THE CONCEPT OF HEFEI ADVANCED LIGHT SOURCE (HALS)*

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Abstract

The HLS (Hefei Light Source) is a dedicated second generation light source, which was constructed and commissioned in 1991. The dipole and undulator radiation of HLS are stronger in the VUV and soft X-ray range. Compared with the fast development of third generation synchrotron radiation light source, the performance of HLS was dropped behind and can not meet the requirement of synchrotron radiation users. For increasing demand of users, a scheme of new VUV and soft X-ray light source, named Hefei Advanced Light Source (HALS), was brought forward in the future plan of National Synchrotron Radiation Laboratory (NSRL). The design consideration of Hefei Advanced Light Source was present in this paper. A storage ring with ultra low emittance was adopted as main body of HALS. For simplicity, the current linac can be upgraded as its injector. The expected light source performance was calculated. The HALS would be one of advanced synchrotron radiation light sources in the world.

INTRODUCTION

Hefei Light Source of National Synchrotron Radiation Laboratory is a dedicated second generation light source, spectrally strongest in VUV and soft X-ray range. HLS has been designed in the late 1980s and began regular operation in 1991[1]. In its 18 years operation, HLS has made significantly contributions to synchrotron radiation research activities in China. Main parameters of HLS were listed in table 1. Comparing with third generation light source, the capability and performance of HLS were dropped behind much and can't meet the requirement of fast development of SR research activities. Some factors severely limit the performance of HLS, such as large beam emittance and a little insertion devices. The brilliance curve was given in the figure 2. The idea of reconstruction of storage ring to lower beam emittance to a few nm·rad and to increase insertion device number was discussed and calculated [2]. Although light source performance would be improved significantly, the length of insertion device (ID) is short due to the limitation of storage ring layout, and production of soft X-ray is difficult due to low beam energy. Thus a proposal of construction of a new VUV and soft X-ray light source in current campus of NSRL was brought forward. Then, two design principles were set, one is that the scale of new light source should be compatible with the campus of NSRL, the other is performance of new light source should be comparable with the advanced VUV and soft X-ray source in the world.

Table 1: Main parameters of HLS

Beam energy (GeV)	0.8
Circumference (m)	66.13
Focusing type	4×TBA
Beam emittance (nm·rad)	165
RF frequency (MHz)	204
Beam intensity (mA)	300
Transverse tunes	3.54/2.60
Momentum compaction	0.048
Available ID	3
Length of straight section (m)	3.3

DESIGN CONSIDERATION

Some features should be attached to future advanced light source, for example, high brilliance, better coherence, polarization, stability and tenability. For special users, ultra-high brilliance or ultra-short pulse is needed. It is not suspicious that undulator radiation is the leading choice for users in current and future light sources. The brilliance of undulator radiation is mainly related to beam emittance:

$$B = \frac{N_{ph}}{4\pi^2 \sigma_{Tx}\sigma_{Tx'}\sigma_{Ty}\sigma_{Ty'}\left(d\omega/\omega\right)} \quad (1),$$

where σ_{Tx} , σ_{Ty} , $\sigma_{Tx'}$, $\sigma_{Ty'}$ are horizontal and vertical source sizes, horizontal and vertical divergence respectively [3]. They mainly determined by electron beam emittance for current light source. To increase brilliance, reducing beam emittance is essential. When beam size is comparable with the photon beam size, the coherent partition of radiation is increasing. To measure coherence of light source, diffraction limited emittance was defined:

$$\varepsilon_{x,y} \le \frac{\lambda}{4\pi} \quad (2),$$

where λ is user-concerned radiation wavelength. When beam emittance is smaller than diffraction limited emittance, the radiation at specified wavelength can be considered having full lateral transverse coherence and show interesting diffraction and interference properties, which are attractive to some users. The polarization can be controlled easily by different type of insertion devices.

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The tenability and stability are basic requirement for successful operation of a light source. For the special requirements for ultra high brilliance or ultra short pulse, various schemes were investigated and experimented. For example, FEL can produce stimulated synchrotron radiation with ultra high power. In linac-based linac, photocathode and magnetic chicane techniques can be used to obtain very short pulse, while in storage ring based light source laser slicing and crab cavity techniques were developed [4,5].

To improve light source performance, different schemes were studied, such as linac-based FEL, linac-based ERL (Energy Recovery Linac), and storage ring with ultra low emittance, named diffraction limited storage ring. With the development of laser driven photocathode electron gun, beam emittance of linac based light source can achieve outstanding level. When normalized beam emittance is 1mm·rad and the beam energy is 10 GeV, the geometrical beam emittance is 0.05nm.rad corresponding to diffraction limited emittance about photon energy 2keV. FEL can provide ultra-high pulsed power for a few users, while ERL is more like a conventional facility and more users can be sustained at same time. Except for several FEL projects are carrying out or proposed, some proposals for ERL are under studying. With the development of third generation light source, principles and techniques of storage ring are well-rounded. The emittance of storage ring is determined by equilibrium between radiation damping and quantum excitation and can be expressed in iso-magnetic lattice:

$$\varepsilon_{x0}\left[nm\cdot rad\right]=1470\frac{\left(E\left[GeV\right]\right)^2}{J_x}\frac{F_1F_2\theta^3}{12\sqrt{15}} \quad (3),$$

where factor F_1 accounts for different focusing type, factor F_2 is dependent on detail lattice design and reflects the distance to theoretical emittance limit of a lattice, θ is deflecting angle of dipole. Due to the square dependence of emittance on energy, there are some difficulties to obtain ultra small emittance at higher energy. To lower emittance of storage ring, more cells and stronger focusing are needed, which would result in very strong nonlinear effects. The dynamic aperture and momentum aperture are key issues of ultra low emittance storage ring design.

HALS SCHEMES

Reviewed main features of advanced light source, the basic scheme of Hefei Advanced Light Source can be determined. As pointed before, the design goal of HALS is an advanced conventional synchrotron radiation facility spectrally strongest in VUV and soft X-ray range. The wavelength of undulator radiation on axis is determined by beam energy E and undulator strength parameter K,

$$\lambda\left[\overset{\circ}{A}\right]=13.056\frac{\lambda_{period}}{nE^2}\left(1+\frac{1}{2}K^2\right) \quad (4),$$

where λ_{period} is period length of undulator, n is harmonic number. There are two reasons which not argue high beam energy, first is low beam energy is helpful to produce long wavelength undulator radiation, another is low beam energy can ease the difficulty of reducing emittance according to (3). Thus energy of HALS is determined about 1.5 GeV, where there is no obvious superiority of linac-based light source versus storage ring in view of emittance. Considering a few users of FEL and unexpected difficulties of ERL for us, the storage ring with ultra low emittance become primary choice of HALS physical design. To satisfy with the special user requirements, the emittance design goal of HALS is determined and is smaller than 0.2nm·rad. Furthermore, the radiation of HALS is coherent above 2.5nm, which named water window in SR research.

Hoping locate the HALS at current campus of NSRL, the radius of storage ring is limited. Of cause, more straight sections for ID are a design principle. Different focusing structures were used in light source design. In the formula (3), the factors F_1 are listed in table 2.

Table 2: F_1 for different focusing structure

	F_1		F_1
DBA	3	FBA	1.796
TBA	2.326	SBA	1.667
QBA	2.0	SBA	1.571

Usually the DBA or TBA would be selected in storage ring design. To lower beam emittance, the Multiple Bend Acromat (MBA) structure is helpful. On the other side, the DBA structure has more flexibility and more straight section. Under circumference limitation, various focusing structure design were studied. If DBA or TBA were selected, the achievable emittance of bare lattice is larger and more damping wigglers are needed. Finally, Five Bend Acromat (FBA) structure was adopted as the standard focusing cell of HALS. Due to strong focusing, the nonlinear effects are very severe in HALS. We have proposed a racetrack configuration, and found that it is very difficult to get acceptable dynamic aperture [6]. Improving lattice symmetry and releasing focusing strength, the dynamic aperture of storage ring was improved. The figure 1 are β function and dispersion function of one cell. There is not dispersion in straight section and most insertion devices are helpful for decreasing beam emittance. The emittance of bare lattice is 0.28nm.rad, with a few damping wiggler, the beam emittance can be lowered than 0.2nm.rad easily. At same time, damping time is also reduced and helpful to fight with intra beam scattering effects. The main parameters of HALS are listed in table 3. Further optimizations of linear optics and nonlinear performance of HALS are undergoing. In near future, some intelligent optimization procedures, such as generic algorithm, annealing algorithm or particle swarm algorithm, would be introduced in optimization.

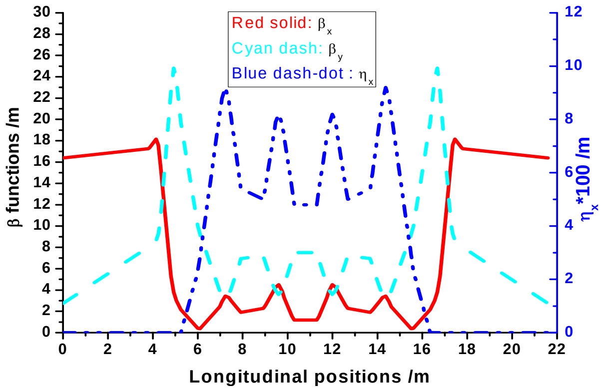

Figure 1: β and dispersion of one cell.

Table 3: Main parameters of HALS

Energy (GeV)	1.5	Circumference (m)	388
Focusing type	18× FBA	Beam intensity (mA)	500
Length of straight section (m)	7.6×18	emittance of bare lattice	0.28 nm·rad
Emittance with damping wiggler	<0.2nm·rad	Energy loss without ID	34keV/ turn
Energy loss with ID	200~300 keV/turn	Energy spread	0.00022
RF frequency (MHz)	~500	Harmonic number	648

The brilliance of HALS and HLS calculated by SPECTRA 8.1 [7] are displayed in figure 2. As expectation, the brilliance of HALS is higher than that of HLS by several orders, also better than the upgrading idea of current HLS storage ring.

The injection scenario was studied preliminarily. A four kicker local bump system at one straight section was employed; whose kick angle is 6.7 mrad. To obtain higher injection efficiency, the low emittance of injected beam is necessary. There are two selections of injectors. The first is construction of a new booster with low emittance. The second is upgrading current linac of HLS to increase beam energy from 0.2 GeV to 1.5 GeV. Serving as injector of HALS, the linac also provide beam for upgrading HLS [8]. There is not obstacle to obtain beam with high quality by upgrading linac technically. Using photocathode, the ultra low beam emittance is easy. The energy stability and energy spread can be controlled to acceptable level. With the help of top-off operation, the severe limitation of poor beam lifetime due to Touschek scattering effects can be removed. Also, the detail injector study should be studied in the future.

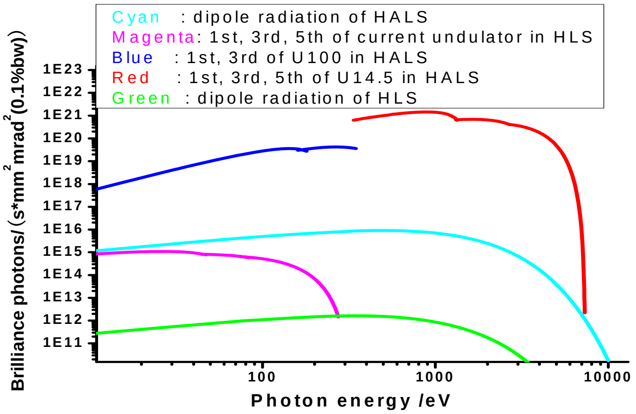

Figure 2: Brilliance curves of HLS and HALS.

OUTLOOK

To enhance competition ability of NSRL, a new VUV and soft X-ray proposal (HALS) was brought forward. According to current design, the HALS would possess of high brilliance and better coherence. At current stage, pilot study of the physical design of HALS is made and not obstacles were found, which can't be overcome. Many issues, such as intrabeam scattering, effects of insertion device, stability, instability, etc, are need addressed in the future. The formal application of HALS preliminary design study to government is undergoing. Finally, we would express our sincere acknowledgment to Dr. J.Payet of CEA for kind discussion of HALS lattice design.

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