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A HMBA LATTICE DESIGN STUDY FOR THE 4 GeV LIGHT SOURCE

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Abstract

The 4th generation storage ring (4GSR) project is scheduled from 2022 to 2027 in South Korea. We proposed a HMBA (Hybrid Multi-Bend Achromatic) lattice for 4GSR. The 4GSR lattice is designed to HMBA lattice with beam energy of 4 GeV, emittance of 53 pm and circumference of 843m. The storage ring includes 32 cells: 32 long sections with each 5.65 m, 16 short straight sections with each 1.3 m for insertion device and 16 short straight sections with each 1.3 m for super-bend. The calculated dynamic aperture is larger than 15mm in both directions and the beam life time is expected to 22.7 hour. In this paper, we will describe the study results of the HMBA lattice design with a 4 GeV light source.

INTRODUCTION

The characteristic of 4GSR is to increase the number of dipole magnets from five to nine, more than conventional two (DBA: Double Bend Achromatic) or three (TBA: Triple Bend Achromatic), thereby reducing the emittance of the storage ring by a factor of 100 compared to 3GSR (3rd generation storage ring). The need for a next-generation light source storage ring with more upgraded performance by light source storage ring experiment users is emerged.

Figure 1 shows the performance distribution along the storage ring circumference of the 3rd generation light source storage ring and 4GSR [1, 2]. The emittances of the storage ring are given proportional to the square of the energy of the electron beam, as shown in Eq. (1), and inversely proportional to the cube of the storage ring circumference (the number of dipole magnets in the storage ring).

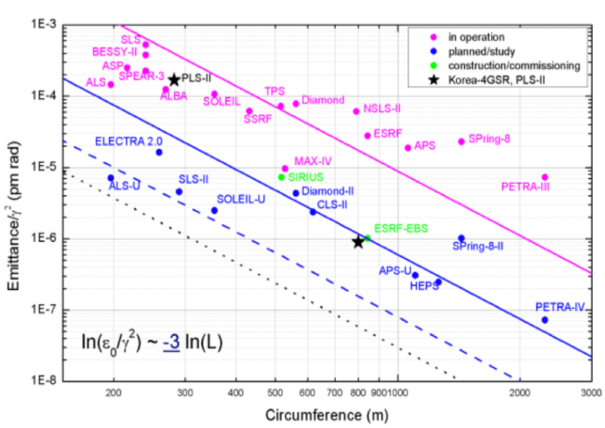

Figure 1. Distribution of performance according to storage ring circumference of 3rd generation light source and 4GSR.

$$\epsilon \sim F(Lattice)\, E^2 / C^3. \tag{1}$$

Compared to PLS-II, as shown in Fig. 1, the 4GSR can expect more than 100 times better performance because its circumference has grown to around 800m.

STORAGE RING DESIGN

Main Idea of Lattice Design

The lattice structure of 4GSR was proposed as a 7BA HMBA-type lattice structure with the APS-U lattice structure [3] as the basic framework. The 4GSR lattice was designed such as a HMBA lattice with a 4 GeV beam energy, 53 pm rad emittance and 842.9 m circumference. In addition, a centre dipole magnet of 2T and long insertion devices (IDs) are installed to provide 10 to 100 keV light source beam for 4GSR beam line users.

The storage ring was designed with 16 periodic cells of ARC1 to install super-bend with 1.3 m and ARC2 without super-bend to install short IDs with 1.3 m. Figure 2 shows the lattice design of ARC1 and ARC2.

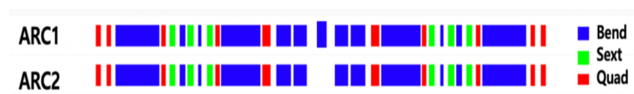

Figure 2. A designed periodic lattice of ARC 1 and ARC 2. Blue item is bending magnet such as super-bend, Longitudinal Gradient Dipoles (LGD), Dipole-Quadrupole magnet (DQ) and reverse bend (RB). Red item shows quadruploe magnets and green item shows sextupole magnets.

The reason that we used combined lattice is there is not so many requirements for centre bend beam line experiments with 2 T centre bend so that we designed two different type of period lattice to provide more possibility of different beam line experiment conditions.

Arc 1 lattice is designed to 7 BA and consists of long straight sections with 5.65 m for long ID and 2 T super-bend. Arc 2 lattice is designed to 6 BA and consists of long straight section with 5.65 m for long ID and 1.3 m short straight section for short ID. Therefore, 4 GSR storage ring includes 32 cells of combined lattice of ARC1 and ARC2.

Lattice Design

Twiss parameters with combined 4GSR lattice are shown in Fig. 3. The emittance of the entire storage ring was designed to be 53 pm rad, and in addition, the emittance of each periodic lattice structure ARC1 and ARC2 is also designed to be 53 pm rad. Therefore, we design to have flexibility on the redesign of the storage ring according to the demand of future 2T centre bend beam line experiments.

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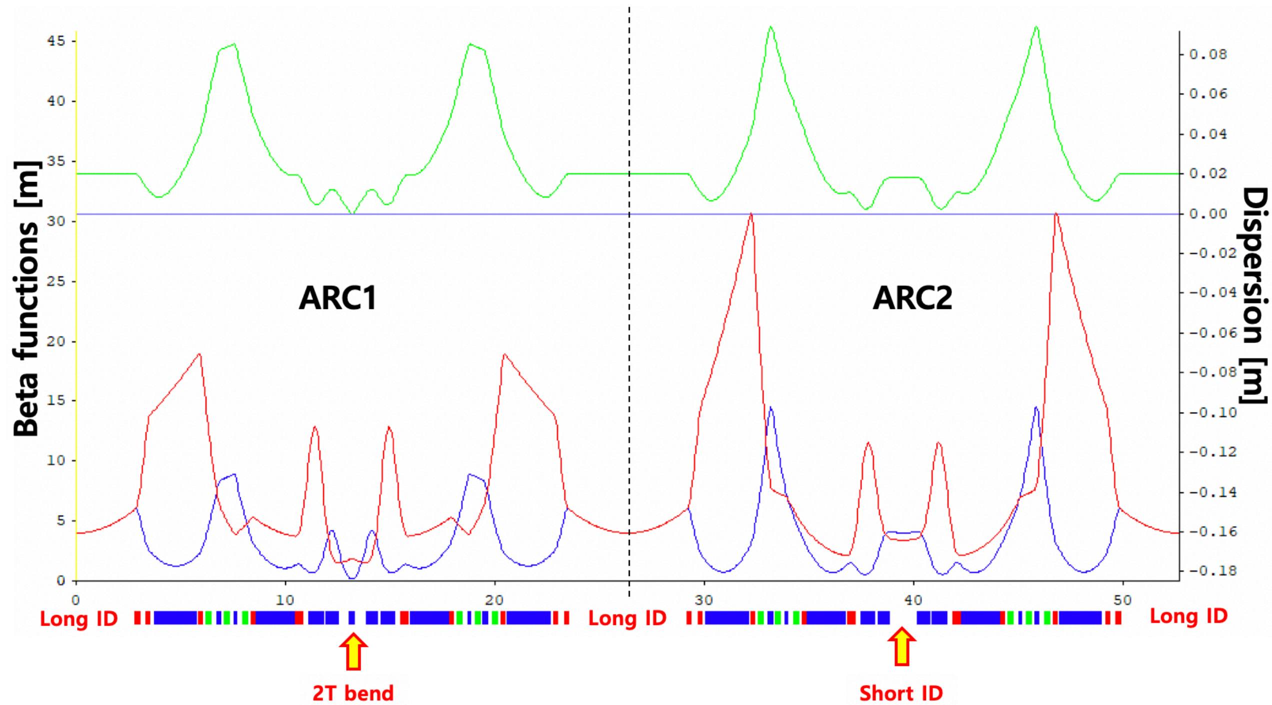

Figure 3: Twiss parameters of combined 4GSR HMBA lattice. The designed natural emittance is 53 pm rad.

Table 1: Designed Lattice Parameters of 4GSR

Parameters [unit]	Value
Energy [GeV]	4
Circumference [m]	842.908
Numbers of 2T super bend section	16
Numbers of 1.3m straight section	16
Numbers of 5.6m straight section (Including injection and RF sections)	32
Numbers of cells	32
RF frequency [MHz]	500
Harmonic number	1406
RF voltage [MV]	3.5
RF MA [%]	5.75
Energy loss [MeV/rev]	1.006
Momentum compaction factor	7.1×10^{-5}
Betatron tune (vx, vy)	71.52 / 25.73
Nat. Chromaticity (H/V)	-99.64 / -112.2
Damping time (x,y,z) [ms]	12.93/22.36/17.59
Beam current [mA]	400
Natural emittance [pm rad]	53
Touschek lifetime [h]	22.66
Energy spread [%]	0.1124
RMS bunch length [mm]	2.94

Both of periodic sector ARC 1 and ARC 2 are designed to achieve a high dispersion bump and a smaller emittance. Four LGDs (Longitudinal Gradient Dipole) with five segments are adopted at both sides of the dispersion bump. The maximum dipole field strength is 0.75 T in the LGDs, while the 2T centre bending magnet is installed only in ARC 1. In addition, 8 DQ(Dipole-Quadrupole) magnets are installed for each sector, 6 of which are reverse bends. 16 quadrupole magnets are installed per sector and the maximum gradient is 69 T/m.

The length of super-bend is designed to 22cm for 2T high gradient field and LGD is designed with five independent segments. The length of LGD1 and LGD2 are 2m and 1.786m, respectively. The magnet field strength of LGD1 and LGD2 for ARC1 and ARC2 are shown in Fig. 4.

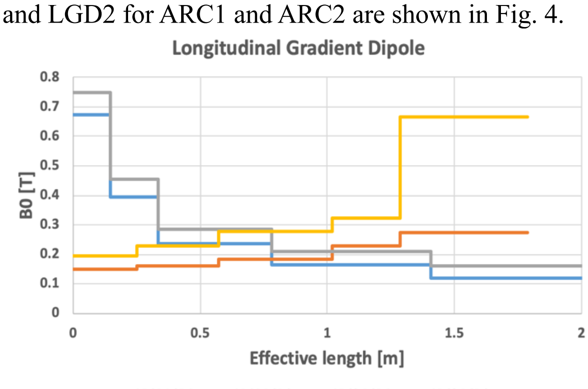

Figure 4: Longitudinal gradient dipole field strength of LGD1 and LGD2 for ARC1 and ARC2.

In the case of 4GSR, the placement of many bending magnets causes the linear beam dynamics to become un-stable, with several quadrupole magnets with strong strength being deployed to mitigate this. This increases the

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absolute value of natural chromaticity, thereby increasing the strength of the chromatic sextupoles after chromatic correction. As the strength of the chromatic sextupoles increases, the geometric non-linear effects is caused by the increase strength of chromatic. Therefore, we tried to use weak sextupole magnets as possible when designing lattice structures for chromaticity correction and tune correction to increase dynamic aperture (DA). 6 sextupole magnets are installed per sector and the maximum gradient is 637 T/m^2. The designed lattice parameters of 4GSR are listed in Table 1.

Non-linear Beam Dynamics

After chromatic correction, non-linear effects by chromatic sextupoles occur, the two possible side effects are the difficulty of off-axis injection due to small area on-momentum dynamics aperture and the rapid loss due to short beam life. These two effects must be suppressed for stable accelerator operation by nonlinear beam dynamics optimization.

Dynamics Aperture It is possible to track whether particles with normal energy in the incident position start from each (x,y) position in the transverse direction and continue to survive after sufficient turns. The transverse area where on momentim particles survive is called on momentum DA. When using off-axis injection scheme, especially in the horizontal direction, sufficient DA is required. An optimized DA due to momentum variations is shown in Fig. 5.

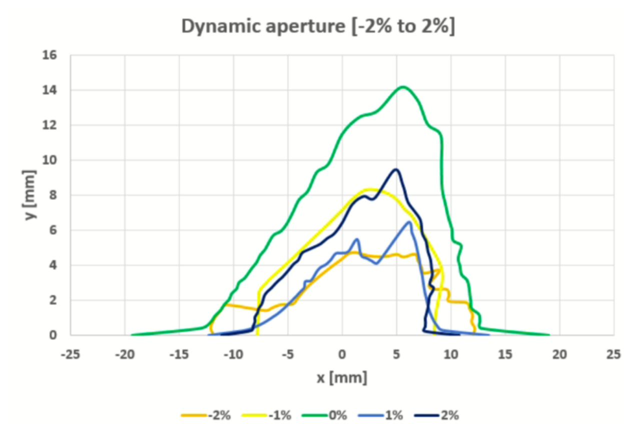

Figure 5. An optimized dynamic aperture of 4GSR.

Beam Lifetime 4th-generation light sources require very small transverse electron beam size in order to maximize photon beam brightness. One of the challenges of small beam size is due to the result of intra beam particle scattering, which make short beam lifetimes due to the Touschek Effect. Therefore, we need optimization of nonlinear beam dynamics due to Touschek effect to maintain long beam lifetime. In order to increase beam life, a family of weak strength sextupole magnets must be used to reduce nonlinear effects. The required energy acceptance to make adequate beam lifetime is typically from 2-5 %.

An energy offset area where the particle is not lost is called a momentum aperture (MA). MA is divided into RFMA, which determines whether to lose in the longitude direction, and lattice momentum aperture (LMA), which determines whether to lose in the transverse direction. RFMA can be controlled by adjusting RF voltage and is rarely affected by transverse beam dynamics. LMA is influenced by linear beam dynamics, but also by non-linear beam dynamics, which is determined by sextupole strength. To raise the Touschek life time, we need to make the LMA bigger, but as the off-momentum DA grows, the LMA becomes larger. An optimized simulation results of beam lifetime is shown in Fig. 6.

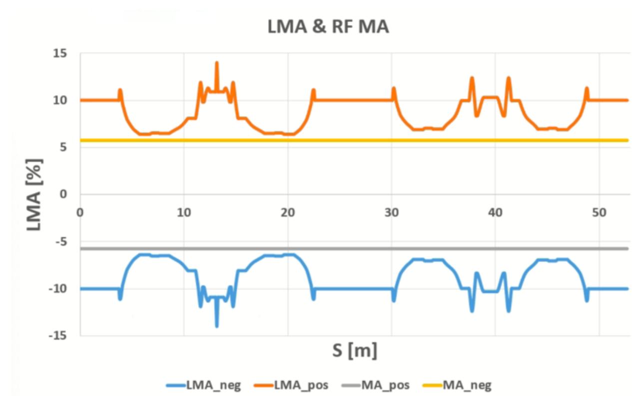

Figure 6. Momentum acceptance for RFMA and LMA.

CONCLUSION

In this proceeding, we designed a storage ring with 4 GeV and emittance of 53 pm rad for 4GSR. After the lattice design, we performed non-linear beam dynamics optimization study. The optimized dynamic aperture for the off-axis beam injection is enough large and the Touschek lifetime can be acceptable for the top-up operation.

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