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STUDY OF THE RAMPING PROCESS FOR Korea-4GSR

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Abstract

The Korea fourth generation storage ring (Korea-4GSR) is a 4 GeV, low emittance light source to be built in Ochang, Korea. The booster ring, which consists of 26 FODO standard cells and 2 dispersion-free cells, ramps the beam energy up from 200 MeV to 4 GeV as part of the injector. The circumference and repetition rate of the booster ring is 772.9 m and 2 Hz, respectively. In this paper, the injection scheme, energy ramping curve, eddy current effect, beam parameters changing curve, and RF voltage during the energy ramping in the booster ring will be presented in detail.

INTRODUCTION

The main purpose of Korea fourth generation storage ring (Korea-4GSR) project is to generate low emittance beam and provide the photon beam, which is 100 times brighter than that of the third-generation storage ring (3GSR). The construction for Korea-4GSR has been underway since 2022 and will be completed in 2027 and start operating the accelerator in 2028 [1].

Korea-4GSR with low emittance consists of 4 GeV storage ring and synchrotron radiation experimental beamline. The light source will be composed of three main parts, a 200 MeV linac with a photocathode gun, a 4 GeV booster ring, and a storage ring.

The storage ring is based on the hybrid multi-bend achromat lattice and its circumference is about 800 m. The storage ring will provide a beam of 4 GeV, 400 mA and 58 pm. The booster ring will be located in the same tunnel as the storage ring and accelerate electrons from 200 MeV to 4 GeV. To properly inject the beam into the booster ring, a septum and kicker magnets are required at the end of linac-to-booster (LTB) transfer line. This paper explains the injection scheme and ramping process of booster ring.

LATTICE DESIGN

The Korea-4GSR booster ring adopts two-fold symmetric lattice with combined-function magnets suitable to provide low emittance and each fold consists of 13 standard FODO cells and 1 dispersion free cells. Figure 1 expresses the optical functions of half-booster [2]. The optical functions in identical cell are β_x=24.18 m, β_y=3.917 m, η_x=0.509 m and η_y=0 m. Table 1 summarizes the main parameters of 4 GeV booster ring lattice. The circumference of the booster is 772.9 m, which is designed to share a tunnel with storage ring.

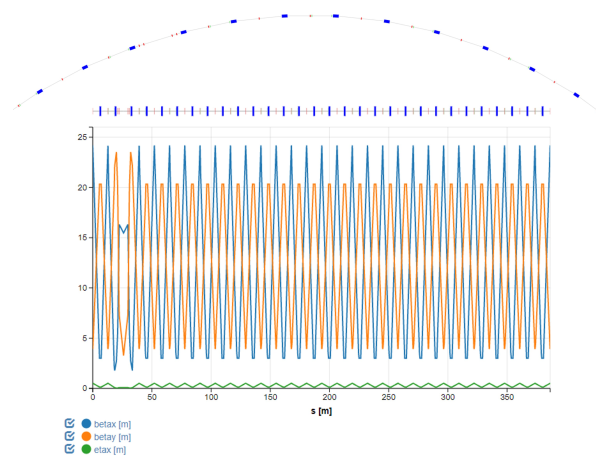

Figure 1: Part of the lattice structure and optical functions of half-booster.

Table 1: Main Parameters of 4 GeV Booster Lattice

Parameter	Value	Unit
Injection energy	0.2	GeV
Extraction energy	4	GeV
Circumference	772.9	m
Beam current	2	mA
Repetition rate	2	Hz
Revolution time	257.8	µs
Natural emittance	7.67	ns
Betatron tune (H/V)	19.2 / 14.2	
Natural chromaticity (H/V)	−12.4 / −8.7	
Damping time (H/V/L)	8.33 / 12.3 / 8.13	µs
RF frequency	499.594	MHz
Harmonic number	1289	
Momentum compaction factor	9.25×10^{-4}	
Energy loss per tune	1.671	MeV
Natural energy spread	1.144×10^{-6}	

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INJECTION SCHEME

A septum(Si) and kicker(Ki) magnets are used for on-axis injection of the booster ring from 200 MeV linac. Figures 2 and 3 show illustrations for LTB-to-booster beam injection scheme and horizontal phase space evolution of the injected beam to booster ring, respectively.

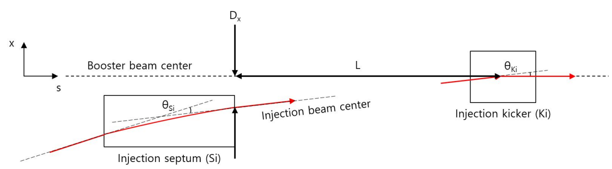

Figure 2: On-axis injection scheme of booster ring.

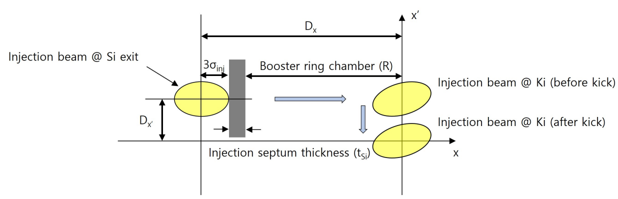

Figure 3: Beam horizontal phase space evolution during the on-axis injection.

The detailed specifications of a septum and kicker magnets can be calculated from spatial limitation, injection beam size, and performance of a power source [3]. For example, injection beam is 20 mm (D_x) away from the ideal orbit center of a booster now that a distance (R) between septum wall and booster orbit center is 17 mm, an injection beam size ($3\sigma_{inj}$) is 1 mm and septum wall thickness(t_{Si}) is 2 mm. Then injection beam center deviates from the design orbit center of the booster as shown in Fig. 4.

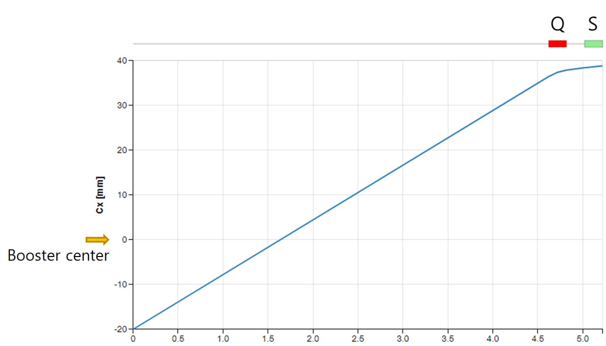

Figure 4: Injection beam center shift before turn on kicker magnet.

Figure 5 shows that injection beam with 20 mm shift passes the ideal center of a booster by a kicker magnet with the angle of 12.22 mrad (θ_{Ki}=$D_{x'}$). The center of a kicker magnet is located 1.637 m from the end of a septum magnet and the length of a kicker magnet is 0.5 m. The specifications of a septum and kicker magnets are being studied and will be modified in detail.

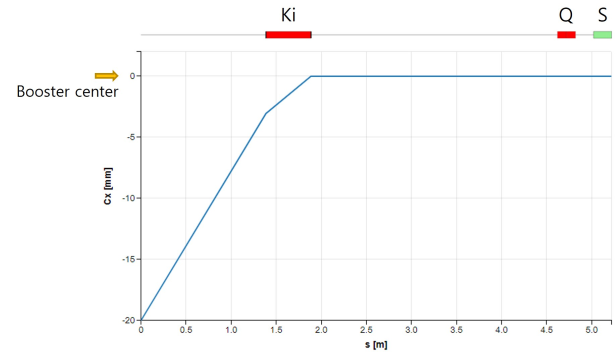

Figure 5: Injection beam center shift after turn on kicker magnet.

BOOSTER RAMPING

Ramping Cycle

A booster ring operates with repetition rate of 2 Hz and energy ramping cycle is shown in Fig. 6. The ramping curve has a flat-bottom shape of 10 ms and ramps up from 200 MeV up to 4 GeV for 250 ms. After the energy reaches 4 GeV, the ramping curve maintains a flat-top shape of 30 ms for beam extraction to storage ring. After beam extraction, the curve rapidly ramps down for 150 ms and the remaining time of 60 ms allows hysteresis effects of magnets.

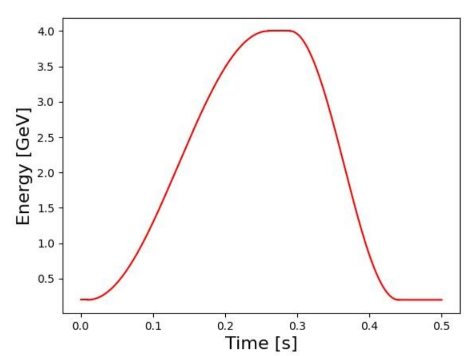

Figure 6: Energy ramping cycle in a booster ring.

Eddy Current Effect

The ramping curve of the booster is determined by time-dependent magnetic fields of the bending magnet [4]. The time-dependent fields produce eddy currents in the vacuum chamber of the bending magnet. An eddy current inside the vacuum chamber generates a distortion of the magnetic field and the field distortion results in a decrease of the field in the center of chamber. The field distortion can be expressed as a sextupolar component and sextupolar components induced by eddy current in the ramping up process of Korea-4GSR booster are shown in Fig. 7. The red and blue lines indicate bending magnets located in an ideal cell and dispersion-free cell, respectively. As shown in Fig. 7, the sextupolar contribution is more important at the low energy region.

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The sextupolar component can be varied depending on the geometric specifications of the bending magnet chamber and the chromaticity change due to the eddy current can be corrected by sextupole magnets.

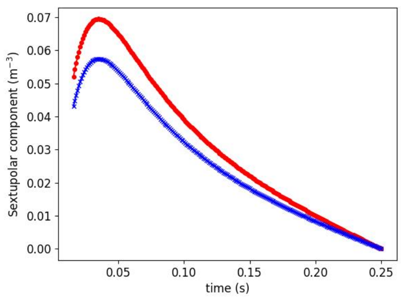

Figure 7: Sextupolar component induced by eddy current in booster ramping-up process (red : bending magnet in ideal cell, blue : bending magnet in dispersion free cell).

Emittance and Energy Spread Evolution

The beam emittance and energy spread evolution in booster ramping-up process can be calculated by following equation,

$$\frac{dA_i}{dt} = -A_i \left(\frac{\dot{E}}{E} + J_i \frac{P_\gamma}{E} \right) + C_q \frac{P_\gamma \gamma^2}{E} G_i \qquad (1)$$

where A_i with $i = 1$ and 2 symbolizes the energy spread $(\sigma_E/E)^2$ and horizontal emittance ε_x, respectively. $\dot{E}$ is the time derivative of energy E, J_1 is longitudinal damping partition number, J_2 is horizontal damping partition number, P_γ is the synchrotron radiation power, C_q is the quantum constant with 3.832×10^{-13} m, γ is the Lorentz factor, G_1=I_3/I_2 and G_2=I_5/I_2. I_2, I_3 and I_5 are 2nd, 3rd and 5th synchrotron ramping integrals, respectively. Equation (1) includes adiabatic damping and quantum excitation. The first term on the right-hand side represents adiabatic damping process, which comes from the effects of beam energy ramping and radiation damping. The second term on the right-hand side indicates quantum excitation and is independent of the emittance.

Figures 8 and 9 show beam emittance and energy spread evolution in ramping-up process of Korea-4GSR booster. The radiation damping effect is very weak at low energy regions but contributes a lot in high energy regions as shown in Fig. 8. In the energy ramping-up process of Korea-4GSR booster, the energy spread does not increase significantly. The calculation results for emittance and energy spread are listed in Table 1.

RF Voltage and Phase

500 MHz PETRA-type 5-cell cavities are scheduled to install in Korea-4GSR booster ring. Figure 10 shows RF voltage ramping-up curve (left) and synchrotron phase changes (right). RF voltage increases from 0.25 to 2.25 MV and synchrotron phase decreases 180 to 132 degree in 250 ms.

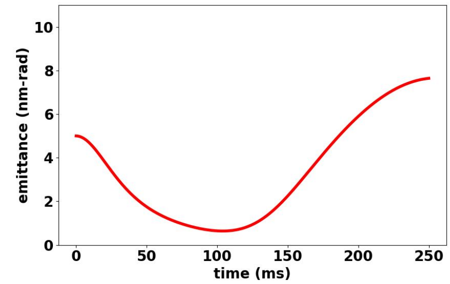

Figure 8: Emittance evolution in booster ramping-up process.

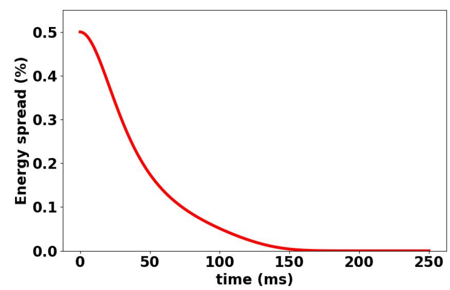

Figure 9: Energy spread evolution in booster ramping-up process.

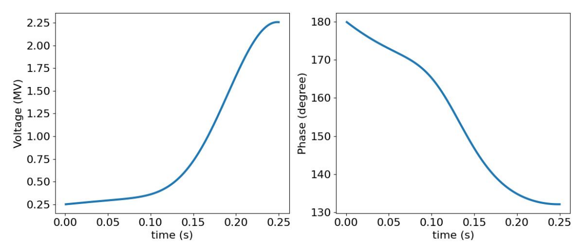

Figure 10: RF voltage ramping-up curve (left) and synchrotron phase changes (right).

SUMMARY

The LTB-to-booster injection scheme and booster ramping process are explained to require low emittance for Korea-4GSR in this paper. The use of a septum and kicker magnets for injection into the booster is under consideration. Study on energy ramping issues in booster is also in progress through numerical analysis and simulation using Elegant code.

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