LOW EMITTANCE BOOSTER DESIGN FOR CANDLE STORAGE RING

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Abstract

The progress in synchrotron based research made the top up operation mode of storage rings as the most attractive option both from beam lifetime and the user points of view. To provide reliable operation of the facility at top-up injection mode the full energy low emittance new booster ring for 3 GeV CANDLE storage ring is designed. The compact synchrotron magnets with integrated quadrupole and sextupole components are used. The new design provides about 20 nm emittance at the top energy with sufficient dynamic aperture and optimal optical properties at straight section for effective extraction. The complete design of the new booster and beam dynamics issues during the energy ramping are presented.

INTRODUCTION

A new full-energy booster synchrotron was designed for CANDLE storage ring [1]. The booster will accelerate a beam from injection energy of 100MeV up to full energy 3GeV. The circumference of the booster is 192 m that is compared with the storage ring circumference in the ratio of 8/9 and both booster synchrotron and storage ring are to be built in the same tunnel. To avoid effects of stray fields upon the storage ring, the average distance between the two rings is 3.8 m.

The booster lattice (Figure 1) has four-fold super-symmetry with 5m long dispersion free four straight sections for RF, injection, extraction and diagnostics. The lattice is designed with FODO cells which consist of combined-function magnets to reach a small emittance of about 20nm.

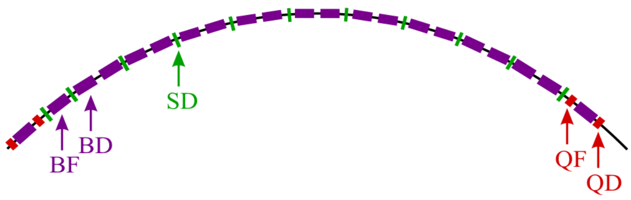

Figure 1: Schematic layout of a quadrant of booster lattice.

The use of combined-function magnets and the fact of booster and storage ring being in the same tunnel give the following advantages:

- saving of building and shielding costs,
- much simple booster-to-storage ring transfer line,
- economic magnets with small field and small gap,
- low emittance beam (20 nm at extraction at 3 GeV) giving a clean injection into the storage ring,
- productive top-up injection.

The booster main parameters are presented in Table 1.

Table 1: Booster Main Parameters

Parameter	Value
Circumference	192 mm
Injection energy	100 MeV
Ejection energy	3 GeV
Straight section length	5m
Emittance at full energy	19.54 nm rad
Energy spread at full energy	$6.58\ 10^{-4}$
Tunes (hor./vert.)	13.44/8.35
Nat. chromaticities (hor./vert.)	-19/-14.2

LATTICE DESIGN

The basic structure of the booster lattice consists of four arcs, each with 5 m long straight section. The arc has two matching cells and 9 FODO cells, each with two combined-function bending magnets BF and BD (having dipole, quadrupole and sextupole fields) separated by 0.55 long drift. Such kind of magnets has been already used for example in SLS [2] and ASP [3]. The main parameters of those magnets are shown in Table 2.

Table 2: Parameters of the combined-function magnets

Name of magnet	BD	BF
Num. of magnets	44	40
Bend angle	6 deg	2.4 deg
Arc length	1.4 m	1.3 m
Quadrupole strength	$-0.638\ m^{-2}$	$0.828\ m^{-2}$
Sextupole strength	$-2.16\ m^{-3}$	$6.61\ m^{-3}$
Magnet gap	26 mm	28 mm

It is advantageous to have the straight sections dispersionless, since both the RF-cavity and the injection elements are located in those straights. Dispersionless straight sections are provided by missing dipole FODO type matching cells which include two families of quadrupole magnets (QF and QD).

A chromaticity correction is incorporated into the pole profile of the booster dipoles. However, defocusing SD sextupoles are installed, which give flexibility in optimizing the chromaticity.

The betatron functions are shown in Figure 2 together with locations of the magnetic elements.

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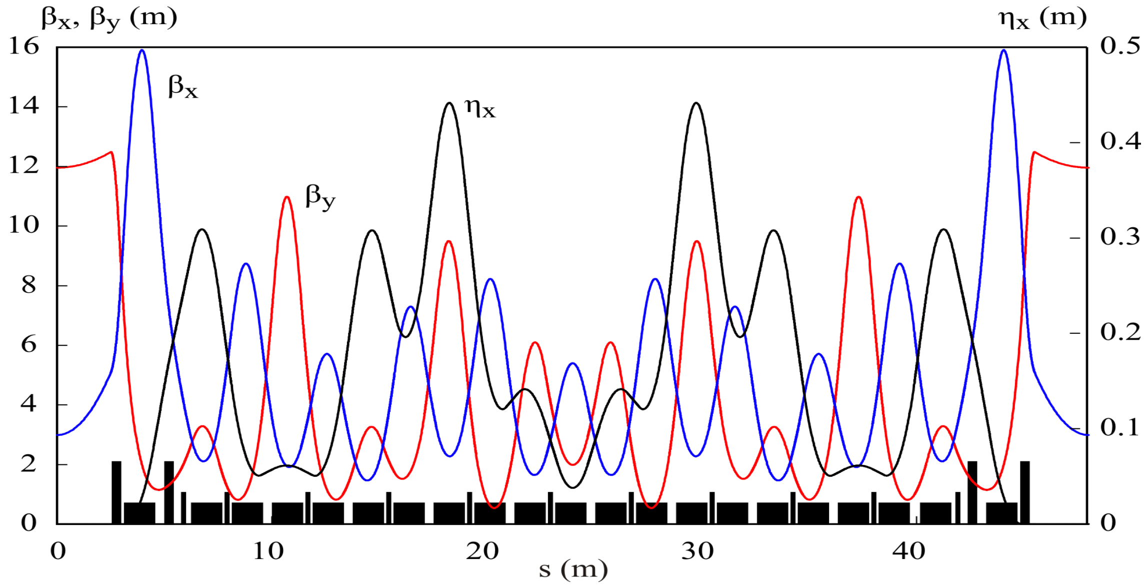

Figure 2: Booster optic functions per one quadrant.

Figure 3 shows the dynamic aperture of the booster at full energy for relative energy deviations -1%, 0% and +1% at the center of the straight section.

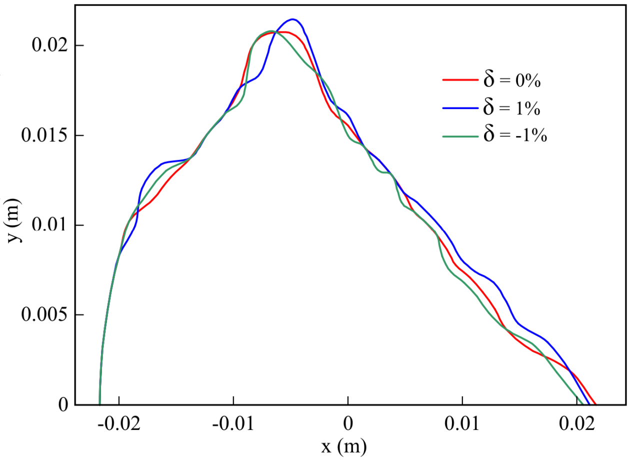

Figure 3: Dynamic aperture of the booster at full energy.

The working point of the betatron oscillations in the resonance diagram corresponds to betatron tunes 13.44 (horizontal) and 8.35 (vertical). Figure 4 shows the momentum dependent tunes at extraction energy. The plot shows stable operation of the beam within an energy deviation range of ± 2%

Simulation results of the ramping process indicate that during the acceleration process particles inside the beam do not cross any strong resonance lines in the frequency map.

ENERGY RAMP

The booster is designed to accelerate electrons from injection energy of 100 MeV to full operational energy of 3 GeV with a repetition rate of 2Hz. The corresponding energy ramp is given by

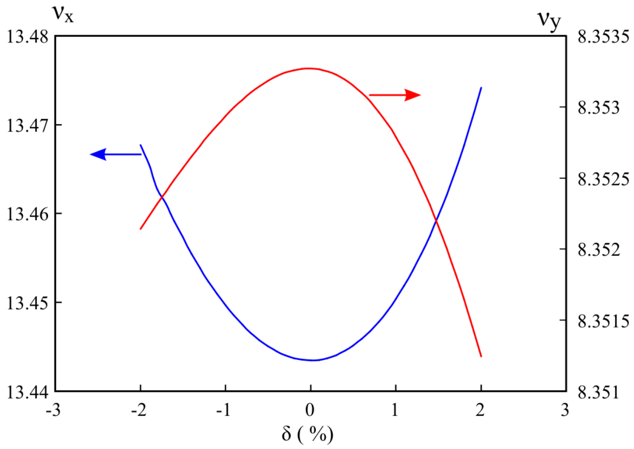

Figure 4: Momentum dependent tunes of the booster at extraction energy 3 GeV.

$$E(t) = E_0 (a - \cos \omega_0 t)\,, \qquad (1)$$

where $\omega_0 = 2\pi f$ is the ramping frequency. In the CANDLE booster case f= 2Hz, $\alpha \approx 1.07$ and E_0=1.45GeV.

The evolution of the beam horizontal emittance and energy spread during the acceleration ramp was done theoretically and by numerical simulation with ELEGANT [4]. The results are presented in Figures 5-6.

The variation of the beam horizontal emittance ε_x during the energy ramp is given by the differential equation

$$\frac{d\varepsilon_x}{dt} = -\varepsilon_x \left(\frac{\dot{E}(t)}{E(t)} + J_x \frac{U(t)}{T_0 E(t)} \right) + C_q \frac{\gamma^2(t) U(t)}{T_0 E(t)} \frac{I_5}{I_2} \qquad (2)$$

where J_x is the horizontal damping partition number, E(t) – the reference particle energy, γ(t) – the relativistic factor, U(t) - the energy loss per turn of the reference particle, T_0 is the revolution period, $C_q \approx 3.832\cdot10^{-13}$m is the so called "quantum constant", I_2 and I_5 are synchrotron radiation integrals defined by the lattice.

For the energy spread the second term in the right hand side of equation (2) must be slightly modified.

The first term on the right side of the equation describes adiabatic and radiation damping processes while the second term (~E^5) describes the effect of quantum excitations caused by synchrotron radiation. Intrabeam scattering effects are neglected since they drop strongly with rising the beam energy and are very low at the booster injection energy of 100 MeV and considered beam current of 10mA. At the beginning of the ramping process the beam size, emittance and energy spread are reduced by adiabatic and radiation damping. They reach their minimum values, then quantum effects become important. At the extraction energy they reach their equilibrium values. The horizontal beam emittance evaluation with energy is shown in Figure 5. The initial beam emittance is taken to be 1 mm-mrad. At the low energy part of the ramp the emittance drops due to adiabatic damping and reaches its minimum at the energy of about 2.3 GeV. Then, the emittance of the beam is driven basically by the radiation damping and quantum fluctuation effects that lead to equilibrium beam emittance of 20 nm-rad at the final beam energy of 3 GeV.

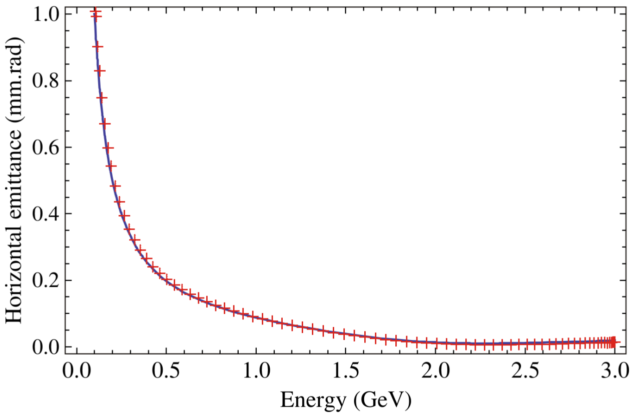

Figure 5: Evolution of the beam horizontal emittance during ramping. Red crests correspond to simulation, blue line – theory.

The injector linac provides an rms energy spread for the beam of better than 0.5% to minimize beam losses during the injection and the first few turns of the beam in the booster. The bunching and radiation related processes that accompany the beam acceleration in the booster shortly after injection drive the rms energy spread within a single bunch. At the energy of about 2 GeV the rms energy spread of the beam is stabilized to the level of 0.04% and reaches its equilibrium value of 0.065% at the extraction energy of 3 GeV (Figure 6).

The initial time structure of the beam is already bunched at the frequency of 500 MHz at bunching system in linac pre-injector section. Further acceleration of the beam in 3 GHz linac captures the particles in 20 degree of 3 GHz structure. Longitudinal autophasing and the damping of the synchrotron (longitudinal) oscillations in booster synchrotron drive the rms bunch length of the accelerated beam to 10 mm at the extraction energy of 3 GeV which comfortably fits into the 500-MHz RF bucket of the storage ring.

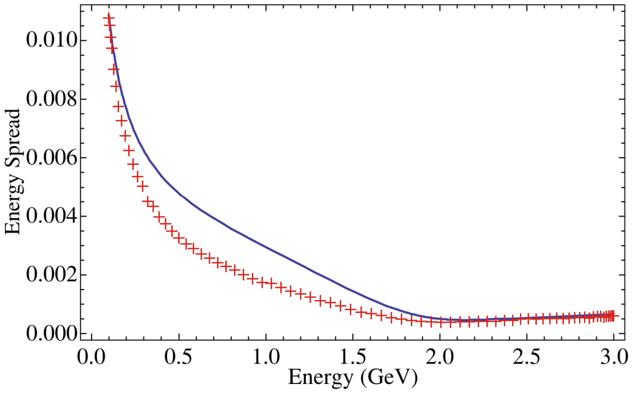

Figure 6: Beam rms energy spread variation during the acceleration process. Red crests correspond to simulation, blue line – theory.

CONCLUSIONS AND OUTLOOK

Low emittance new booster ring for 3 GeV CANDLE storage ring is designed to provide reliable operation of the facility at top-up injection mode. The beam dynamics issues during the energy ramp are studied.

Further investigations have to be done to estimate the magnetic field and alignment errors impact on the closed orbit and to find an appropriate way of optimal closed-orbit correction. The maximal horizontal and vertical excursions possible for which there will be no significant emittance blow-up and hence no beamloss for the nominal injection emittance after tens of thousands of turns are of particular interest.

The effect of eddy currents upon the field components and the possibility of its compensation will be studied.

In numerical simulation with ELEGANT the synchrotron radiation effects are taken into account in one point of the ring. Consideration of those effects magnet by magnet leads to beam blow up. The explanation of that phenomenon has also to be done.

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