

# A NEW INJECTION SYSTEM FOR KURCHATOV SOURCE OF SR

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## Abstract

The accelerator complex of the KCSR consists of 2.5 GeV main storage ring, 450 MeV booster storage ring and 80 MeV linac. A project of the complex modernization comprising new brighter optical lattices of main storage ring and new injection system were developed in KCSR.

New optical lattices will allow to reduce natural beam emittance from present 100 nm•rad to 18 nm•rad. But due to significant decrease of dynamic aperture the efficiency of injection from the booster storage ring having big natural emittance will be drastically reduced.

A new 2.5 GeV booster synchrotron (BS) with 50 nm•rad emittance was developed to overcome this problems. It will be placed in the same tunnel with main ring. Modernization project provides for a possibility to increase injection energy from linac to BS from 80 MeV to 160 MeV by double electron bunches transition through linac structure.

## FULL ENERGY BOOSTER

The synchrotron will be placed “concentrically” with the Siberia-2 ring in the same tunnel [1]. Fig. 1 shows an overview of the accelerator complex after upgrade.

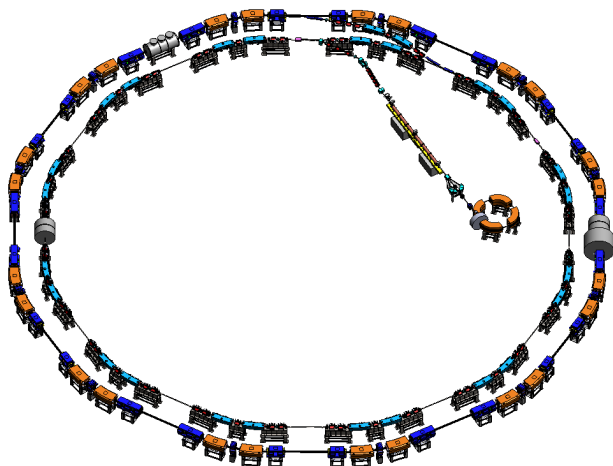


Figure 1: Accelerator complex after upgrade.

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. Main parameters of the booster are presented in Table 1.

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. To provide enough space for the injection and

extraction devices and for the RF cavities, straight sections of 2.6 m long are used.

The variations of the betatron functions  $\beta_x$  and  $\beta_y$  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 before and after quadrupole doublet. Optical functions of one superperiod of the BS are shown in Fig. 2.

Table 1: KCSR Booster Synchrotron Parameters.

Injection/extraction energy	80/2500 MeV
Circumference	110.9 m
Cycling frequency	1 Hz
Emittance	51 nm•rad
Momentum compaction	0.0108
Betatron tunes: $Q_x/Q_y$	6.83/4.57
Chromaticity: $\xi_x/\xi_y$	-13.27/-8.77
R.m.s. energy spread	$9 \times 10^{-4}$
Energy loss per turn	622 keV
Damping times: $\tau_x, \tau_y, \tau_s$	3.08, 2.97, 1.46 ms
Beam current	10 mA
RF frequency	181.1 MHz
Harmonic number	67
Synchrotron tune: $Q_s$	0.092

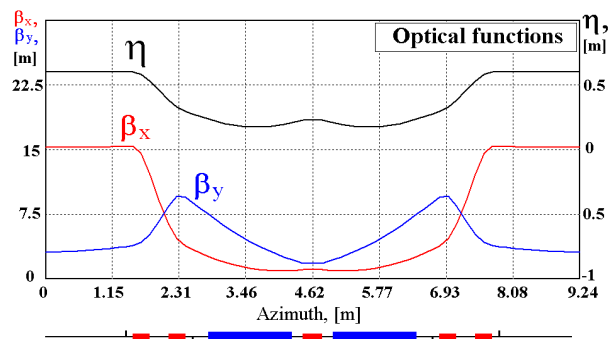


Figure 2: Optical functions of the booster synchrotron.

## Closed orbit distortion

Orbit correction system of the booster synchrotron consists of 36 beam position monitors (BPMs), 24 correctors. To examine the orbit correction scheme, a computer simulation of COD has been carried out using the MAD code. The results are listed in Table 2.

Table 2: Orbit distortions and corrector strength.

	$\langle x \rangle$	$\sigma_x$	$\langle y \rangle$	$\sigma_y$
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

The error values used in COD simulation have Gaussian distribution truncated at  $2\sigma$ , where  $\sigma$  is the standard deviation (Table 3).

Table 3: Errors used in COD simulation.

Error type	$\sigma$
Magnet displacement: $\Delta x, \Delta y, \Delta s$	0.2, 0.2, 0.2 mm
Magnet rotation angle	0.2 mrad
Dipole field error $\Delta B/B$	$2 \times 10^{-4}$

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  $\Delta X_{inj} = 46$  mm. We have adopted for the aperture in all elements of the booster synchrotron:

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

### Chromaticity and dynamic aperture

To compensate the natural chromaticity  $\xi_x = -13.3$ ,  $\xi_y = -8.8$ , two families of sextupole magnets are used. Total number of sextupole magnets is 48: 24 focusing (SF) and 24 defocusing (SD) magnets. 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 during the ramping (see Fig. 3).

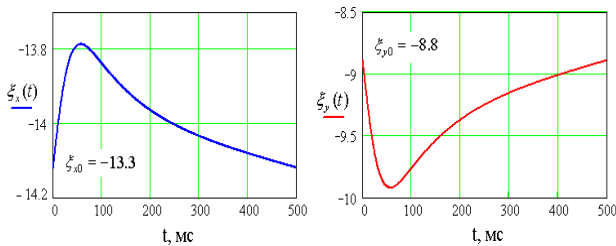


Figure 3: Change of the chromaticity during ramping.

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. 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  $20 \times 50 \text{ mm}^2$ .

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. 4; geometrical aperture is shown by bold blue line.

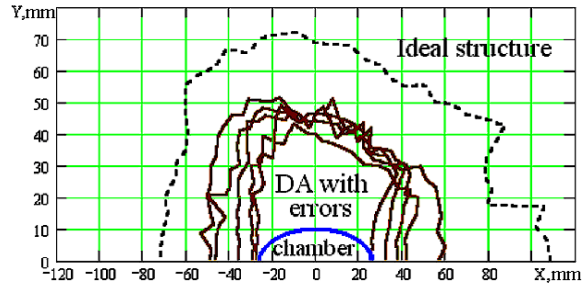


Figure 4: Dynamic aperture with the errors.

One can see that dynamic aperture for chosen working point exceeds geometrical one even with errors (Table 3) taken into account.

Tune diagram of main betatron resonances (up to 4-th order) close to the working point is shown in Fig.5, working point is indicated by a dagger.

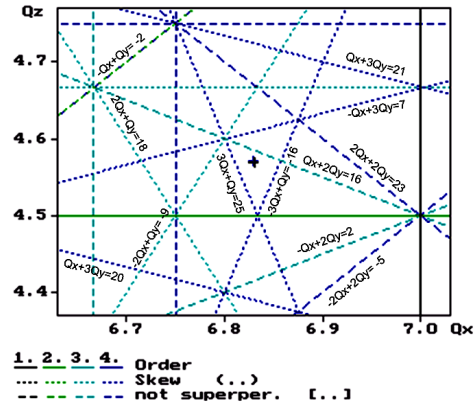


Figure 5: Tune diagram and working point.

### Magnets

All booster magnets will be made laminated and glued. 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 booster magnets are illustrated in Fig 6 and their main parameters are listed in Table 3.

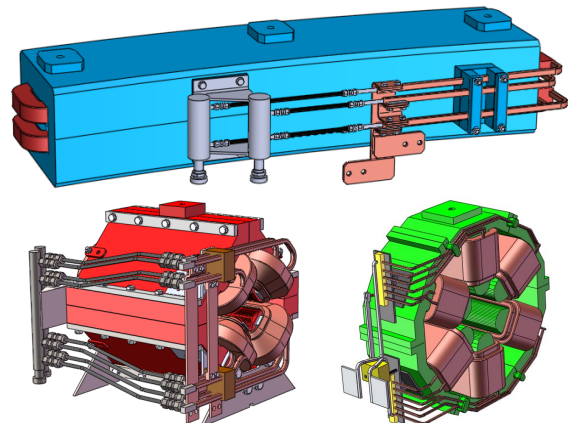


Figure 6: Main booster magnets.

Table 3: Magnets parameters.

	Dipole	Quads	Sextupole
Number of magnets	27	60	48
Gap / bore diameter	24 mm	Ø50 mm	Ø60 mm
Effective length	1.45 m	0.3 m	0.1 m
Maximum strength	1.5 T	30 T/m	270 T/m <sup>2</sup>
Maximal current	1820 A	420 A	120 A
Total voltage (1 Hz cycle)	800 V	340 V	86 V

**Injection and extraction**

Injection and extraction are made in horizontal plane. A single-turn injection scheme is used for BS. During one injection cycle 18 ns bunch train is entered into the booster from linear accelerator. Transversal momentum of the injected beam is compensated by a fast magnetic kicker. Large deflection angle provided by fast magnetic kicker at low (160 MeV) energy allows to use for injection the convenient bending magnet of ETL-1 channel instead of a septum magnet.

To provide beam extraction in a single turn, the “slow-bump, fast kick” method is used. An orbit bump with 19 mm offset at the septum azimuth is created using build in correction coils of four dipole magnets, which are turned on in 10 ms. Then the fast kicker deflects a beam into the septum aperture.

**PREINJECTOR**

Existing 80 MeV standing wave linac will be used as preinjector for BS. Energy doubling scheme with direct and reverse electron beam passing through the accelerating structure of linac is suggested. Additional optical structure, i.e. magnetic mirror will be used (Fig. 6). Electrons energy will increase from 80 MeV to about 160 MeV.

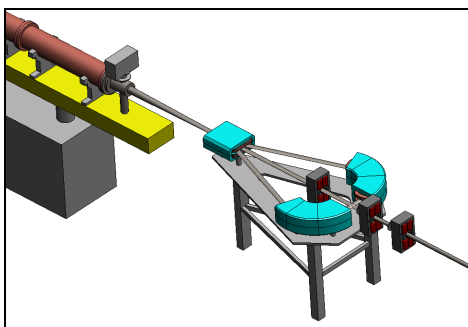


Figure 6: Magnetic mirror.

Existing scheme of injection into “Siberia-1” will operate in routine mode when magnetic mirror is off. Linac will be 80 MeV injector for “Siberia-1” in this case.

When magnetic mirror is on, it will reflect particles back to the linac for additional acceleration during reverse passing through the accelerator structure and then electrons will be injected into the booster. In this scheme it is necessary to move electron gun from the trajectory of reflected and secondary accelerated electron beam. This can be done by breaking coaxial condition between

electron gun and linac. Additional weak magnet to deflect 40 keV electrons is needed between electron gun and linac (Fig. 7). This magnet will cause vanishing deflection of 160 MeV electrons.

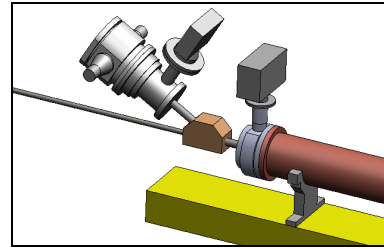


Figure 7: Possible position of electron gun.

Main feature of magnetic mirror is achromatic and isochronous 180° - turn. Optical functions of one half of the mirror are shown in Fig. 8.

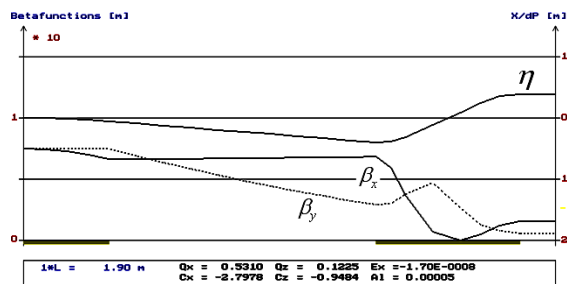


Figure 8: Optical functions of magnetic mirror.

Bending magnets of the mirror are combined function magnets composed of three sections with different gradients. The design of such magnet is shown on Fig. 9. The main optical property of these magnets is that dispersion function crosses zero inside magnets. It allows to create the compact isochronous 180° - turn.

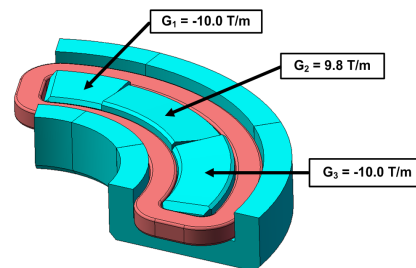


Figure 9: Mirror magnet design.

**CONCLUSIONS**

The new injection system will increase reliability of Siberia-2 work at 2.5 GeV. The magnetic and RF systems are not changed, because the energy is fixed. A periodical injection for reaching an "infinite" life time is possible. The booster electron beam has small phase volumes, so there is an opportunity of accumulation in Siberia-2 at work with small DA (in small emittances structures).

**REFERENCES**

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