CONCEPTUAL DESIGN OF A BOOSTER PS FOR DESY–III

IHEP– DESY Project Team: compiled by S. Ivanov[1] and J. Maidment[2]
[1] IHEP, PO35, Protvino, Moscow Region, 142284, Russia
[2] DESY, Notkestrasse 85, D–22607, Hamburg, Germany

Abstract

Within the framework of the IHEP–DESY Collaboration, IHEP has completed a design study of an 800 MeV Booster PS for DESY–III, the first circular accelerator of the HERA *p*-injector chain. Use of this ring offers a factor 5 increase in the space-charge limit of DESY–III. Achieving brighter *p*-beams is one of the future options presently discussed in the HERA luminosity upgrade [1]. This paper outlines technical details of the proposed Booster synchrotron.

1 INTRODUCTION

Protons are accelerated in DESY–III from 50 MeV (kinetic energy) to a momentum of 7.5 GeV/c. The beam intensity is $N \simeq 1.3 \cdot 10^{12}$ p.p.p. in 11 bunches. Normalized transverse emittances $\varepsilon_{z,x}$ (at 1σ, without π) are about 2.5 μm vertically, z and 5.0 μm horizontally, x. The transverse beam brightness ($\propto N/\varepsilon_{z,x}$) is limited by the Coulomb tune shift effect.

To increase the space-charge limit of DESY–III by a factor of 5, an intermediate Booster synchrotron is proposed. Its primary specification is given in Table 1.

Table 1: Main parameters of the Booster

Repetition rate	1	Hz
Maximum energy (kinetic)	800	MeV
Injection energy (kinetic)	50	MeV
Beam intensity	$\geq 2 \cdot 10^{11}$	p.p.p.
Circumference	57.6	m
Revolution frequency	1.635–	
	–4.381	MHz
RF harmonic number	2	
Vertical emittance, ε_z	0.8	μm
Horizontal emittance, ε_x	1.2	μm
Bunch longitudinal area	≤ 0.080	eV·s

The input beam comprises ∼6 turns of (50±0.12) MeV H^- ions from Linac–III injected via a thin stripping foil. RF capture is quasi-adiabatic resulting in 2 bunches with a bunch-factor (bunch length/bunch separation) B=0.54, full momentum spread $\Delta p/p$=±0.28%, and longitudinal area 0.068 eV·s. At injection, for the lattice adopted, the subsequent Coulomb tune shifts are ΔQ_z=0.20 and ΔQ_x=0.14.

5 Booster cycles are used to fill 10 of 11 DESY–III buckets in 4–5 s. Two bunches are injected on each occasion. One bucket is left empty to ease injection into DESY–III.

The Booster may be sited in the existing Experimental Hall 1. Fig. 1 shows its plan view. The straight section containing the RF cavity runs anti-parallel to the Linac–III output beam line. Space is provided inside the hall to permit outer radiation shielding assembled from 80 cm thick heavy-concrete blocks.

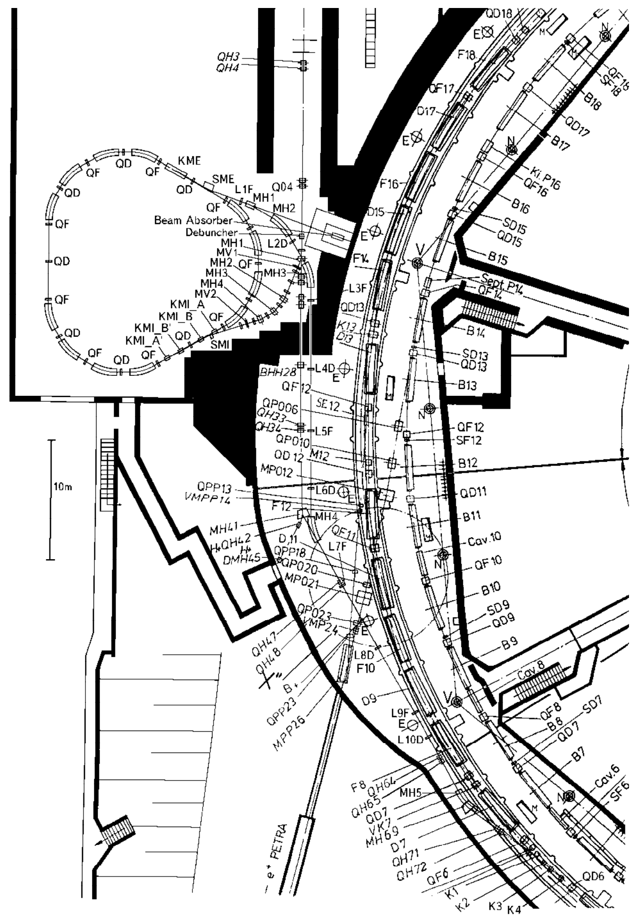

Figure 1: Plan view of the Booster and DESY–III.

Injection into and extraction from the Booster are performed horizontally. The Booster orbit is in the same plane as that of DESY–III. The beam path is elevated from the Linac's level in the injection beam-line.

During commissioning and machine studies, the extracted beam is directed to an absorber.

The ejection beam-line terminates in straight section #6 of DESY–III presently used for injection from Linac–III. The existing (50 MeV) beam-line from the Linac will thus be replaced.

2 TECHNICAL DESCRIPTION

2.1 Lattice and Magnets

There are 12 dipoles (D), 9 focussing (QF) and 9 defocussing (QD) quadrupoles arranged in a FODO pattern as shown in Fig. 2. The lattice has a 3-fold symmetry, a total length of 57.6 m and consists of 3 superperiods *ab*, *bc*, *ca* of 19.2 m length each. A superperiod contains 3 cells of 6.4 m. Dipoles are omitted from each central cell yielding six 2.97 m long utility straight sections to house RF cavity, injection and ejection systems, etc.

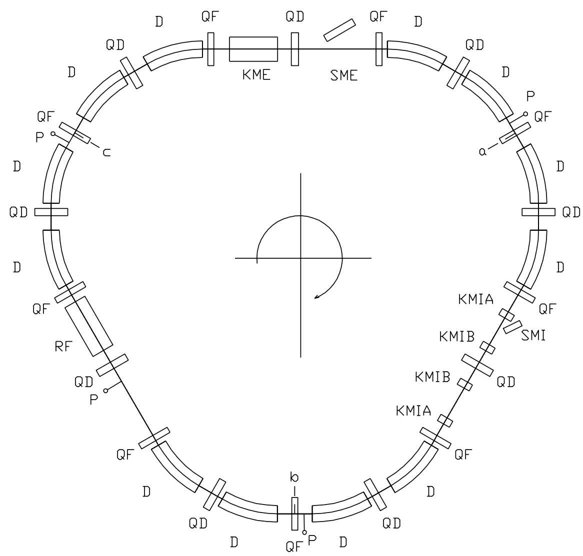

Figure 2: Layout of the Booster.

The transition energy γ_{tr}=2.208 (1.133 GeV kinetic) is set above the top design energy of the ring. The nominal working point is put into the center of the stability region (Q_z=2.25, Q_x=2.25), some variation is possible. The natural linear chromaticity $\chi = p(\partial Q/\partial p)$ is -1.854 vertically and -1.277 horizontally. Fig. 3 shows the amplitude and dispersion functions within a superperiod.

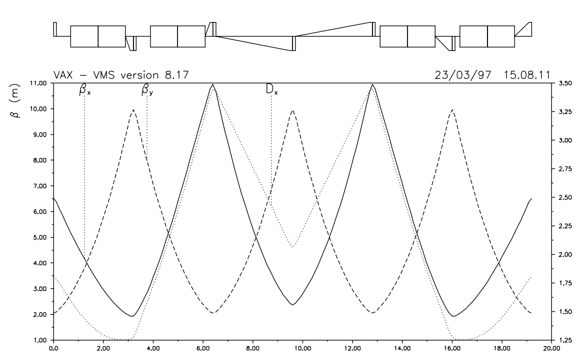

Figure 3: Dynamical functions of the lattice.

The magnet parameters are listed in Table 2. To provide aperture for the injected beam and retain the ring symmetry 3 QDs in the center of each superperiod have an enlarged 84.6 mm inner diameter obtained with a pole face tooling.

Table 2: Lattice magnet data

Dipole magnet D		
Magnetic length	2.2	m
Bending radius	4.2017	m
Bending angle	30	deg
Field at 50/800 MeV	0.2464/1.1617	T
Rate of field rise	2.615	T/s
Gap	64	mm
Quadrupole QF		
Magnetic length	0.230	m
Ratio $G/(B\rho)$	1.5956	m^{-2}
Gradient at 50/800 MeV	1.656/7.810	T/m
Rate of gradient rise	17.58	T/m/s
Diameter	75	mm
Quadrupole QD		
Magnetic length	0.230	m
Ratio $G/(B\rho)$	1.8973	m^{-2}
Gradient at 50/800 MeV	1.973/9.304	T/m
Rate of gradient rise	20.94	T/m/s
Diameter	75 (84.6)	mm

For orbit correction, 9 vertical plus 9 horizontal individually powered dipole correctors are installed near each focussing (for a given direction) lens. Their integrated field strength is 0.0042 T·m. Prior to extraction, a pulsed horizontal orbit bump is applied. Additional windings on 4 correctors adjacent to the ejection straight increase the strength to 0.014 T·m.

The 3 D-, QF- and QD-circuits are independently powered and provide betatron tune adjustment within ±10%.

To correct for linear betatron coupling 2 skew quadrupoles with integrated gradient 0.06 T are foreseen.

Chromaticity is kept close to zero (negative) throughout the cycle by 3 vertical and 3 horizontal sextupole correctors with integrated double gradient 12 T/m.

2.2 Vacuum System

The stainless steel beam pipe has an elliptic cross-section of 59×87 mm^2 internally (vertical × horizontal) which is sufficient to accommodate the beam at $\pm4\sigma$ level. The wall thickness is 1.5 mm. The pipe size is kept constant around the ring, the only exception being a segment of injection straight section near and inside QD where the chamber is extended to 59×112 mm^2.

The residual gas pressure is $\lesssim 2\cdot10^{-7}$ Torr to ensure emittance growth $\lesssim$10% due to beam-gas scattering. The ring and in/out beam-lines are evacuated with sputter-ion pumps whose pumping speeds are 100 l/s (7 units), 250 l/s (9) and 400 l/s (1). To achieve a pre-vacuum, a moving pump station with a 100 l/s turbo-molecular pump is employed.

2.3 Accelerating System

A ferrite loaded cavity similar to that in use at DESY–III is used. The frequency range is 3.269–8.763 MHz. The acceleration time of 0.4 s (of which 0.3 s is a simple linear ramp) complies with a 1 Hz cycle rate. The peak energy gain is 0.633 keV/turn and the RF voltage V is kept constant at 3.0 kV during the bulk of acceleration, being ultimately lowered to 0.9 kV to match bunches longitudinally at transfer. An adiabatic 100%-capture regime is foreseen with a slow linear ramping of V from 0 to 3.0 kV in 3 ms during a soft start of dB/dt from flat-bottom.

The RF system is equipped with several control loops: (1) a DC-coupled feedback around the power amplifier to handle varying beam loading of the cavity; (2) a combination of AC-coupled phase and amplitude beam feedbacks to damp the in-phase mode of dipole and quadrupole oscillations of bunches; (3) a conventional DC-coupled tuning loop closed via the ferrite bias current circuit to keep the loading angle at 0°. Any out of phase dipole motion is damped before transfer on a 100 ms flat-top with a fixed-frequency beam feedback acting through the RF cavity driven off-resonance at 4.381 MHz (half of the top frequency).

2.4 Injection and Ejection Systems

The injection system is sketched in plan view in Fig. 4. The beam is injected horizontally in ∼6 turns. Pulsed kicker magnets KMI_A, KMI_B, KMI_B′ and KMI_A′ drive a fast symmetrical bump of the closed orbit. The H^- beam enters via septum SMI into KMI_B and merges with a circulating p-beam upstream of QD. On being stripped in the thin (≲40 μg/cm^2) carbon foil, the injected particles arrive at the prescribed orbit. Magnet data is given in Table 3.

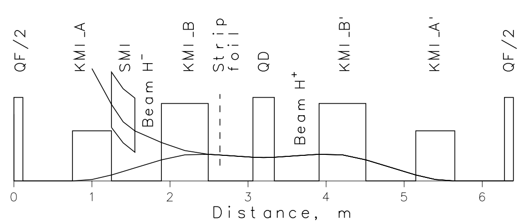

Figure 4: Beam injection into the Booster.

Table 3: Injection system magnets

	KMI_A	KMI_B	SMI
Length, m	0.500	0.600	0.300
Field strength, mT	73.6	74.5	552
Aperture V×H, mm^2	38×76	52×106	33×46
Deflection, mrad	35.5	43.2	160.0
Fall time of field, μs	2	2	—

The ejection system is sketched in Fig. 5. The beam is ejected horizontally in 1 turn with kicker (KME) and septum (SME) magnets. The central QD increases the deflection towards SME. To relax requirements on KME, a closed-orbit bump resulting in a 10.6 mm beam off-set at the entry to SMI is driven with 4 normal dipole correctors DCH. Magnet data is given in Table 4. The rise time of the fast kicker KME allows a bunch length of at most 150°(RF). The bunch length at transfer is ≲130°, which leaves an 8 ns safety gap.

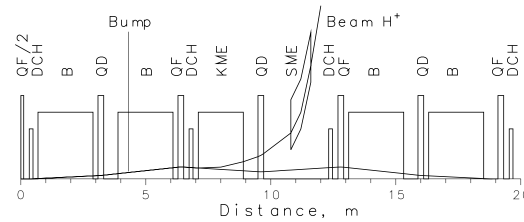

Figure 5: Beam ejection from the Booster.

Table 4: Ejection system magnets

	KME	SME
Length, m	1.800	0.800
Field strength, mT	33.7	964
Aperture V×H, mm^2	52×76	30×45
Deflection, mrad	12.43	158.0
Rise time of field, ns	65	—

2.5 Beam Transfer Lines

A plan view of the injection and ejection beam-lines is shown in Fig. 1.

The injection line length (from the existing Q04 to QF/2 in the Booster) is 21.919 m along the beam path. There are, in total, 8 quadrupoles, 4 horizontal and 2 vertical bending dipoles installed. The beam is deflected by 60° to the right and elevated by +44 cm in height from Linac–III level to the plane of the Booster. The elevation angle is 64.5 mrad w.r.t. the horizontal plane.

The ejection line length (from QF/2 in Booster to QD6/2 in SS#6 of DESY–III) is 74.739 m along the beam path. There are 10 quadrupoles and 5 horizontal bending dipoles. The beam is directed to an absorber by the unpowered switch dipole MH1. Bending magnets MH2–5 are identical to the Booster dipoles (MH2–4 are powered to ensure a standard 30° bend). Ejection and injection beam-lines cross with a 44 cm separation in height. The section MH3–MH4 runs parallel (at ∼0.8 m) to the existing beam-line from the Linac to DESY–III. After MH4 the new beam-line has the same horizontal projection as the former one.

Each beam line provides matching of the lattice functions at the input of the Booster and DESY–III respectively.

3 REFERENCES

[1] W.Ebeling, J.Maidment, in Proc. of the Workshop 1995/96 *"Future Physics at HERA"*, v.2, p.1167.