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PRELIMINARY DESIGN OF INSERTION DEVICES AT HEFEI ADVANCED LIGHT FACILITY*

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Abstract

Hefei Advance Light Facility (HALF) is a 2.2 GeV diffraction-limited storage ring, which is developed by National Synchrotron Radiation Laboratory in China. It has 20 long straight sections and 20 middle straight sections. All the experimental stations in the first stage will employ undulator as the light source. In this paper, we introduce the preliminary design of insertion devices of HALF, which includes 11 undulators and 2 wigglers. The undulator design is carefully optimized based on the current undulator technology and experiment user demands. The photon flux of these undulators can cover the photon energy from 5 eV to 10 keV with the flux greater than 10^{14} phs/s/0.1% B.W. It can reach an ultra-high brilliance at the soft X-ray wavelength region. Most of the insertion devices are the elliptically polarized undulators and the in-vacuum undulators, therefore the light source of HALF will be charactered by a flexible tunability on polarization state and a broad range of photon energy from VUV to X-ray wavelength region.

INTRODUCTION

Benefitting from the great advantage on reducing emittance of the diffraction-limited storage ring with multibend achromat lattice, the storage ring light source gone through a prosperous development in the past ten years. Many laboratories have finished or planed to update the current devices or build a new storage ring. Hefei Advance Light Facility (HALF) is a 2.2 GeV diffraction-limited storage ring, which is a brand-new project and is developed by National Synchrotron Radiation Laboratory in China [1, 2]. The whole project of HALF will be completed in the next five years. It has a circumference near 480 m, in which 20 long straight sections and 20 middle straight sections are planned. All the experimental stations in the first stage will employ undulator as the light source. The relevant parameters at straight section are given in Table 1. The insertion devices of HALF includes 11 undulators and 2 wigglers. Table 2 shows the preliminary parameters of the insertion devices at HALF. It can be classified into three classes, including circularly polarized undulators which have 6 elliptically polarized undulators (EPU) and 1 helical undulator (HU), 4 linearly polarized undulators (LPU) and 2 in-vacuum undulators (IVU). One short IVU will be installed in middle straight section and the others are all in long straight sections. The minimum gap of two IVUs is set to 6 mm and all the other out-vacuum undulators have the same minimum gap of 12 mm.

Table 1: Parameters of Electron Beam at Straight Section (SC) of HALF

Parameter	Specification	Unit
Beam energy	2.2	GeV
Average current	350	mA
Horizontal emittance	176.4	pm·rad
Vertical emittance	13.2	pm·rad
Hor. beta function long/middle SC	6.834/2.518	m
Ver. beta function long/middle SC	2.536/1.930	m
Hor. dispersion function long/middle SC	0.0005/0.0304	m
Length of long/middle SC	5.3/2.2	m

Table 2: Parameters of Insertion Devices at HALF

ID Type	Period (mm)	Period Number	Max. K	Length (m)	Number
HU	115	35	9.87	4.2	1
EPU	102	40	12.30	4.2	1
EPU	60	68	5.76	4.2	1
EPU	43	96	3.33	4.2	2
EPU	41	42	2.95	1.8	2
IVU	21	182 52	2.10	4.2 1.5	2
LPU	38	110 105	3.41	4.2 4.0	2
Wiggler	100	41	15.92	4.2	2

UNDULATOR DESIGN

As summarized in Table 2, more than half of the insertion devices are circularly polarized undulators. One helical undulator is aimed to emit radiation with pure circular polarization state. This undulator is chosen as the Spring-8 type helical undulator [3], in which the middle row pole is used to generate vertical magnetic field and two outside rows are used to generate horizontal magnetic field , as shown in Fig.

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1. The magnetic fields on horizontal and vertical directions are optimized as much as possible to make them always be the same at different undulator gap and constant phase shift. Though the field strength is sacrificed to some extent in comparison to a typical EPU, it has the advantage to allow the experiment user maintain polarization state when scanning the gap.

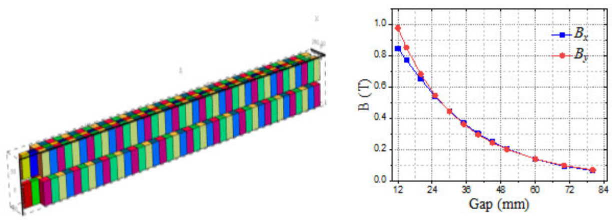

Figure 1: Left is the radia model of the helical undulator and right is the magnetic field depending on undulator gap.

All the other six circularly polarized undulators are the normal EPU, which are used to generate the flexibly tuned polarized radiation from linear to circular polarization state. Specially, in order to detecting spin and orbital moment of material in X-ray magnetic linear/circular dichroism, a special undulator system is utilized to realize a fast polarization switching. As shown in Fig. 2, two EPU41 are installed sequentially and connected by a phase shifter in one straight section. The electromagnetic phase shifter between two EPUs is normally used to match the radiation fields between two EPUs with a same polarization state. In the polarization switching mode, two EPUs works with an opposite polarization state and the phase shifter is utilized to deflect the beam, then the polarization switching can be realized at the end of beam line.

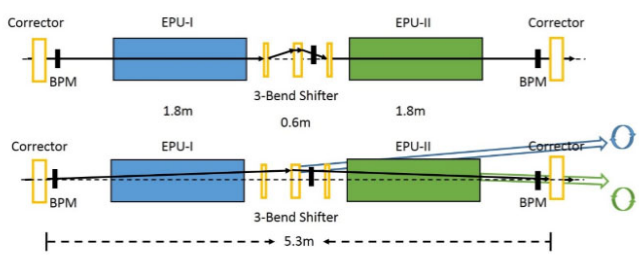

Figure 2: The double EPU system in which the upper case works as a single undulator and the lower case works with a divergence angle between two EPUs.

The above undulators are all arranged with Halbach permanent magnet arrays. The rest of undulators are hybrid undulator, in which the magnetic pole is chosen with FeCoV and the permanent magnet is NdFeB with a remanence of 1.3 T. Two IVUs and two LPUs are optimized to generate a high radiation flux from fundamental harmonic to a high (7th~9th) harmonic. The phase errors in these planar undulators are limited in a small level to ensure the harmonic flux does not suffer a significant decrease. Two damping wigglers are mainly used to reduce the damping times and emittance. The schematics of these undulators are neglected here. With the design parameters of HALF, the radiation performance are summarized below. The photon flux of these undulators can cover the photon energy from 5 eV to 10 keV with the flux greater than 10^{14} phs/s/0.1% B.W. It can reach an ultra-high brilliance at the soft X-ray wavelength region. Benefitting from the extremely low emittance of 190 pm·rad even considering intra-beam scattering effect at 350 mA average current, a considerable coherent fraction of photon flux can be preserved even at soft X-ray region.

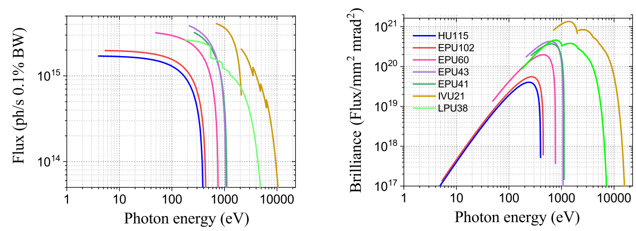

Figure 3: The radiation flux and brilliance for different undulators.

In physical design of undulator, based on the user demands for wavelength cover range and photon flux, the peak field and period length are determined by optimizing the three-dimensional sizes of magnet blocks with the given remanence of a specific magnet material. In addition, the field integrals must be well optimized by the termination and correct coil. Figure 4 shows the first and second field integrals by a preliminary termination design. EPU43 is taken as an example to show the field integrals under different undulator gap. An anti-symmetric termination with the air space is employed. The field integrals can be reduced to a small level for different polarization mode within a large gap range. Actually, the distribution and variation of field integral are complicated, the field integral optimized by termination in physics only can reflect the basic change tendency of field integral. For each undulator, several groups of correct coil will be installed to further optimize the field integrals under different situations.

To successfully operate an undulator in a fourth generation storage ring, the multipole field also should be carefully corrected. Generally speaking, besides the local/global compensation by storage ring, there are several methods to correct multipole field from undulator itself, including the magic finger, the L-shimming and the current strip [4–6]. Some of the circularly polarized undulators at HALF have a large period length with a high peak field and a long undulator length, which will introduce a strong effect to electron beam then arise a potential risk for beam injection and stored beam, especially for the vertical polarization state of EPU. In this condition, only employing the magic finger and L-shimming possibly cannot fully compensate the effects from multipole field. At HALF, we plan to employ a group of current strips to correct the multipole field. The current strips are fixed on the surface of vacuum pipe along undulator.

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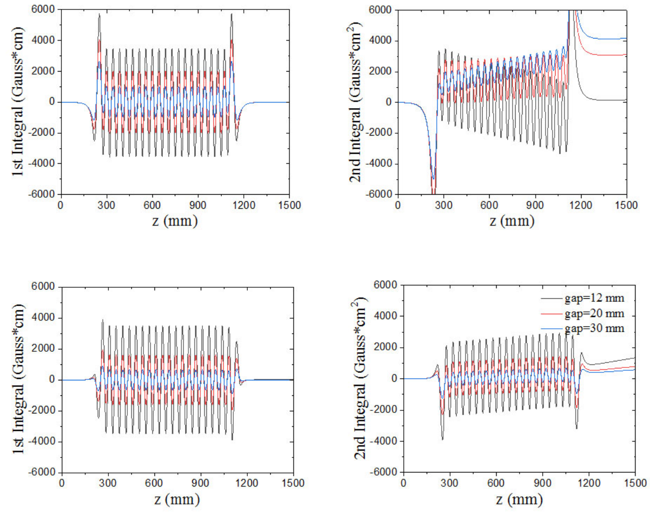

Figure 4: The first (left) and second (right) field integrals at horizontal (upper) and vertical (lower) directions for different gap of EPU43.

The radia model of current strips is shown in Fig. 5. The multipole field is optimized by the combination of intelligent optimization algorithm and the kick map method [7]. Through optimizing the current setting of each strip, the kicker strength by undulator can be reduced by at least one order of magnitude. In the preliminary design of undulators at HALF, all the circularly polarized undulators will employ the current strips. The specific parameters of current strip, such as the strip sizes and currents, will be further optimized with consideration of the available space and heat problem.

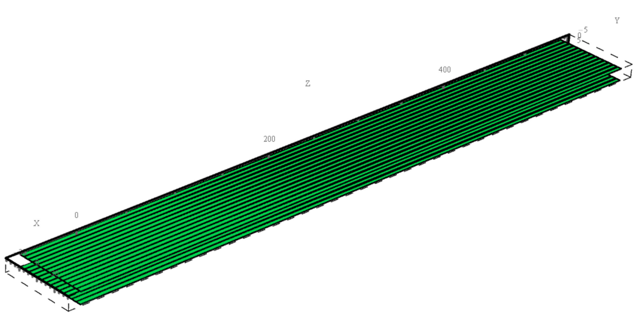

Figure 5: The radia model of current strips.

SUMMARY

This paper introduced the preliminary design of insertion devices at HALF. Currently, the parameters of all the undulators are almost fixed. It can make us bring into full play the advantage of HALF from VUV to soft X-ray region. We will soon carry on the development and manufacture process of HALF undulators.

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