MODERNIZATION PROJECT OF SYNCHROTRON SOURCE IN KURCHATOV INSTITUT: BOOSTER SYNCHROTRON

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Abstract

A project of the new 2.5 GeV booster synchrotron to provide more effective injection of electron beam into Siberia-2, top-up injection, and for enhancement of light source performance, is developing in KCSR [1]. Existing 450 MeV storage ring Siberia-1 will be replaced by new synchrotron. The beam will be injected into the synchrotron at 80 MeV energy from the linear accelerator existed now. Top-up injection into Siberia-2 will permit to avoid the collective instabilities especially important during an injection, when insertion devices are using. In this report, the synchrotron parameters are presented, the basic systems are briefly described.

INTRODUCTION

The synchrotron will be placed “concentrically” with the Siberia-2 ring in the same tunnel [2]. One of the main features of the booster is relatively small natural horizontal emittance of extracted electron beam (with respect to the 800 nm·rad emittance of the beam from Siberia-1). It allows injecting the beam into new and more “bright” optical structures of Siberia-2 with small dynamic apertures. The booster consists of 12 superperiods (see Fig. 1.).

Main parameters of the booster are presented in Table 1.

Table 1: KCSR Booster Synchrotron Parameters

Injection energy	80 MeV
Extraction energy	2.5 GeV
Circumference	110.9 m
Cycling frequency	1 Hz
Emittance	52.6 nm·rad
Momentum compaction	0.0107
Betatron tunes: Q_x/Q_y	6.83/4.57
Chromaticity: ξ_x/ξ_y	–14.12/–8.89
R.m.s. energy spread	9×10^{-4}
Energy loss per turn	622 keV
Damping times: τ_x, τ_y, τ_s	3.08, 2.97, 1.46 ms
Beam current	20 mA
RF frequency	720 MHz
Harmonic number	268
Synchrotron tune: Q_s	0.092

MAGNETIC LATTICE

The modified Chasman-Green lattice with 12-fold symmetry is used for the booster. One period consists of 2 bending magnets, 5 quadrupole lenses and 4 sextupole lenses (two families for natural chromaticity correction). To provide enough space for the injection and extraction devices and for the RF cavities, straight sections of 2.6 m long are used.

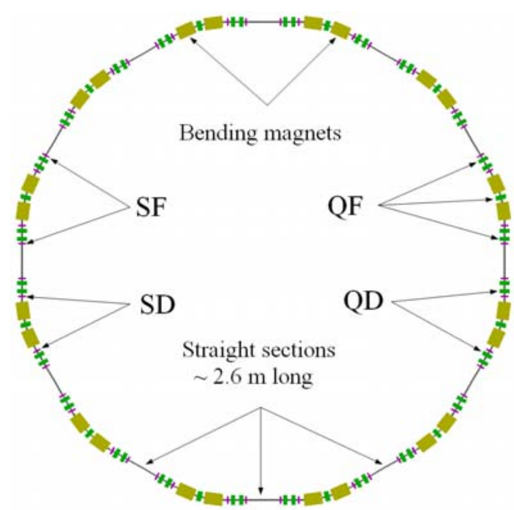

Figure 1: Layout of the booster synchrotron.

The variations of the betatron functions β_x and β_y are rather large along the booster ring, while dispersion function $\eta_x \neq 0$ at all azimuths. It means that we can correct natural chromaticity with weak sextupole lenses installed upstream and downstream from quadrupole doublet. Optical functions of one superperiod of the booster are shown in Fig 2.

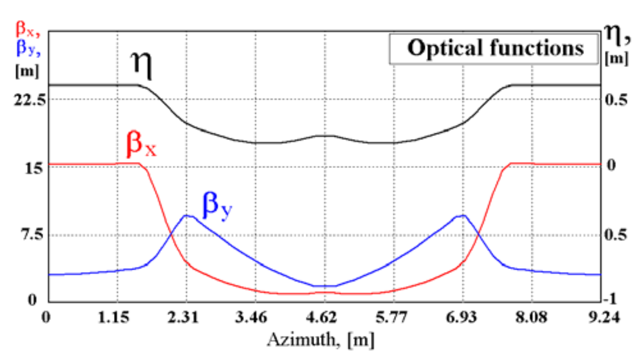

Figure 2: Optical functions of the booster synchrotron.

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 30 beam position monitors (BPMs), 24 horizontal and 24 vertical correctors which are build in the sextupoles. It defines the number of correctors.

To examine the orbit correction scheme, a computer simulation of COD has been carried out using the MAD code. A set of 1000 COD samples was calculated with random dipole field errors and misalignments 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: $\Delta x, \Delta y, \Delta s$	0.2, 0.2, 0.2 mm
Magnet rotation angle	0.2 mrad
Dipole field error $\Delta B/B$	2×10^{-4}

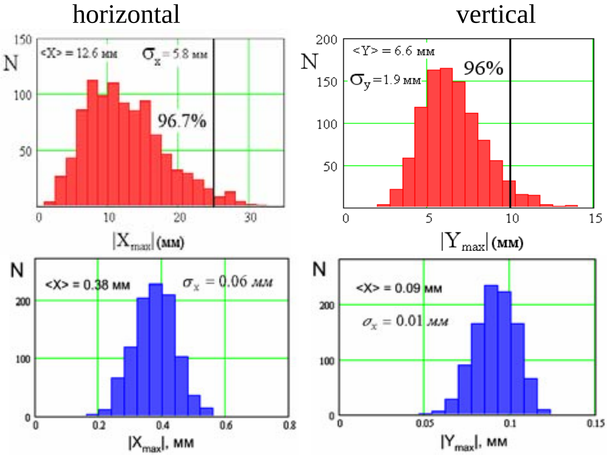

Figure 3: COD distribution before and after correction.

The simulation results are shown in Figure 3, there are histograms of maximum values of the 1000 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:

	<x>	σ_x	<y>	σ_y
Max. random COD, mm	12.6	5.8	6.6	1.9
Max. corrected COD, mm	0.38	0.06	0.09	0.01
Correctors strength, mrad	0.54	0.1	0.41	0.07

Vertical size of vacuum chamber is defined by possible COD values, while horizontal one is defined by electron beam size during injection into the synchrotron (full horizontal beam size at injection ΔX_{inj} = 46 mm). There will be no additional space inside vacuum chamber for initial horizontal COD, thus we have adopted for the aperture:

$$A_x = \pm 25 \text{ mm}, \qquad A_y = \pm 10 \text{ mm}$$

in all elements of the booster synchrotron..

DYNAMIC APERTURE

To compensate the natural chromaticity $\xi_x = -14.1$, $\xi_y = -8.9$, two family of sextupole magnets are used. Total number of sextupole magnets is 48, 24 focusing and 24 defocusing ones. 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 total chromaticity value depends on time (or energy) during the ramping (see Fig 4).

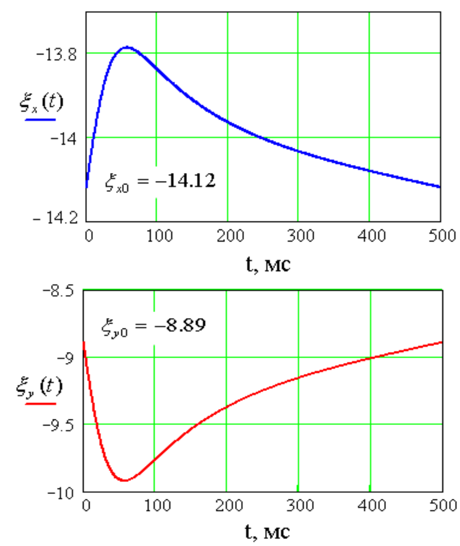

Figure 4: Change of the chromaticity during ramping.

After 56 ms from acceleration begin the eddy currents contribution to the total chromaticity reaches its maximum value. Strength of SF magnet should be increased on 0.4% and SD magnet should be strengthen on 7.7% to compensate maximum contribution of eddy currents.

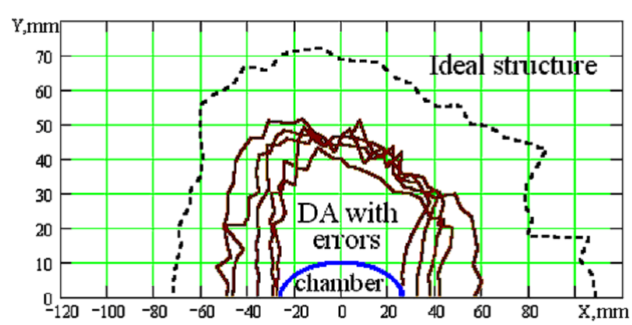

Figure 5: Dynamic aperture with the errors.

Estimation of eddy currents effects has been done for an elliptical vacuum chamber made of 1 mm-thick stainless steel, with the internal cross-section of 20×50 mm^2.

The working point (Q_x=6.83, Q_y=4.57) is chosen away from the strong sextupole resonances reducing the dynamic aperture. The dynamical apertures for ideal structure and for structure with errors (five sets) are shown in Fig. 5; geometrical aperture is shown by bold blue line. One can see that dynamic aperture for chosen working point exceed geometrical one even with errors taken into account.

Tune diagram of main betatron resonances (up to 4 order) close to the working point is shown in Fig. 6, working point is indicated by a dagger.

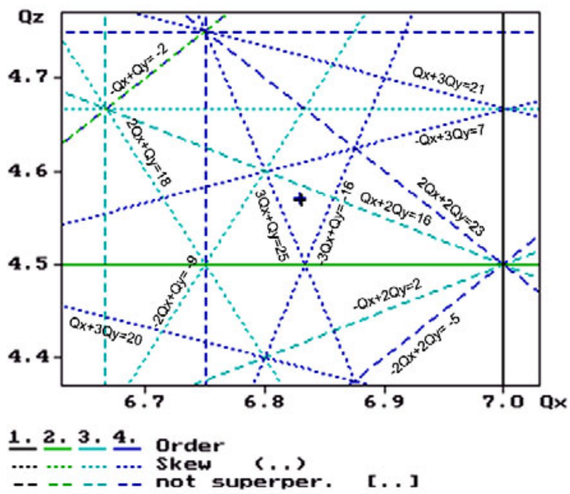

Figure 6: Tune diagram and working point.

INJECTION AND EXTRACTION

Injection and extraction are made in horizontal plane. A single-turn injection scheme is used for the booster synchrotron (see Fig 7). During one injection cycle 18 ns train of the bunches is entered into booster from linear accelerator. The transversal momentum of the injected beam is compensated by a fast kicker K. The storage of the electron is not foreseen in booster. Input septum magnet is shifted from equilibrium orbit at 30 mm.

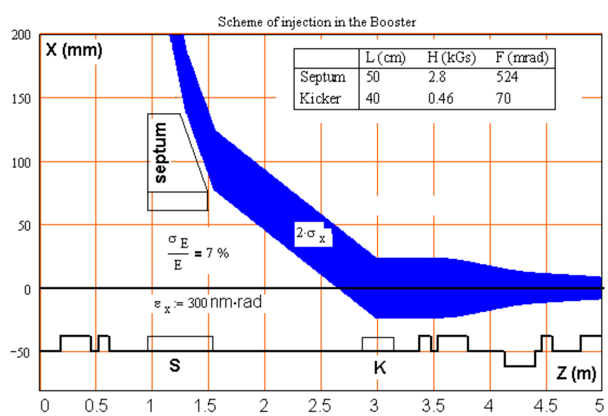

Figure 7: Injection scheme.

To provide beam extraction in a single turn, the "slow-bump, fast kick" method is used. An orbit bump with 4-mm offset at the septum azimuth S is created using four correctors B1-B4 which are turned on in 10 ms. Then the fast kicker K places a beam into the septum aperture. The extraction scheme and two beam trajectories (slow bump and extraction) with 3σ-envelope are shown in Fig. 8.

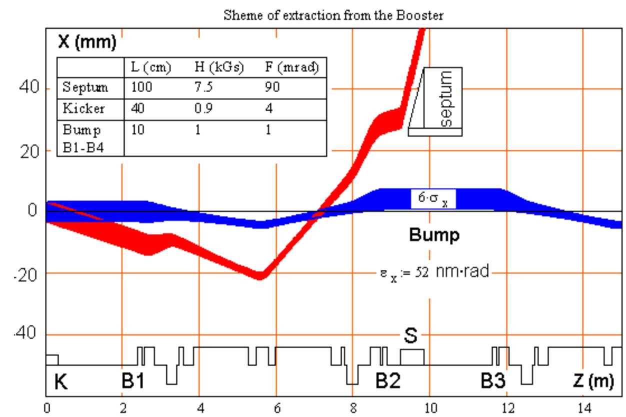

Figure 8: Extraction scheme.

Main parameters of the injection and extraction magnets are presented in Figs. 7, 8.

MAGNETS AND POWER SUPPLY

All the booster magnets will be made as such as laminated and glued ones. The lamination sheet thickness is 1 mm. Dipole bending magnets are H-type with parallel edges. All dipoles are connected in series. Quadrupole lenses have 3 families and sextupole lenses have 2 families. Each family of lenses is connected in series and fed by own power supply. Main parameters of dipole bending magnets, quadrupole and sextupole lenses are presented in Table 4.

Table 4:

	Dipole	Quadrupole	Sextupole
Number of magnets	24	60	48
Gap / bore diameter	24 mm	Ø50 mm	Ø60 mm
Effective length	1.45 m	0.3 m	0.1 m
Maximal field	1.5 T	30 T/m	270 T/m^2
$\Delta B/B$ in 20×50 mm^2 aperture	2×10^{-4}	5×10^{-4}	5×10^{-4}
Maximal current	850 A	420 A	120 A
Total resistance	0.28 Ω	0.6 Ω	0.6 Ω
Total inductance	0.14 H	0.086 H	0.029 H
Total voltage (1 Hz cycle)	600 V	340 V	86 V

REFERENCES

[1] V. Anashin et al., Nucl. Instr. Meth., A282 (1989), p. 369-374.

[2] V.Korchuganov at al., Nucl. Instr. Meth., A543 (2005), p.14-18.