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HEFEI ADVANCED LIGHT SOURCE: A FUTURE SOFT X-RAY DIFFRACTION-LIMITED STORAGE RING AT NSRL

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Abstract

To meet the fast-growing demands for high-quality low-energy photon beams, a new synchrotron radiation light source conception was brought forward several years ago by National Synchrotron Radiation Laboratory, which was named Hefei Advanced Light Source (HALS). The dominant radiation of HALS will be located in the VUV and soft X-ray region, which will be complementary with that of SSRF and HEPS. Except for high brilliance, high transverse coherence will be another signature feature of HALS. To achieve these goals, a multi-bend achromat based diffraction-limited storage ring was adopted as the main body of HALS. The general description and preliminary design of HALS will be briefly presented in this paper. Under the support of the Chinese Academy of Sciences and local government, the preliminary research and development (R&D) for HALS is undergoing. Several key technologies will be developed in the R&D project, which will lay good foundation for the construction of HALS.

INTRODUCTION

Hefei Light Source (HLS) was the first dedicated VUV and soft X-ray synchrotron radiation light source in mainland China, which was constructed nearly thirty years ago. After a major upgrade that was successfully finished several years ago, the beam emittance of HLS was reduced to about 38 nm·rad at the energy of 0.8 GeV and the number of straight sections for insertion devices was increased to 6 by adopting a strong focusing double-bend achromat lattice [1]. At present, the beam intensity is 360 mA, and 10 beamlines are in operation. The operation time of HLS is about 7000 hours per year, and the user time is more than 5000 hours per year. The operation status is stable.

But several key factors of HLS limit its performance. First, the beam energy is too low, which limits the highest achievable photon energy of short-period undulators. Second, the beam emittance is relatively large, resulting in relatively low photon beam brilliance. Third, the number of insertion devices is limited, and half of the beamlines are bending magnet ones, which have much lower photon flux and brilliance. Compared with the advanced VUV and soft X-ray light sources in the world, the capability and competitive power of HLS are not satisfactory nowadays, which can not meet the need of science development in the new century.

Ten years ago, a new ring-based synchrotron radiation light source, named Hefei Advanced Light Source (HALS) was brought forward [2]. During these years, the lattice design for the HALS storage ring has been studied continuously [3-9]. At present, the design goal of HALS is aimed at a soft X-ray diffraction limited storage ring (DLSR) light source. In 2017, the construction of comprehensive national science centers, possessing several major national science and technology infrastructures, were started in Beijing, Shanghai and Hefei cities. Like SSRF in Shanghai, HEPS in Beijing, a more advanced light source is indispensible for Hefei comprehensive national science center. And then, in the same year, the HALS research and development (R&D) project was approved by the Chinese Academy of Sciences (CAS) and local government, whose purpose is to optimize the design of HALS and develop the key technologies for the construction of HALS. In this paper, the situation of HALS will be briefly described.

GENERAL DESCRIPTION OF HALS

HALS is aimed to be a world-class DLSR in the soft X-ray regime. The beam energy is chosen to be in the range of 2.0 ~ 2.4 GeV in order that the radiation from undulators with different undulator periods can cover VUV and soft X-ray spectrum, and a higher beam energy is helpful to fight against the intrabeam scattering (IBS) effect under high beam intensity. Fig. 1 shows the layout of the HALS accelerator complex, which is composed of a DLSR, a full energy linac and a beam transfer line. In the present design, the circumference of the storage ring is 672 m, composed of 32 identical seven-bend achromat cells. Excluding two straight sections for RF system and beam injection components, the maximum number of straight sections for insertion devices is 30. Together with bending magnet beamlines, the total number of beamlines of HALS will be about 60. In the latest HALS storage ring lattice, the natural beam emittance is 23 pm·rad at 2.4 GeV [9], which is achieved by employing some longitudinal gradient bends (LGBs) and anti-bends (ABs).

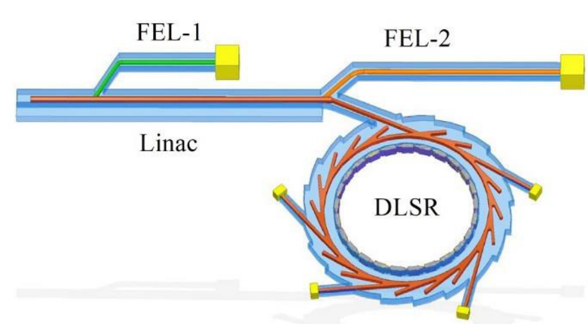

Figure 1: Schematic of the layout of the HALS accelerator complex.

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Due to limited dynamic aperture (DA) of storage ring, the on-axis injection scheme has to be adopted for HALS. Because rather good on- and off-momentum DAs as well as large dynamic momentum aperture (MA) have been achieved in the HALS lattice design [9], the longitudinal beam stacking [10] will be used to implement the beam injection and accumulation. So a full energy linac can be adopted as the injector for the HALS storage ring. A beam transfer line will be used to transfer the injected beam to the storage ring, which is of relatively traditional design. Benefiting from the fast development of linac-driven free electron laser (FEL) facilities, the linac beam quality, such as beam energy stability, energy spread and beam emittance, is better than before. As an injector to meet the requirement of storage ring injection, the linac also has a great potential to develop linac-driven FELs. So in the future, the HALS accelerator complex, including a DLSR and linac-driven EUV and soft X-ray FELs, will provide complementary capability to various users.

PHYSICS DESIGN OF THE HALS STORAGE RING

To achieve an ultra-low emittance of tens of pm·rad as well as relatively large DA and dynamic MA, some multi-bend achromat (MBA) lattices have been intensively studied for the HALS storage ring in these two years [6-9]. In the HALS lattice study, to better solve the problem of extremely strong nonlinear dynamics, we have proposed two MBA lattice concepts – the locally symmetric MBA [7] and the MBA with interleaved dispersion bumps [8]. In these two MBA concepts, most of the nonlinear effects caused by sextupoles can be efficiently cancelled out within one cell and also many families of sextupoles can be used in one cell for nonlinear optimization. Following these two concepts, 8BA, 6BA and 7BA lattices have been designed for HALS with emittances of about 30 pm·rad, and not only relatively large on- and off-momentum DAs but also very large dynamic MA has been achieved [7, 9].

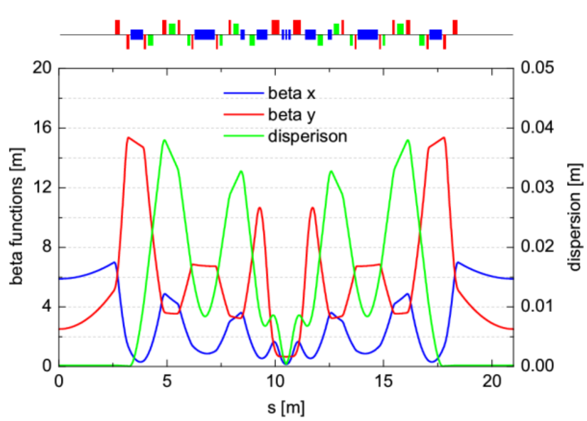

Figure 2: The magnet layout and linear optical functions of the latest HALS storage ring lattice.

Fig. 2 shows the latest HALS storage ring lattice [9], a 7BA designed using the concept of the MBA with interleaved dispersion bumps. Some LGBs and ABs were employed in designing the lattice, and a lower natural emittance of 23 pm·rad was achieved. In the lattice design, lots of parameters of magnets, including quadrupole and combined function dipole strengths, quadrupole and dipole positions, dipole lengths and fields, were optimized using particle swarm optimization algorithm, which we had applied to storage ring lattice design and optimization [11-13]. The main parameters of the storage ring are listed in Table 1. Like in Sirius [14], the middle bend complex of the lattice consists of two defocusing combined function dipoles and one superbend in the center with a high dipole field of 2T, which can extend the bending magnet radiation to shorter wavelengths. Fig. 3 shows the optimized on- and off-momentum DAs, which are all relatively large. The dynamic MA at long straight sections is even larger than 10%, see [9]. The maximum strength of quadrupoles employed in the lattice is about 80 T/m, and the maximum strength of sextupoles is about 4000 T/m^2.

Table 1: Main Parameters of the Latest Design of the HALS Storage Ring (Bare Lattice)

Parameter	Value
Energy	2.4 GeV
Circumference	672 m
Number of cells	32
Natural emittance	23.0 pm·rad
Transverse tunes	78.304, 29.382
Natural chromaticities	-109, -126
Momentum compaction factor	4.50×10^{-5}
Natural energy spread	8.20×10^{-4}
Energy loss per turn	212.4 keV
Damping times	35, 51, 33 ms
Beta functions at long straights	5.881, 2.507 m

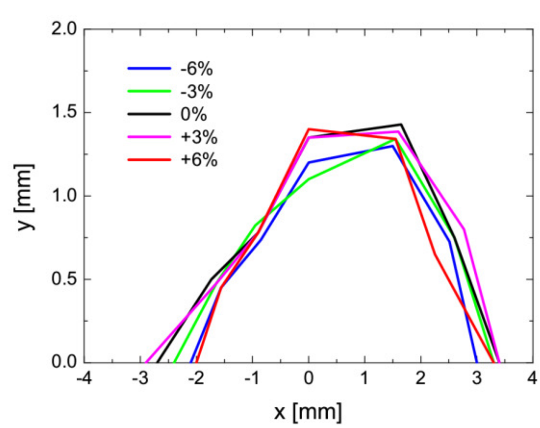

Figure 3: On- and off-momentum DAs of the latest HALS storage ring.

The rather good on- and off-momentum nonlinear dynamics performance can not only guarantee a long beam lifetime, but also provide the use of the longitudinal injection scheme [10] in the HALS storage ring. The process of beam injection was numerically simulated, and the result showed that the efficiency was high enough to maintain a

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top-up operation of the storage ring. The IBS effect is serious in the HALS storage ring, which will cause emittance increase. To mitigate this effect, a bunch lengthening RF system will be needed and also a full-coupling operation will be considered. For a given beam current, a higher frequency RF system is better for mitigating the IBS effect, but places a greater demand on the fast kicker for longitudinal injection. The additional damping from insertion devices has a beneficial effect on emittance reduction. Besides, beam instabilities and impedance models of various components are being studied for HALS.

Fig. 4 and Fig. 5 show the expected radiation performance of the HALS storage ring. Fig. 4 gives the brightness curves for some undulators, and Fig. 5 gives the transverse coherent fraction, from which we can see that the coherent fraction exceeds 50% at 10 keV.

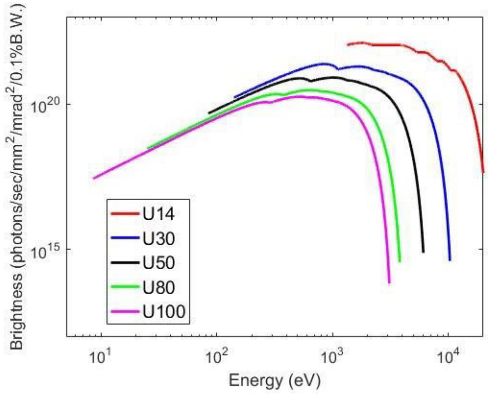

Figure 4: Brightness vs. photon energy for some undulators.

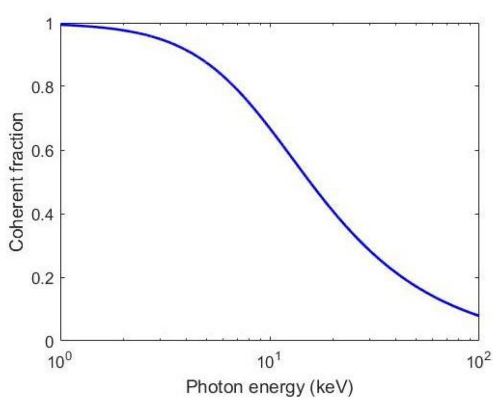

Figure 5: Coherent fraction vs. photon energy.

SUMMARY AND OUTLOOK

The HALS brought forward at NSRL is aimed to be a soft X-ray DLSR with both high brightness and high transverse coherence. The preliminary R&D project for HALS has been supported by the CAS and local government. The HALS storage ring of the latest design consists of 32 cells of 7BA lattice with a natural emittance of 23 pm·rad, and relatively large on- and off-momentum DAs and large enough dynamic MA have been achieved. Thus, the longitudinal injection scheme was adopted for the HALS storage ring with a full energy linac as the injector. Further physics design of the HALS storage ring, including lattice design and optimization, injection physics design, beam instability estimates and impedance calculations, error analysis and others, is being intensively studied. In addition, some key technologies are being studied under the support of the R&D project, such as high quality magnets, highly stable mechanical support, fast kicker, NEG-coated vacuum chamber, beam instrumentation, and so on.

ACKNOWLEDGEMENTS

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