A PROJECT OF THE 2.5 GEV BOOSTER-SYNCHROTRON IN BINP

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Abstract

A project of the 2.5 GeV booster synchrotron to provide effective injection of electron and positron beams into VEPP-2000 and VEPP-4M storage rings, and for future facilities, is developing in BINP. The beams are injected to synchrotron at 510 MeV energy from a damping ring, which is the part of the new injection facility [1]. In this report, the synchrotron parameters are presented, the basic systems are briefly described.

INTRODUCTION

The main feature of the booster is heavy current (~50mA). The booster (see Fig. 1.) consists of two half-rings and two long straight section. Main parameters of the booster are presented in Table 1.

Table 1: Booster Parameters

Injection energy	0.51 GeV
Extraction energy	2.5 GeV
Circumference	132 m
Cycling frequency	1 Hz
Emittance	50 nm
Momentum compaction	0.0132
Betatron tunes: Q_x/Q_y	9.116 / 9.1
Chromaticity: ξ_x/ξ_y	−11.6 /−11.4
R.m.s. energy spread	8.2×10^{-4}
Energy loss per turn	517 keV
Damping times: τ_x, τ_y, τ_s	4.4, 4.2, 2.1 ms
Beam current	50 mA
RF frequency	181 MHz
Harmonic number	80
Synchrotron tune: Q_s	7.6×10^{-3}

MAGNET LATTICE

The FODO lattice with 4-fold symmetry is used for the booster. One period consists of 7 standard FODO cells and 1 cell without one bending magnet. To provide enough space for the injection and extraction devices and for the RF cavity, two long straight sections are used.

The betatron amplitude functions are regular in the half-rings and are increased in the straight sections to provide effective beam storing. The dispersion is small everywhere in the ring, and it is practically zero in the straight sections. Optical functions of one half of the booster are shown in Fig 2.

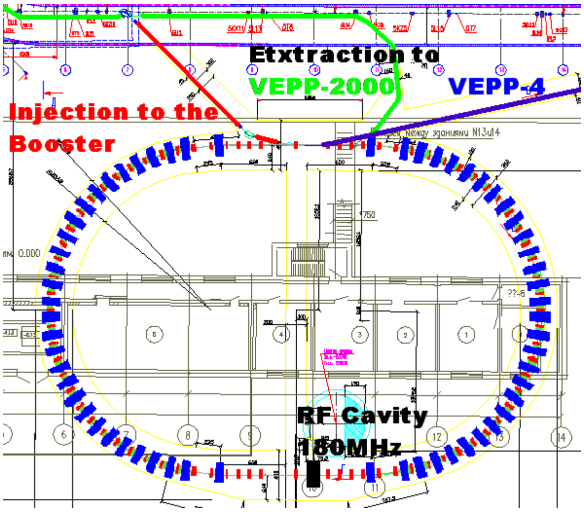

Figure 1: Layout of the synchrotron.

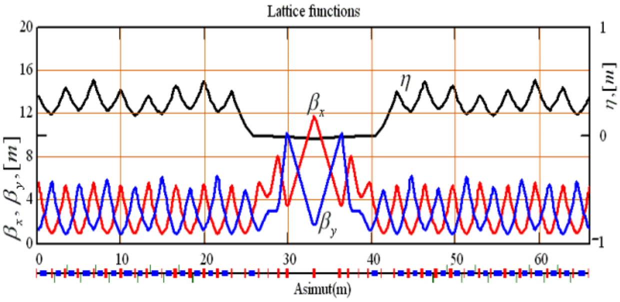

Figure 2: Optical functions.

Emittance of accelerated beam in the booster for the different final energy are shown on Fig. 3.

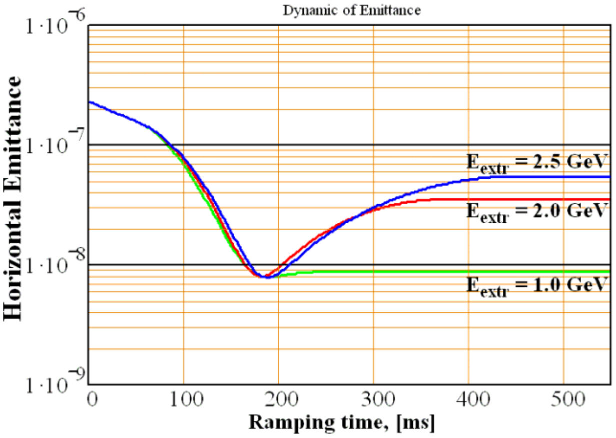

Figure 3: Beam emittance during the energy ramp.

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CLOSED ORBIT AND BEAM ENVELOPE

The magnet misalignments and field errors produce a closed orbit distortion (COD), which should be reduced to rather small values. Orbit correction system of the booster synchrotron consists of 48 beam position monitors (BPMs), 28 horizontal and 24 vertical correctors. The numbers of BPMs and correctors are chosen to provide good COD correction with reasonable values of the correctors' strength.

To examine the orbit correction scheme, a computer simulation of COD has been carried out using the MAD code. A set of 500 COD samples was calculated with random misalignment and field errors applied to each magnet. The error values have Gaussian distribution truncated at 2σ, where σ is the standard deviation. The tolerances are presented in Table 2.

Table 2:

Error type	σ
Magnet displacement: $\Delta x, \Delta y, \Delta s$	0.1, 0.1, 0.1 mm
Magnet rotation angle	0.5 mrad
Dipole field error $\Delta B/B$	0.5×10^{-3}
Quadrupole gradient error $\Delta G/G$	1.0×10^{-3}
BPM reading error	50 µm

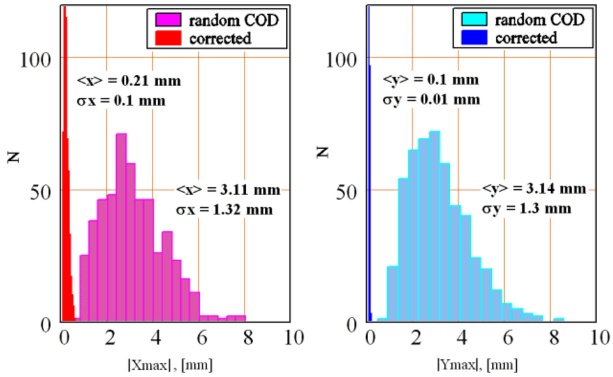


Figure 4: COD distribution before and after correction

The simulation results are shown in Figure 4, there are histograms of maximum values of the 500 random CODs, before and after correction. Assuming Gaussian distribution of probability, a mean value and standard deviation have been calculated from each histogram. The results are listed in Table 3.

Table 3:

	$\langle x \rangle$	σ_x	$\langle y \rangle$	σ_y
Max. random COD, mm	3.11	1.32	3.14	1.3
Max. corrected COD, mm	0.21	0.1	0.1	0.01
Correctors' strength, mrad	0.2	0.04	0.19	0.03

Residual beam oscillation after injection and maximal possible COD estimated above determine demands for geometric aperture of the vacuum chamber:

$$x_{max}=12.4\text{ mm}=4.4\text{ mm (COD)}+8.0\text{ mm (beam size);}$$
$$y_{max}=7.5\text{ mm}=4.5\text{ mm (COD)}+3.0\text{ mm (beam size).}$$

Taking into account a heavy-current booster and possible transverse instabilities of the beam, we have adopted for the aperture:

$$A_x = \pm 25\text{ mm}, \qquad A_y = \pm 12\text{ mm}$$

in all the elements of the booster synchrotron.

For the chosen geometry of the vacuum chamber the values of longitudinal and normalized transverse impedance are estimated as ≤ 0.5 Ω and ≤ 0.2 MΩ correspondingly [2]. In a single-bunch mode the current is expected to be limited by the vertical instability at 60 mA. In radial plane there are no limits, because radial aperture is 2 greater than vertical.

DYNAMIC APERTURE

To compensate the natural chromaticity $\xi_x = -11.6$, $\xi_y = -11.4$, 2 family of sextupole magnets are used. Total number of sextupole magnets is 56, 28 focusing and 28 defocusing ones. However, during the energy ramping, there is a quite fast magnetic field change, which induces eddy currents in the vacuum chamber. These eddy currents result in a sextupole component B'' in the dipole magnets. Value of this component is proportional to the field ramping speed $\delta B/B$, and therefore the sextupole strength depends on time (or energy) during the ramping (see Fig 5).

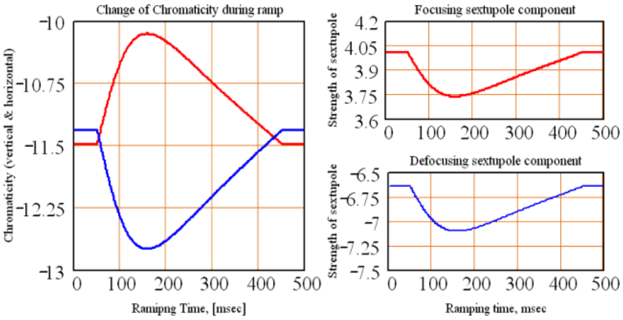


Figure 5: Change of the chromaticity and sextupole magnets strength during ramping.

Upper estimation of eddy currents effects has been done for an elliptical vacuum chamber made of 1 mm-thick stainless steel, with the cross-section of 24×50 mm^2. The dynamical aperture exceeds enough the geometrical one. And one can see in Fig. 6, compensation of eddy current effects does not reduce the dynamic aperture.

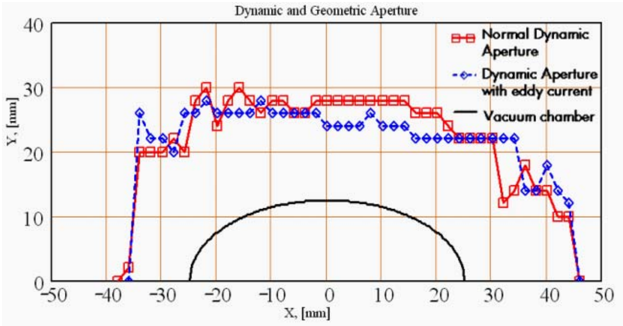


Figure 6: Dynamic aperture.

The working point (Q_x=9.11, Q_y= 9.1) is chosen away from the strong sextupole resonances reducing the dynamic aperture. Tune diagram is shown in Fig. 7, the marked area corresponds to the 0.5% gradient error of the FODO cell quadrupoles.

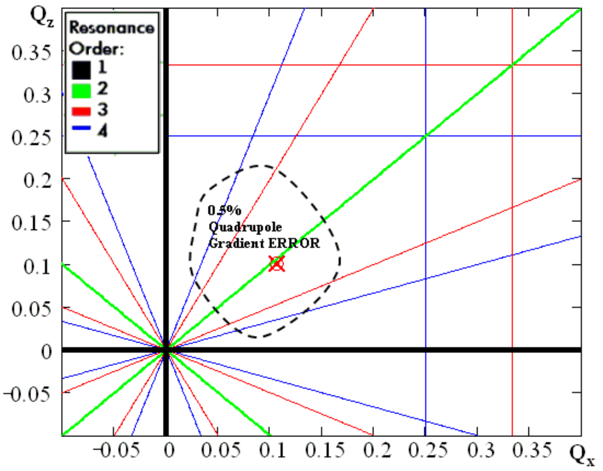
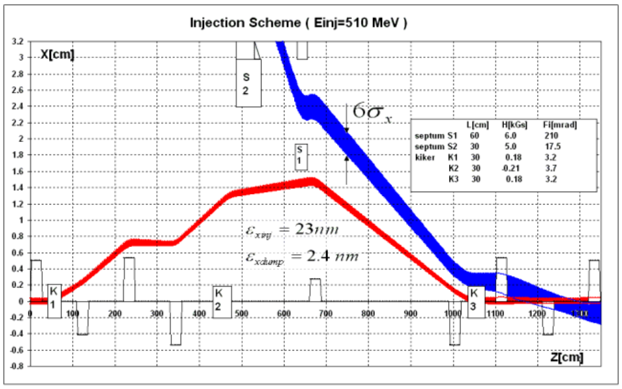


Figure 7: Tune diagram.

INJECTION AND EXTRACTION

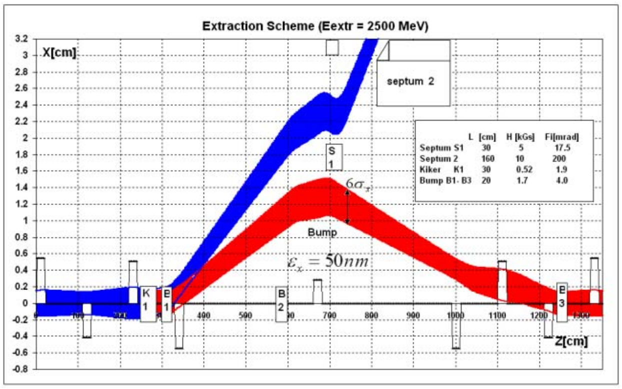
Beam injection and extraction are carried out in horizontal plane. A single-turn injection scheme is used for the booster synchrotron (see Fig 8). In the single-bunch mode, an injecting beam put on the equilibrium orbit by the fast kicker K3. In the storing mode, individual bunches are injected one-by-one into the booster, in one or few buckets by using 3 fast kickers. The septum sheet is placed with the 16-mm offset from the booster equilibrium orbit. Since the injected beam trajectory in the central F-quadrupole is 24-mm out of the equilibrium orbit, the aperture of this quadrupole is increased in comparison with the regular quadrupoles.



	L[cm]	H[kGs]	Fi[mrad]
septum S1	60	6.0	210
septum S2	30	5.0	17.5
kiker K1	30	0.18	3.2
K2	30	-0.21	3.7
K3	30	0.18	3.2

Figure 8: Injection scheme.

To provide beam extraction in a single turn, the "slow-bump, fast kick" method is used. The extraction septum S1 is placed symmetrically to the injection one relative to the central F-quadrupole. An orbit bump with 13-mm offset at the S1 azimuth is created using three correctors BM1-BM3 in 10 ms. Then the fast kicker K places a beam into the septum S1 aperture. The extraction scheme and two beam trajectories (slow bump and extraction) with 3σ-envelope are shown in Fig. 9.



	L [cm]	H [kGs]	FI[mrad]
Septum S1	30	5	17.5
Septum 2	160	10	200
Kiker K1	30	0.52	1.9
Bump B1- B3	20	1.7	4.0

Figure 9: Extraction scheme.

Main parameters of the injection and extraction magnets are also presented in Figs. 8, 9.

MAGNETS AND POWER SUPPLY

All the booster magnets will be made laminated and glued. The thickness of the laminations is 0.5 mm. The dipole magnets are curved H-type dipoles with parallel edges. All the dipoles are powered in-series, both F and D families of 31 quadrupoles in FODO cells are also powered in-series. 18 straight-section quadrupoles are powered in F-D pairs from 9 power supplies. Main parameters of the dipole and quadrupole magnets are presented in Table 4.

Table 4:

	Dipole	Quadrupole
Number of magnets	60	80
Gap	25 mm	Ø50 mm
Effective magnetic length	0.7 m	0.26 m
Maximal field	1.247 T	35 T/m
$\Delta B/B$ in 25×50 mm^2 aperture	2×10^{-4}	1×10^{-3}
Maximal current	850 A	500 A
Total resistance	0.28 Ω	-
Total inductance	0.14 H	-
Total voltage (1 Hz cycle)	750 V	-

REFERENCES

[1] P.V. Logatchov et al, Status of VEPP-5 Injection Complex, proceedings of RuPAC 2004.

[2] F. Perez-Impedance, loss factor and beam stability calculation for the ANKA storage ring, Proceeding of EPAC 98, p. 993-995.