of this method are: the need of a fast kicker with a fall time less than 100 ns and the small intensity of the stored currents of 3.3 mA in the booster.

- multiturn injection, which requires three kicker magnets with a moderate fall time of 9 μs instead of one fast kicker. The advantage of this method is the increased stored current of 14 mA in the booster. Therefore the multibunch injection is an interesting option to reduce the filling time of the storage ring in the singlebunch mode from 16 minutes to 3.8 minutes.

Singleturn Injection: A layout of the singleturn injection has been developed together with the Budker Institute of Nuclear Physics in Novosibirsk [1] [2]:
The 50 MeV beam, from the microtron pre-accelerator, is bent in the horizontal plane by a septum magnet, the bending angle being 250 mrad. The injected beam travels through a defocusing quadrupole, a dipole magnet and a focusing quadrupole. It finally enters the fast kicker at an angle of -8.7 mrad. The fast kicker deflects the beam onto the central orbit. A top view of the injection region is sketched in figure 1. The main parameters of the injection elements are listed in table 1.

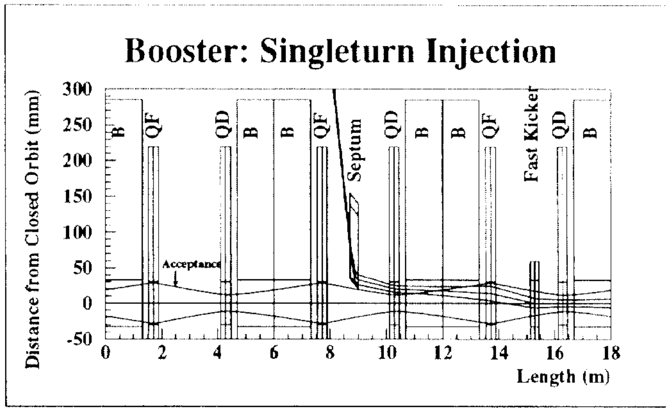

Figure 1: *Injection region for the singleturn injection into the booster*

Multiturn Injection: The multiturn injection scheme allows to store higher currents. The gain of the multiturn injection is defined as the stored beam current achieved by multiturn injection normalized to the stored singleturn current.

	Max. Magn. Induction (G)	Length (m)	Pulse duration (μs)
Septum	1,960	0.300	200
Fast Kicker	49	0.300	0.32

Table 1: *Main parameters of the magnetic elements for singleturn injection into the booster*

To reach a high gain it is necessary to study the influence of the multiturn parameters and their interdependence. Simulations using the program MULTI [3] have been performed to tune the different parameters. Free parameters at a fixed working point are: the optical functions at the end of the transfer line ($\beta_x, \alpha_x, D_x, D_x'$) and the fall time of the magnetic field of the kicker magnets. Assuming an energy spread of $dp/p = 2 \cdot 10^{-3}$, a horizontal emittance of $\epsilon_x = 0.5\ mm \cdot mrad$ and a maximum pulse length of $\Delta t = 2.0\ \mu s$ given by the microtron, one ends up with a gain of 4.2 or a stored current of 14 mA . A phase space diagram of the injected and stored beam is shown in figure 2.

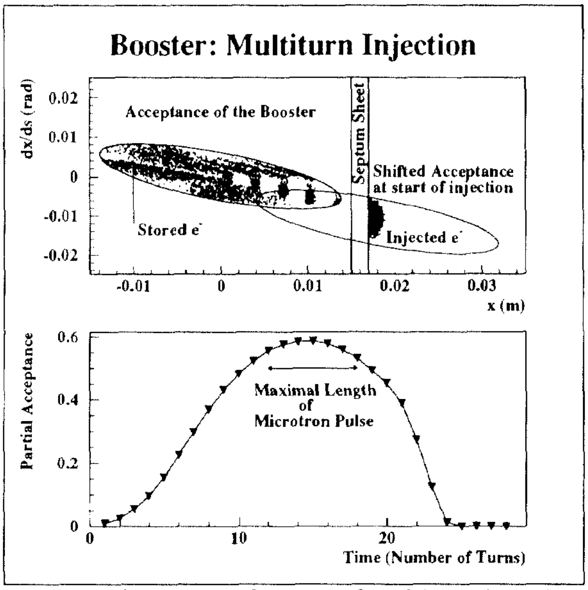

Figure 2: *Phase space diagram of multiturn injection and partial acceptance as a function of time for a septum thickness of 2 mm and a horizontal tune of the Booster of $Q_x = 4.4$.*

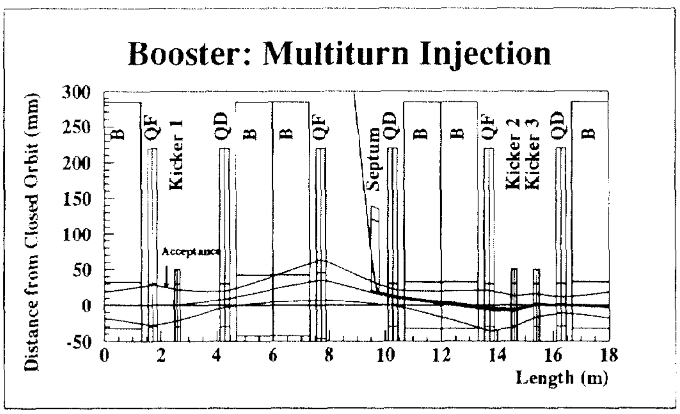

Figure 3: *Top view of the injection region for the multiturn injection into the booster. The $3\sigma_x$ - envelope, the maximum closed orbit distortion and the booster acceptance are illustrated.*

The optimized parameters of the multiturn injection are presented in table 2.

In the multiturn injection process three kicker magnets bump the closed orbit to the septum. The magnetic fields required to achieve a maximum closed orbit distortion of 18 mm at the end of the septum are modest: $B_{max,1} = 48$ G, $B_{max,2} = 126$ G and $B_{max,3} = 110$ G. The length of each kicker is 200 mm. Injection starts when the closed orbit distortion is reached and decreases again. The reduction of the closed orbit bump prevents the electrons, from colliding with the septum foil, when coming back after some turns round the booster. The injection process ends when the closed orbit bump is reaches zero.

Quality of the injected Beam	
Horizontal emittance ϵ_{inj}	0.5 mmmrad
Momentum spread $\frac{dp}{p}_{inj}$	2 o/oo
pulse length	$\geq 10\mu s$
Optical Functions at the End of the Transferline	
Horizontal beta function β_{inj}	0.25 m
α_{inj}	0.0 rad
Horizontal dispersion D_{inj}	0.0 m
Derivative of the dispersion D'_{inj}	0.0 rad
Distance between the septum and the center of the injected beam dx	0.5 mm
Angle of the injected beam relative to the undistorted C.O. dx'	-10.5 mrad
Booster Parameters	
Horizontal bet function β_{SR}	2.3 m
α_{SR}	0.938 rad
Horizontal dispersion D_{SR}	0.77 m
Derivative of the dispersion D'_{SR}	0.269 rad
Horizontal Acceptance A_{SR}	84 mmmrad
Horizontal tune Q_x	4.4
Parameters of the Injection Elements	
Thickness of the septum sheet d_{Septum}	2 mm
Distance between the septum and the undistorted C.O.	15 mm
Kicker fall time τ	9.0 μs
Maximum C.O. distortion	18 mm
Maximum angle distortion of the C.O.	-11.6 mrad
Gain	**8.38**

Table 2: *Optimized set of parameters for multiturn injection at a horizontal tune of $Q_x = 4.4$ and a septum thickness of $d_{Septum} = 2mm$*

The layout of the septum is the same as in the case of singleturn injection mode.

In figure 3 the injection region for multiturn injection is shown including the maximum closed orbit bump and the 3 σ_x - envelope of the incoming beam.

1.2 Extraction

The extraction system of the booster consists of two parts: three kicker magnets to push the closed orbit to the extraction septa and a fast kicker, a pre - and main septum which extract the beam.

To extract the beam at full energy the closed orbit is bumped to the extraction pre-septum. The electron beam is first deflected by a fast kicker ($\alpha_{FastKicker} = 2.7$ mrad), then deflected by the pre-septum by 24 mrad. The main septum finally extracts the beam. Its bending angle is 217 mrad. In figure 4 the layout of the extraction region is presented. The main parameters of the extraction elements are summarized in table 3.

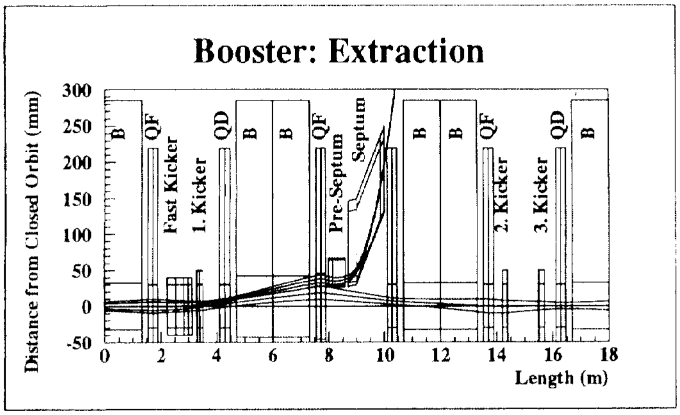

Figure 4: *Top view of the extraction region of the booster. The $3\sigma_x$ - envelopes for the distorted and extracted beam are shown.*

The extracted beam travels through the last focusing quadrupole with a large offset of 38 mm from the magnetic axis. Which is significantly outside the 'good field radius' of 30 mm. This leads to an emittance growth since the quadrupole gradient changes across the transversal beam dimensions.

	Max. Magn. Induction (G)	Length (m)	Pulse Duration (μs)
Closed Orbit Distortion:			
Kicker 1	1,130	0.200	150
Kicker 2	990	0.200	150
Kicker 3	-380	0.200	150
Extraction:			
Fast Kicker	210	0.900	0.32
Pre-Septum	2,670	0.600	200
Septum	11,100	1.30	200

Table 3: *Main parameters of the magnetic elements for the booster extraction*

A Monte Carlo program was developed to study this effect. At an offset of 38 mm the emittance of $\epsilon_i = 0.2$ mmmrad grows by 50 % which seems to be tolerable. In figure 5 the emittance growth as a function of the beam offset in the quadrupole is shown.

2 STORAGE RING

2.1 Injection

To inject the beam into the storage ring the closed orbit is shifted parallel to the septum magnet by four kicker magnets. The length of each kicker is 600 mm. Their maximum magnetic field is $B_{max} = 4.44$ kG.

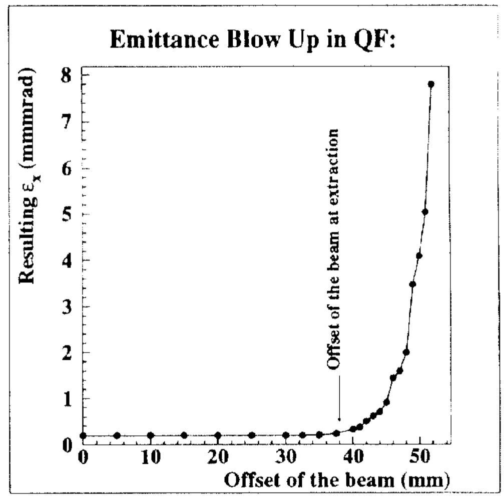

Figure 5: *Emittance growth as a function of the beam's offset when passing the last quadrupole QF at extraction.*

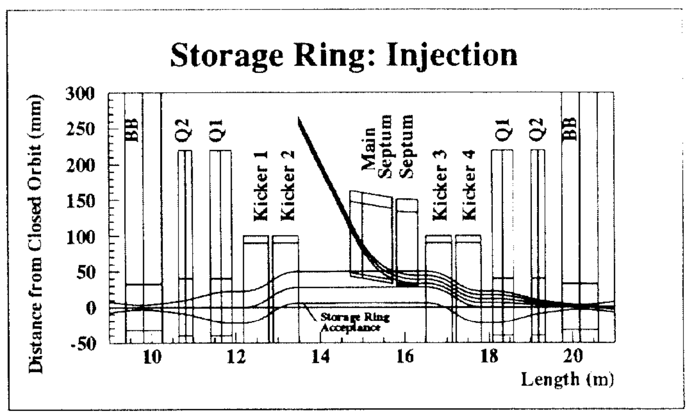

Figure 6: *Top view of the injection section of the storage ring. Sketched are the $3\sigma_x$ - envelopes of the injected beam, the maximum closed orbit distortion and the acceptance.*

The length of the main septum is 1 m, its maximum magnetic field $B_{max} = 6.67$ kG. The corresponding numbers of the pre-septum are l = 500 mm and $B_{max} = 2.67$ kG. Kickers and septa are driven by sine half wave pulsers with a time constant of $\tau_{Kicker} = 4.\mu s$ and $\tau_{Septa} = 200 \mu s$. A top view of the injection section is shown in figure 6.

3 REFERENCES

[1] *B. N. Sukhina et al.*, BINP, Novosibirsk: priv. communications

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[3] *M. Grieser*, MPI für Kernphysik, Heidelberg: priv. communications