

# DESIGN OF 1.5 GeV COMPACT STORAGE RING FOR THE EUV AND SOFT X-RAYS

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## Abstract

Recently, there has been discussions about the need for the next-generation synchrotron light source facility in Korea. The facility in consideration is composed of a super-conducting linear accelerator for the injector, a storage ring for the EUV and soft X-rays, and a main storage ring for hard X-rays. In this study, design concepts of the soft X-ray storage ring are presented. To effectively utilize the small space allocated for the soft X-ray storage ring, a compact storage ring is taken into account. The compact storage ring is a synchrotron accelerator of which diameter is shorter than the length of injector beamline. In this paper, we report design concepts and optimization of the compact storage ring for the EUV and soft X-ray users. The lattice of the storage ring is modelled by utilizing ELEGANT simulation code to optimize beam parameters and performance of the ring.

## INTRODUCTION

In Korea, the necessity of a novel synchrotron light source facility has steadily been raised as the number of synchrotron beamline users are rapidly growing. Many Korean researchers have been discussing the new facility. The blueprint of huge synchrotron light source facility is shown in Fig. 1. There are three parts in the envisioned facility; a super-conducting linear accelerator (LINAC), a storage ring for the extreme ultraviolet radiation (EUV) and soft X-rays, and a main storage ring, which is a multi-bend achromat (MBA) based diffraction limited storage ring (DLSR). In this study, the storage ring for soft X-ray is presented. Since the site where the storage ring will be constructed is not wide, a compact storage ring (CSR) is considered. The design is performed with ELEGANT beam dynamics simulation code [1].

## COMPACT STORAGE RING DESIGN

Although it is not strictly defined, the diameter of the compact storage ring is considered smaller than the length of the injector beamline. We tried to make the circumference of the CSR less than 50 m. In our design, it was assumed that energy of electron beam is 1.5 GeV and RF system is equivalent to Pohang Light Source (PLS) RF system [2]. The RF frequency is 500 MHz, and the wavelength of RF is 0.6 m. Since the circumference of the CSR should be an



Figure 1: Blueprint of the envisioned synchrotron radiation facility. The storage ring for the EUV and soft X-rays (in red box) is presented in this study.

integer multiple of the wavelength, the circumference is set to 48 m. In this case, the harmonic number is 80.

The super-period of CSR was set to four. There are four arcs and four drift spaces to secure room for insertion devices such as undulators and RF cavities. The longest drift line is 3 m long. The structure of storage ring is shown in Fig. 2. In an arc, two bending magnets are located. Five focusing quadrupoles and two defocusing quadrupoles are located around those bending magnets.

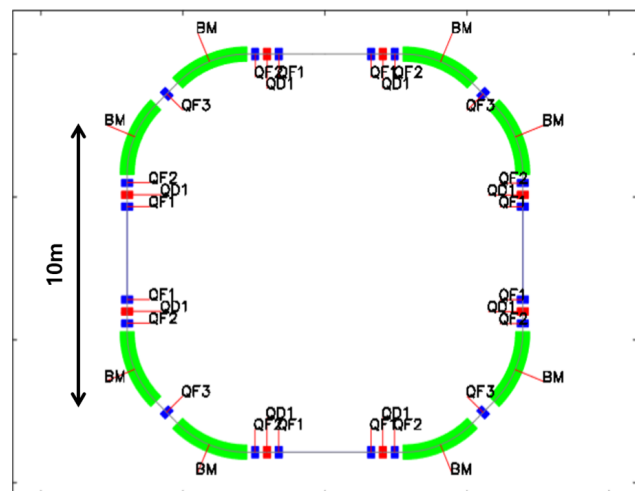


Figure 2: Layout of the designed CSR. QF corresponds to focusing quadrupole magnet, QD corresponds to defocusing quadrupole magnet, and BM corresponds to bending magnet.

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To make good use of insertion devices, it is important to make the size of electron beam small. The small beamsize can be obtained by making dispersion functions zero. The magnet strengths were optimized by performing simulations with ELEGANT code for the dispersion-free drift space. The result of the designed CSR is summarized in Table 1.

Table 1: Parameters of Designed CSR

Element	Value	Unit
Shape	4-corner	-
Circumference	48	m
Super-period	4	-
Revolution Time	$1.6 \times 10^{-7}$	s
Harmonic Number	80	-
Radiation Loss/turn	195.49	keV
Natural Emittance	$6.4019 \times 10^{-7}$	m · rad
$\sigma_x$ at BM <sup>a</sup> Center	0.12	mm
Critical Wavelength	0.57	nm
Energy Spread	$7.0137 \times 10^{-4}$	-
Momentum Compaction Factor	0.1703	-
Bending Angle	45	°
Bending Radius	3.4506	m
Bending Magnet Field	1.45	T
Max Strength of QF <sup>b</sup>	4.77	m <sup>-2</sup>
Max Strength of QD <sup>c</sup>	5.11	m <sup>-2</sup>
Max Field Gradient of QF	23.8659	T/m
Max Field Gradient of QD	25.5670	T/m
Horizontal Tune	2.8887	-
Vertical Tune	1.2113	-
$\tau_x$	3.5807	ms
$\tau_y$	3.7010	ms
$\tau_\epsilon$	1.9026	ms

<sup>a</sup>Bending Magnet

<sup>b</sup>Focusing Quadrupole

<sup>c</sup>Defocusing Quadrupole

In our design, the magnetic field of bending magnet is 1.45 T, and the maximum field gradient of quadrupole is 25.5670 T/m. In general, the maximum magnetic field of a bending magnet is around 1.5 T and the maximum gradient of a quadrupole is less than 30 T/m. Therefore it is considered that there is no fabrication problem with magnets of our design.

The  $\beta$ -functions and dispersion functions at location of magnets are shown in Fig. 3. The dispersion function is zero at the longest drift space. It is expected that small beamsize for the effective use of insertion devices can be obtained with our design.

The critical wavelength of synchrotron radiation with the designed bending magnets is given by [3]

$$\lambda_c = \frac{1.86}{E^2 \cdot B}, \quad (1)$$

where  $\lambda_c$  is critical wavelength in nm,  $E$  is the beam energy

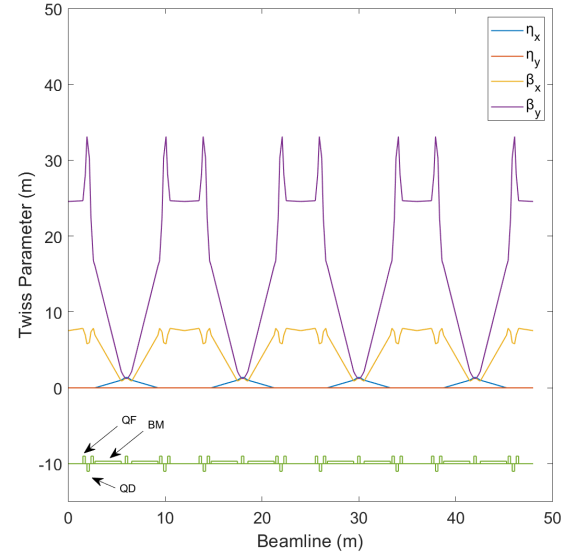


Figure 3: Betatron function and dispersion function along the beamline.

in GeV, and  $B$  corresponds to the field strength of the bending magnet in tesla. The critical wavelength of the designed CSR is 0.57 nm. It corresponds to soft X-ray region.

For the stable operation of CSR, the working point should be out of resonance condition. The resonance condition is given by [3]

$$k\nu_x + l\nu_y = mN, \quad (2)$$

where  $\nu_x$ , and  $\nu_y$  are the horizontal tune and the vertical tune, respectively.  $k, l, m$  are any integers,  $N$  is the number of symmetry. The order of resonance is defined as  $|k| + |l|$ . The working point of the designed the CSR in the tune diagram is shown in Fig. 4. The resonance line is plotted up to the 3rd order. As the working point is out of the resonance lines, it is believed that there will be no strong resonance problem during the normal operation of the designed CSR.

To generate high quality X-ray for the high resolution images, the electron beam must be small. The minimum beamsize at the middle of the bending magnet is calculated as follows [4]

$$\sigma_{xc} = \frac{\sqrt{C_q} \rho \gamma \theta^2}{24} \left( \frac{1.6}{J_x} + \frac{1}{J_\epsilon} \right)^{\frac{1}{2}}, \quad (3)$$

where  $C_q$  is the quantum constant,  $\gamma$  is the Lorentz factor,  $\rho$  is the bending radius.  $\theta$  is the bending angle,  $J_x$  is the horizontal damping partition number, and  $J_\epsilon$  is the longitudinal damping partition number. The minimum horizontal beamsize at the middle of the bending magnet of our design is 0.12 mm. The vertical beamsize is much smaller than the horizontal beamsize due to the horizontal bending and dispersion.

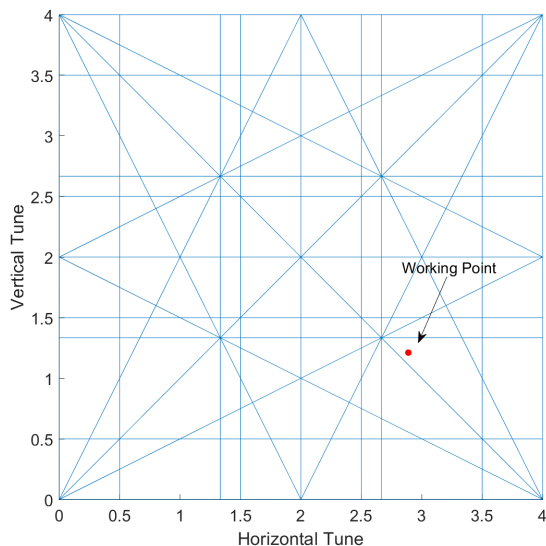


Figure 4: The resonance diagram (up to the 3rd order).

## CONCLUSION

In this paper, we have studied the design concept of a CSR for the EUV and soft X-rays light source. By utilizing ELEGANT simulation code, the lattice of the CSR was designed and some parameters were estimated. As a result, a CSR with an electron beam energy of 1.5 GeV, a circumference

of 48 m, and a beamsize of 0.12 mm at the bending magnet was designed. It is expected that good quality soft X-ray can be produced with our design.

However, the current CSR design is not optimized yet, and the design is continuously on going. There are several tasks for better results. One of the tasks is to make the beamsize smaller. Even though the beamsize of our design is small enough to be used for experiments, a much higher quality experiment could be performed if the beamsize becomes smaller. To achieve this goal, one of our future plans is to introduce the MBA lattice. Our current CSR was based on the double-bend achromat (DBA) one. It is expected that a much lower emittance can be obtained if the DBA lattice is replaced by the MBA based one.

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