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2.5 GeV BOOSTER SYNCHROTRON FOR A NEW KURCHATOV SYNCHROTRON RADIATION SOURCE

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Abstract

The Project of complete modernization of the current accelerator complex is in progress in the NRC «Kurchatov Institute». A new booster synchrotron is a part of the injection complex for a new 3-d generation synchrotron light source. The booster has to ensure reliable and stable operation of the upgraded main storage ring. The paper presents the final design of the new booster synchrotron and its main parameters.

INTRODUCTION

The Kurchatov synchrotron radiation source consists of the 2.5 GeV main storage ring, the 450 MeV booster synchrotron and the 80 MeV linac [1]. The current main ring is the second generation light source with electron beam emittance of 98 nm×rad. The accelerator complex has been in operation for over 20 years in its current configuration. Improvement of the qualities of synchrotron radiation beams is associated with the modernization of the entire accelerator complex and the replacement of the main ring with the 3-d generation source [2].

The need to increase the spectral flux and brightness of a light source demands the creation of a new structure with low electron beam emittance (~1–10 nm×rad) for the main ring. A feature of a low-emittance structure is a high natural chromaticity and a small dynamic aperture. A small aperture can lead to a significant decrease in the efficiency of the electron beam injection from the current booster synchrotron with the high-emittance structure into the new main ring. The need to ensure long-term spatial and temporal stability of photon beams dictates high requirements for temperature stabilization of the main ring (±0.1°C). These requirements can be achieved with constant currents in the magnets and the accelerating RF structure, i.e. when the storage ring is operating at the same energy. In addition, with the possibility of injection at full energy and periodic sub-accumulation of electrons from the booster synchrotron, it becomes possible to carry out experiments on synchrotron radiation without interruptions for re-accumulation of electrons and energy rise in the main storage ring. These conditions do not allow using the current booster synchrotron with electron beam emittance of 800 nm×rad and energy of 450 MeV as an injector for the new low-emittance main ring.

The new booster synchrotron must have a symmetrical structure with a periodicity equal to or multiples of the main ring structure. The length of the main drift spaces must be about 2 m to accommodate the magnets of the beam transport channels and the RF cavity. The booster lattice must have relatively small values of Twiss parameters along a beam orbit and the natural emittance from 40 to 60 nm×rad at the energy of 2.5 GeV.

BOOSTER LATTICE

The booster magnet lattice is based on the modified DBA structure with 12 cells. The total number of magnets is the 24 dipoles, the 60 quadrupoles, the 48 sextupoles and the 24 correctors. The booster synchrotron will be located in the same tunnel with the main storage ring. The main lattice parameters are given in Table 1. The optics functions are shown in Fig. 1.

Table 1: The Booster Lattice Parameters

Energy, GeV	0.2 – 2.5
Circumference, m	110.9
Operating frequency, Hz	1
RF-frequency, MHz	181.168
Harmonic number	67
Beam current, mA	10 – 15
Tunes x/y	7.178/4.367
Nat. Chromaticity x/y	-9.0/-8.6
Nat. emittance at 2.5 GeV, nm×rad	43.4
Momentum compaction factor	0.01
Energy spread at 2.5 GeV	8.4×10^{-4}
Energy loss per turn at 2.5 GeV, keV	539
Damping time x/y/s at 2.5 GeV, msec	3.5/3.4/1.7

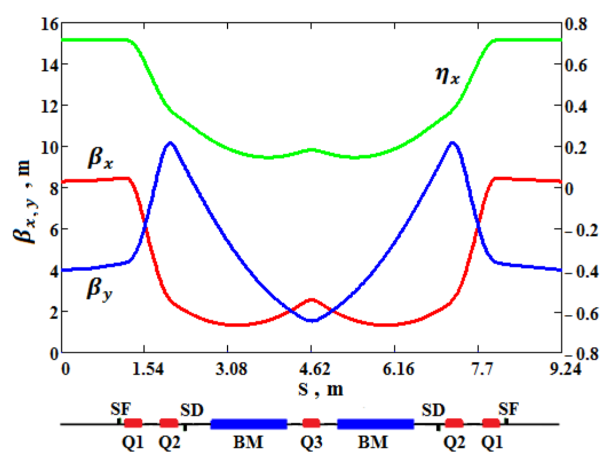

Figure 1: Twiss parameters for one booster cell.

The booster lattice provides the natural emittance of 43.4 nm×rad at the energy of 2.5 GeV. The horizontal and vertical tunes are located far from structure resonances. The dynamic aperture, taking into account chromaticity corrections, is in horizontal from -93 to +129 mm and in vertical of ±105 mm at the center of the main drift. It's

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higher than the physical aperture, defined by the vacuum chamber in horizontal of ±25 mm and in vertical of ±10 mm.

The main contribution to the electron beam lifetime of the booster synchrotron is the elastic scattering. The minimum lifetime of 45 sec is at the injection energy of 200 MeV and gas residual pressure of 100 nTorr. This lifetime is sufficient for the optimal booster operation, since immediately after injection the electrons are accelerated from energy of 200 MeV to 2.5 GeV. But to reduce the induced radioactivity it is necessary to provide the residual pressure not higher than 10 nTorr. Note that the minimum lifetime determined by the Touschek effect for one bunch with current of 10 mA is 2 hours at the energy of 1.6 GeV.

LATTICE ERRORS

Alignment errors of the magnets and the magnetic fields errors lead to displacements of the equilibrium orbit and shifts of the betatron tunes. The booster lattice with and without errors was studied using the MAD-X program [3]. 1000 sets of random errors with a Gaussian distribution bounded by an interval of ±2σ were included in calculations. As a result the values of permissible errors for magnets of the booster synchrotron were determined. The permissible errors are: shifts of magnets in three directions – 0.2 mm, turns around three axes – 0.1 mrad, the dipole field relative error – 10^{-4}, the relative dipole field gradient error – 2×10^{-4}, the relative quadrupole field gradient error – 5×10^{-4}.

According to calculations, the mean values of the deviation of the equilibrium orbit are in horizontal of 7.5 mm and in vertical of 6.9 mm. The largest contribution to orbit distortions is made by the alignment errors of the quadrupole magnets in the horizontal and vertical directions.

To correct orbit in the booster synchrotron 24 correctors and 24 correction coils of dipole magnets will be used. To calculate closed orbit correction the SVD algorithm was used in the MAD-X program [4]. As a result, the average value of the maximum strength of the correctors is in horizontal of 0.3 mrad and in vertical of 0.48 mrad. The average value of the maximum strength of the correction coils is in horizontal of 0.19 mrad. The strength corresponds to the rotation angle of the particle trajectory in the magnet. After the correction, the residual orbit deviations are in horizontal of 0.12 mm and in vertical of 0.14 mm.

According to calculations, the betatron tunes is shifted towards the difference resonances of the 3-d and 4-th orders. The betatron tunes and lines of the resonances are shown in Fig. 2. The largest contribution to tunes shifts is made by the alignment errors of the quadrupole and sextupole magnets in the horizontal direction, the quadrupole field gradient error and the dipole field gradient error. However the dynamic aperture remains larger than the physical aperture (Fig. 3).

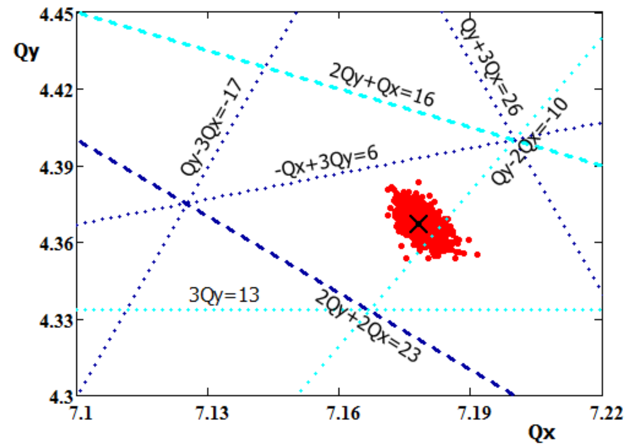

Figure 2: The betatron tunes diagram: the black cross – tunes for the lattice without errors, read points – tunes for the lattice with 1000 sets of random errors.

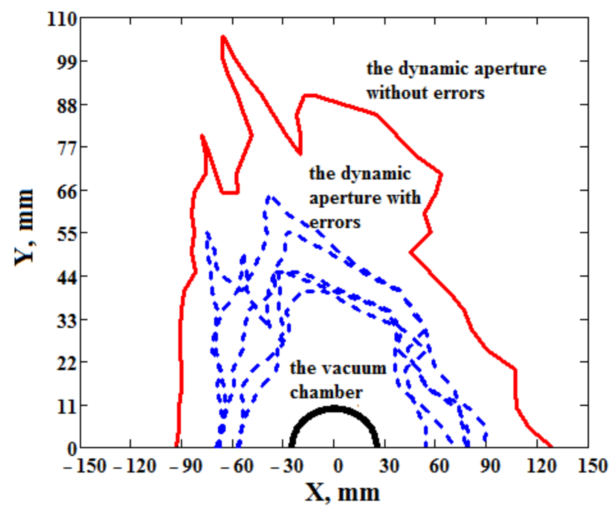

Figure 3: Dynamic aperture for the booster lattice.

MAGNETS

The booster synchrotron will operate in a cyclic mode with a frequency of 1 Hz in the energy range from 200 MeV to 2.5 GeV. The presence of alternating magnetic fields determines the manufacturing technology of the magnets of the booster synchrotron. The yoke of each magnet will be laminated, i.e. will be assembled from 1 mm thick magnetic steel sheets. To ensure high quality of the magnetic field, the profile of each sheet must be made with an accuracy of 10–20 µm. The entire internal geometry of the magnet yoke must be maintained with the same accuracy during assembly. At present, stamping is a proven technology for producing sheets.

The dipole magnet of the booster synchrotron must provide a 15-degree angle of rotation of the particle trajectory over the entire range of operating energies. In this case, the magnetic field in the pole gap varies from 0.1 to 1.3 T. The pole gap is 24 mm. The length of the magnet in the magnetic field (the effective length) required to obtain the indicated rotation angle is 1679.363 mm with a bending radius of 6415 mm and a

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magnet yoke length of 1674 mm. The ends of the magnet are parallel to each other.

The quadrupole magnets of the booster synchrotron are grouped into three families: two families of focusing lenses and one family of defocusing lenses. The magnets must provide the required magnetic field gradients with an effective length of 320 mm. The maximum gradients of the quadrupole field at energy of 2.5 GeV are 21.12 T/m, 20.89 T/m, and –23.55 T/m, respectively. The radius of the circle inscribed between the poles of the quadrupole is 25 mm. The yoke length of the quadrupole is 300 mm.

The booster synchrotron sextupole magnets are divided into two families: lenses for correcting horizontal chromaticity and lenses for correcting vertical chromaticity. The required gradients of the sextupole field at energy of 2.5 GeV are 90 T/m^2 and -215 T/m^2, respectively. The effective length and the length of the magnet yoke are 100 mm. The radius of the circle inscribed between the poles of the sextupole is 30 mm.

The correcting magnet combines the functions of a horizontal and a vertical corrector and is a frame dipole magnet. The corrector has to provide a maximum angle of rotation of the particle trajectory of 0.48 mrad with a magnet yoke length of 100 mm.

Direct current sources are required to power the magnetic elements of the booster synchrotron. These sources must operate with inductive loads with time constants of about 0.5 s for dipole magnets, about 0.2 s for quadrupole and sextupole magnets, 20–50 ms for correcting magnets. The booster synchrotron will operate in a cyclic mode; therefore, the source current at both levels and during the rise of the beam energy must be stabilized with high accuracy. In addition, the sources must have a sufficiently high output voltage for the forced increase and decrease of the current in the magnets and ensure operation with periodically oscillating high voltage of both polarities.

Coils of magnets are connected to the electrical network sequentially by families. It is possible to divide the magnets into groups within the same family. For example, not all 24 dipole magnets can be powered from one source, but 12 or 6 magnets. This approach reduces the requirements for the power characteristics of power supplies and increases the safety of the installation as a whole. The final decisions on the scheme for connecting the magnets will be made at the stage of engineering studies of the communications of the accelerator complex.

To achieve a high quality of the magnetic field and the required magnets parameters, the geometry of all magnets is determined by 2D- and 3D-simulations of magnetic fields. For more information on magnets design, see a paper [5] at this conference.

RF SYSTEM

The RF system of the booster synchrotron is assumed to be similar to that currently operating at the main storage ring of the Kurchatov synchrotron radiation source [6]. It is based on the one RF generator and the one accelerating cavity. The operating frequency of the booster RF system is taken to be equal to the RF frequency of the main storage ring – 181 MHz, which corresponds to the 67th harmonic of the circulation frequency in the booster synchrotron (2.704 MHz). This choice is optimal from the point of view of the best synchronization of both accelerators, the transfer of electron bunches into predetermined separatrices without losses and increasing the coherent oscillations.

The RF generator is based on an output stage with a tube module (tetrode). The long-term operating output power of the RF generator is 200 kW in continuous mode at the frequency range from 180 to 182 MHz. Power is transmitted from the RF generator to the cavity via a 75 Ohm coaxial waveguide (feeder). The cavity of the booster synchrotron has a design similar to the cavities of the operating main storage ring. The design feature of the cavity is the presence of tuners for automatic frequency control of the fundamental mode and tuners for manual control of the frequencies of the high order modes. The stability of the RF system under load by the beam current is provided by a feedback system, with the help of which it is possible to set and stabilize the accelerating voltage and the phase difference between the feeder current and the accelerating voltage.

The RF system of the booster synchrotron will ensure the capture of electrons into the acceleration mode with a current of 10-15 mA and an energy spread of ± 1.5% when a beam is injected from the linac and provide an energy acceptance within 0.5% at an energy of 2.5 GeV to establish a reasonable beam lifetime, and also compensate for losses energy by electrons for synchrotron radiation. The energy losses per turn are 22.1 eV at 200 MeV and 538.7 keV at 2.5 GeV.

CONCLUSION

The booster lattice based on modified DBA structure satisfies the requirement of placing the synchrotron in the same tunnel with the main storage ring. It consists of 12 cells, each with mirror symmetry about the center of the cell. This lattice significantly reduces the strength of machine resonances in the working range of betatron frequencies and is stable against various kinds of magnetic field errors within the permissible values. The structure of the booster synchrotron has a large dynamic aperture with compensated natural chromaticity and low natural emittance, which is necessary and sufficient for efficient transfer of the electron beam from the booster synchrotron to the main storage ring with minimal particle losses.

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