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STUDY ON BEAM INJECTION AND RAMPING EFFICIENCY FOR Korea-4GSR BOOSTER SYNCHROTRON

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Abstract

The Korea fourth-generation storage ring (Korea-4GSR) project was launched in 2021 to generate high-brightness photon beams as a diffraction-limited light source. The 200 MeV beam is injected into the booster synchrotron. The beam parameters and transmission efficiency fluctuate with initial beam conditions such as Twiss parameters and centroid offset during the injection and energy ramping process. Therefore, the study on the initial conditions of the incident beam to the booster synchrotron needs to be carried out to gain high beam quality and efficiency. This paper presents the energy ramping results of the beams injected into the booster synchrotron with various initial beam conditions.

INTRODUCTION

The innovation of the fourth-generation storage ring (4GSR) light sources based on a multi-bend achromat (MBA) lattice allows the production of electron beams with an ultra-low emittance in the order of tens of nm rad. In turn, the low emittance of electron beams leads to a brighter and more coherent photon beam. Therefore, various 4GSR light source facilities for improved X-ray beam performance are being built or planned to be built worldwide, starting with the MAX-IV in 2016 [1].

With a rising demand for a high-performance synchrotron radiation facility in the Republic of Korea, the construction project for a new 4GSR light source facility - the Korea-4GSR project - began in 2021. The Korea-4GSR light source will provide a high-quality photon beam that is 100 times brighter and 100 times more coherent than that of the third-generation storage ring (3GSR), the Pohang light source-II (PLS-II), for various applications, such as basic scientific research and industrial use. The Korea-4GSR light source consists of a 200 MeV linac, a booster synchrotron, and a storage ring with an energy of 4 GeV and a circumference of 800 m, with the booster synchrotron and storage ring installed within the same tunnel. The anticipated emittance and current of electron beams are ~ 60 pm and 400 mA, respectively. A total of 52 beamlines can be installed, and up to 60 beamlines can be installed with a canted insertion device (ID) if necessary. The Korea-4GSR light source, including the 10 beamlines to be initially built, is currently under construction and will be in operation from 2028 [2, 3].

It is necessary to confirm the beam injection efficiency and energy ramping process in the booster synchrotron to achieve the designed high-beam quality in the storage ring.

BOOSTER SYNCHROTRON

The Korea-4GSR booster synchrotron has a circumference of 773 m, which is almost identical to the circumference of the storage ring. It adopts a two-fold symmetric lattice consisting of 60 FODO cells, including 56 standard cells and 4 matching cells. The standard and matching cells comprise combined-function bending magnets with a bending angle of 6.07 ° and 5.02 °, respectively. Figure 1 shows the optical functions (β_x, β_y, η_x) for the one straight and four standard cells of the booster synchrotron. The booster synchrotron operates with a repetition rate of 2 Hz and accelerates the 200 MeV electron beams up to 4 GeV during the ramping-up process in 0.25 s. Table 1 summarizes the main parameters of the Korea-4GSR booster synchrotron at 4 GeV.

Table 1: Main Parameters of Korea-4GSR Booster Lattice at 4 GeV

Parameter	Value	Unit
Injection energy	0.2	GeV
Extraction energy	4	GeV
Circumference	772.893	m
Beam current	2	mA
Repetition rate	2	Hz
Revolution time	2.578	µs
Natural emittance	7.67	nm rad
Betatron tune (H/V)	19.2 / 13.2	
Natural chromaticity (H/V)	−12.7 / −7.8	
Damping time (H/V/L)	8.43 / 12.3 / 8.03	ms
RF frequency	499.594	MHz
Harmonic number	1288	
Momentum compaction factor	9.3×10^{-4}	
Energy loss per tune	1.671	MeV
Natural energy spread	0.106	%

BOOSTER ACCEPTANCE

The motion of an individual particle is described in terms of transverse and longitudinal motions. Some of the particles are lost due to the various aperture limitations. The large acceptance of the booster synchrotron is crucial to have

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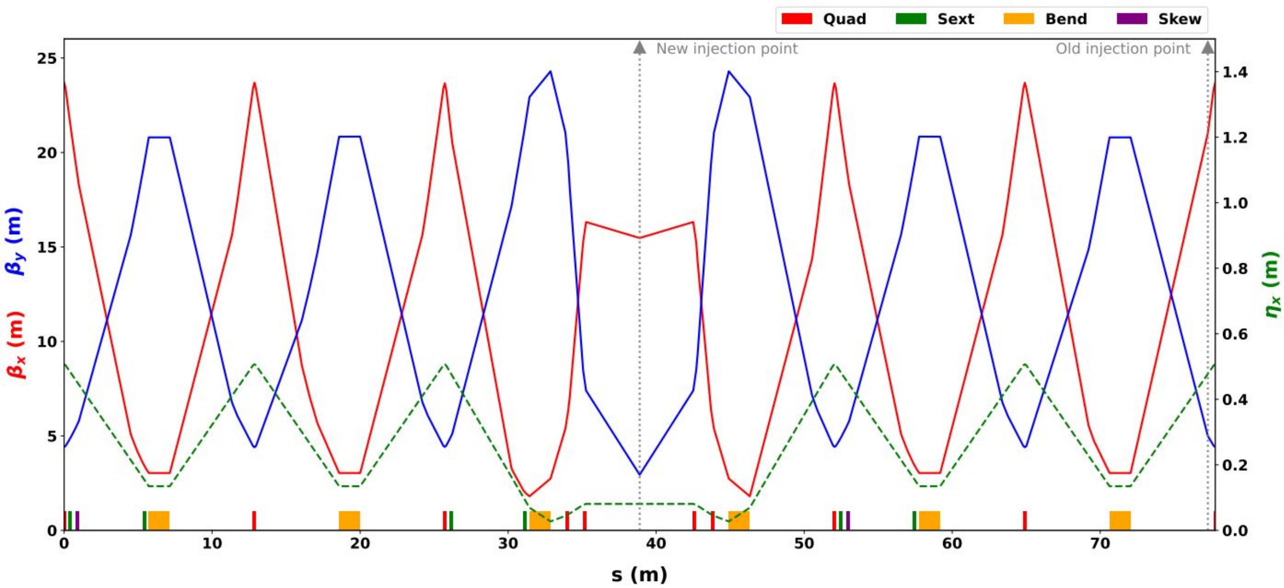

Figure 1: Lattice functions for 4 ideal cells and 2 matching cells of the Korea-4GSR booster synchrotron.

a high booster injection efficiency and reduce the requirements on the lilac gun. The injection point of the booster synchrotron has been optimized to the new injection point shown in Fig. 1, considering various aperture limitations outlined in the following subsections when compared to the old injection point.

Transverse Acceptance

To alleviate the charge requirements on the linac gun and inject more charge into the storage ring, we are studying the possibility of transversely stacking bunches in the booster synchrotron. The top and bottom plots in Fig. 2 represent the transverse acceptance at the old and new injection points of the booster synchrotron, respectively. The red elliptical line is calculated from the lattice parameters, and the black cross marks represent the simulation results using ELEGANT tracking [4]. The blue dots are the initial beam distributions injected from the 200 MeV linac. The maximum offset in the horizontal position improves at the new injection point.

RF Acceptance

The RF acceptance is determined by parameters including the RF voltage, frequency, momentum compaction factor, and energy loss per turn. The RF voltage value of the Korea-4GSR booster synchrotron at 200 MeV is 0.3 MV, and then the maximum value of the RF bucket height is about 2.8 %. As shown in Fig. 3, as the voltage value at the initial energy increases, the maximum RF bucket height increases.

Dynamic Aperture

The dynamic aperture generally shrinks with the energy deviation, because of the chromatic and nonlinear effects. Figure 4 shows the ELEGANT results of 400 turn simulations of the dynamic aperture of the booster synchrotron with and without errors at the old (top) and new (bottom)

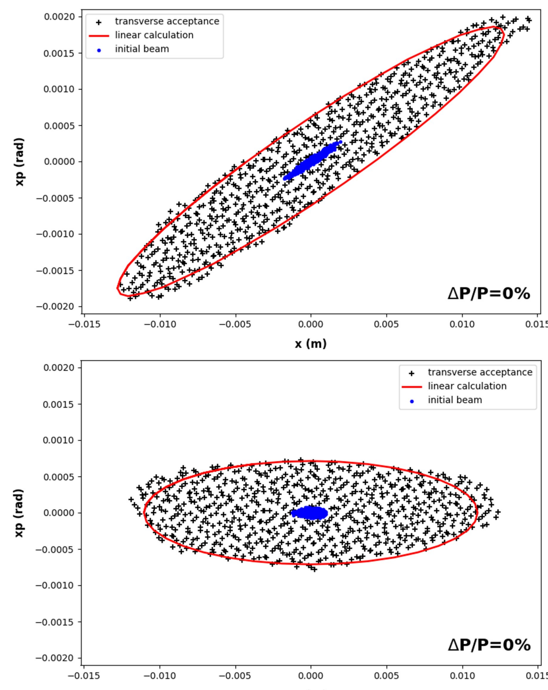

Figure 2: Transverse acceptance of the old (top) and new (bottom) injection point at the 200 MeV booster synchrotron.

injection positions. As shown in Fig. 4, both with and without the momentum errors, the dynamic aperture at the new injection point is improved by about 2.5 times compared to that at the old injection point.

RAMPING PERFORMANCE

The evolution of beam emittance and energy spread during the booster synchrotron ramping-up process can be calculated by following the equation,

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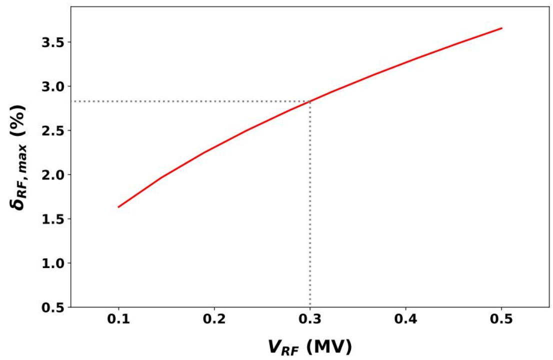

Figure 3: RF acceptance variations according to the initial voltage values at the 200 MeV booster synchrotron.

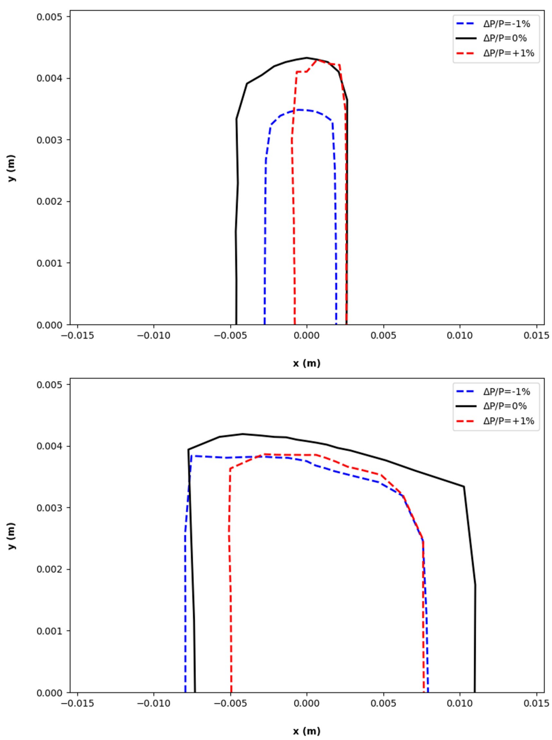

Figure 4: On and off momentum dynamic aperture at the old (top) and new (bottom) injection point at the 200 MeV booster synchrotron.

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

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 radiation integrals, respectively. The first term on the right-hand side in Equation (1) represents the adiabatic damping process, which comes from the effects of beam energy ramping and radiation damping, and the second term on the right-hand side indicates quantum excitation.

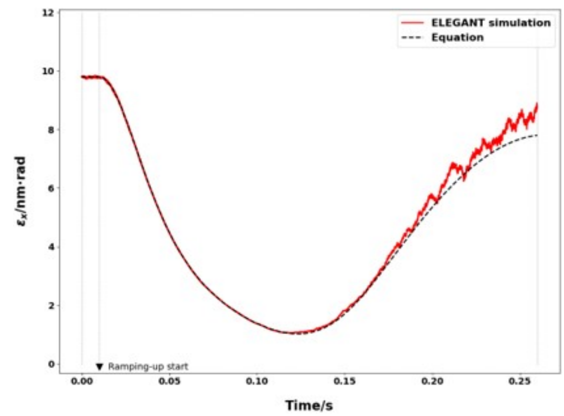

Figure 5: Emittance evolution during the ramping-up process of the Korea-4GSR booster synchrotron.

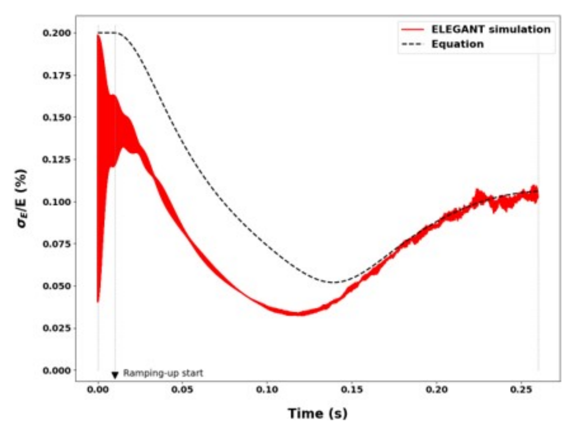

Figure 6: Energy spread evolution during the ramping-up process of the Korea-4GSR booster synchrotron.

Figures 5 and 6 show the beam emittance and energy spread evolutions during the ramping-up process of the Korea-4GSR booster synchrotron [5]. The red solid lines in Figs. 5 and 6 represent the ELEGANT simulation results, and the black dashed lines are the calculation results derived from Eq. (1). As shown in Fig. 6, the RF bucket height of 2.8 % in Fig. 3 is sufficient when considering the energy spread variation during the ramping-up process.

SUMMARY

To gain high beam quality and efficiency, studies on the various aperture limitations for the injection point and the variations of the beam parameters during the ramping-up process in the Korea-4GSR booster synchrotron are performed. The optimized injection point for 200 MeV beams and the results of the ELEGANT tracking simulation are explained in in this paper.

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