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PROJECT OF WUHAN PHOTON SOURCE

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Abstract

Wuhan Photon Source (WHPS) has been designed as a fourth-generation light source, which consists of a low energy storage ring (1.5 GeV), a medium energy storage ring (4.0 GeV) and a linac working as a full energy injector. It has been planned to build the low energy light source first as the Phase I project, and then the medium energy light source after its completion. The low energy storage ring has been optimized with the main design parameters as following: An 8-cell, 500 mA storage ring, with circumference 180 m and nature emittance 238.4 pm.rad. Based on hybrid-7BA lattice structure, it reaches soft X-ray diffraction limit. And at the middle of each cell, a 3.5 T superB magnet is used to extend the photon energy to hard X-ray region. The swap-out injection is chosen due to the small dynamic aperture and a full energy S-band LINAC will be used as its injector. A 3rd harmonic cavity is designed for bunch lengthening to keep sufficient lifetime. More details of WHPS phase I project will be described in this paper.

INTRODUCTION

Wuhan Photon Source (WHPS) has been designed as a fourth-generation light source, which consists of a low energy storage ring (1.5 GeV), a medium energy storage ring (4.0 GeV) and a linac working as a full energy injector. It has been planned to build the low energy light source first as the Phase I project, and then the medium energy light source after its completion.

By using 3.5 T superB magnet, the photon energy of the low energy ring is extended to hard X-ray region. In the phase I project, eight beamlines are planned to build.

- Multifunction extreme UV lithography technology
- Extreme ultraviolet lithography applications
- Nano-focusing full-resolution electronic structure
- VUV spectroscopy and photoionization mass spectrometry
- Soft X-ray microscopic imaging
- In situ X-ray absorption spectroscopy
- In situ material diffraction
- Protein crystallography and biomedical application

In the following sections, the design of the WHPS phase I accelerator system will be described briefly.

1.5 GeV STOARGE RING LATTICE

Wuhan Photon Source 1.5 GeV storage ring, with 180 m circumference, is designed to use a 7BA lattice structure with eight cells and eight 6.8 m straight sections. One straight section will be used for the injection and extraction system, one section for the RF system and the bunch stretching system, and the remaining six sections for the insertion devices.

To minimize the beam emittance as much as possible in a small storage ring, in addition to using the 7BA structure, reverse bending, combined transversal and longitudinal gradient bending are also used in the lattice design. The lattice design uses the concept for ESRF-EBS scheme [1]. The main magnets of each cell include seven dipoles combined with transversal and longitudinal gradient, ten quadrupoles, four quadrupoles combined with reverse bending, six sextuples, and the magnet layout is shown in Fig. 1. The nature emittance of the low energy storage ring is 238.4 pm.rad and the beta function at the middle of the straight section are 3 m and 2 m in horizontal and vertical, respectively. Table 1 shows the main parameters of the 1.5 GeV storage ring.

Table 1: WHPS 1.5 GeV Storage Ring Main Parameters

Energy	1.5 GeV
Circumference	180 m
Straight sections	8x6.8 m
RF frequency	499.654 MHz
Harmonic number	300
Maximum current	500 mA
Betatron tune	20.22/11.29
Natural emittance	238.4 pm.rad
Natural chromaticity	-46.31/-33.04
Momentum compaction	$4.5\text{x}10^{-4}$
Radiation loss per turn	108.7 keV
Damping times (H/V/L)	7.4/16.6/22.2 ms
Relative energy spread	$1.21\text{x}10^{-3}$

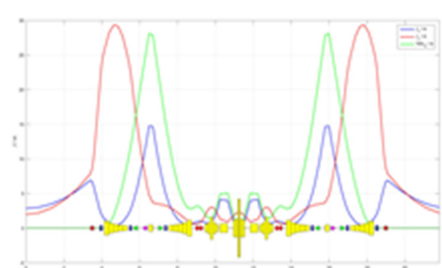

Figure 1: Optical functions and magnet layout of one cell of the storage ring.

Figure 2 shows the dynamic aperture at the center of the straight section. With 6 mm and 2 mm for on- and off-momentum particles, respectively, it is big enough for swap-out injection requirement. Figure 3 shows the energy acceptance along the ring. The minimum value of energy acceptance along the ring exceeds 2%, and the average value is -2.5% to 2.1%, combined with 20% coupling and a 3rd harmonic cavity for bunch lengthening, the Touschek lifetime at 500 mA will be about 5 hours, which matches the requirement for the top-up operation. Figure 4 shows the

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frequency map analyzing result for on-momentum particles, which is tracked 2048 turns with radiation and RF off. There are two strong resonance lines which caused the beam instability, $v_x+2v_y=43$ and $3v_x+v_y=72$.

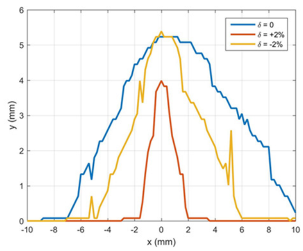

Figure 2: Dynamic aperture at the center of 1.5 GeV storage ring straight section.

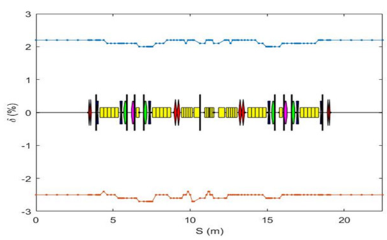

Figure 3: Optical functions and magnet layout of one cell of the storage ring.

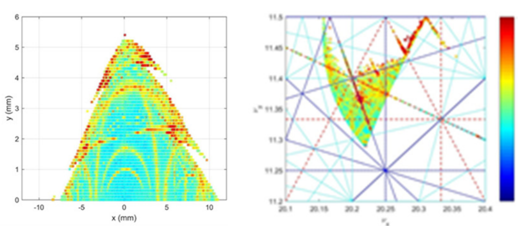

Figure 4: On-momentum FMA at the injection point.

MAGNET SYSTEM

Each cell has four different types of dipoles, and their magnetic field distribution is shown in Fig. 5. The dipole strength order for Bend1 and Bend7 is reversed, so do Bend2/Bend6 and Bend3/Bend5. Almost all dipoles are designed with transversal and longitudinal combined gradient, except the center one, there is no transversal gradient in 3.5 T region. The minimum arc height is about 11 mm in the Bend3/Bend5, and more than 20 mm in the Bend2/Bend6. To reduce good field requirement and size of the dipole, the dipole will be designed as a group of 3 or 5 small rectangular bends and each of them will be set along the beam trajectory.

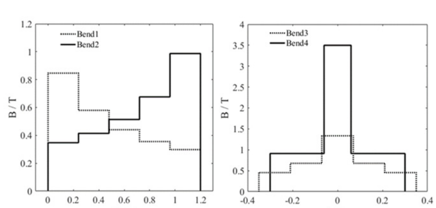

Figure 5: Magnetic field distribution of the dipoles.

All sextupoles are equipped with skew quadrupole and H/V corrector coils. Three independent H/V correctors are set at each end of straight section and the entrance of the superB dipole.

RF SYSTEM

Two BESSY type room temperature 500 MHz RF cavities and one third harmonic cavity will be installed in one 6.8 m straight section. The main parameters of the 500 MHz cavity are shown in Table 2.

Table 2: Main Parameters of RF Systems

Parameters	Value
Number of Cavity	2
Frequency (MHz)	499.654 +/- 0.150
Power per cavity (kW)	100
Voltage per cavity (MV)	0.45
Frequency stability	$1\text{x}10^{-8}$ or 5 Hz
Voltage stability	1%
Phase stability	1 degree
Energy loss per turn (kV)	108.7 (Dipole) + 60 (ID)

ERRORS AND CORRECTION

Detailed error analysis and its requirements are one of the most important contents in the storage ring design. According to the particle tracking analyzing results, the 1.5 GeV storage ring alignment error rms values are set to 80 μm and 80 μrad, and the magnetic field error rms value is $5\text{x}10^{-4,}$ respectively. Figure 6 shows the dynamic aperture of the on-momentum particles at the injection point with 100 random multipole error settings.

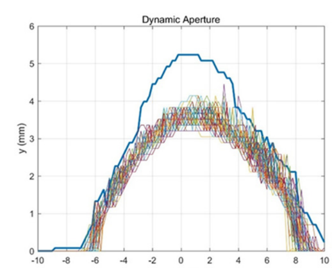

Figure 6: Dynamic aperture at injection point (100 seeds).

The storage ring orbit correction system includes BPMs and correctors, and all of them are horizontal and vertical combined. Each 7BA cell includes twelve BPMs and nine correctors. Six of the correctors are combined in the sextuples and other three are independent. The final corrected COD rms value is about 50 μm in horizontal and 40 μm in vertical, respectively. The orbit correction simulation assumes a corrector error of 0.5% and a BPM reading error of 0.2 μm. The strongest corrector strength does not exceed 2 mrad.

INJECTION AND EXTRACTION SYSTEM

The swap-out injection and extraction system will be installed in a straight section, as shown in Fig. 7, and Table 3

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shows the main parameters of the kicker. The kicker is using a strip line structure, which was successfully designed and manufactured in ALS-U [2], APS-U [3] and HALS [4]. The septa include a 0.6 m, 120 mrad DC septum and a 0.4 m, 45 mrad, 100 µs half-sin waveform in-vacuum septum.

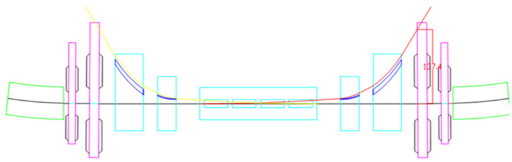


Figure 7: The injection and extraction system layout.

Table 3: Main Parameters of the Kickers

Parameters	Value
Bend Angle (mrad)	1.45x4
Length (m)	0.5x4 + 0.1x3
Good Field Region (HxV)	17 mm x14 mm
Ramping Up/Down time (ns)	< 3
Flat-top time (ns)	7
Repetition	10
Flat-top Flatness	< 10%
Flat-top reproducibility	< 1%
Power Supply Voltage (kV)	> 17

FULL ENERGY LINAC INJECTOR

WHPS will use a full-energy LINAC as its injector. The LINAC accelerator, which stays about 6 m under the storage ring, will provide 1.5 and 4.0 GeV electron bunches for the low energy and medium energy storage rings, respectively, and possibly drive an X-ray free electron laser (FEL) in the future, as shown in Fig. 8. The LINAC mainly includes the electron gun, accelerating structures, beam transport system, beam diagnostic instruments, control and timing system, high-voltage modulators and high-power klystrons. The baseline design of the electron source is to use a photocathode RF gun, in order to meet simultaneously the requirements of high bunch charge for the storage rings and high peak current for the FEL. Meanwhile, an injector with two electron guns (a thermionic cathode gun for the ring and a photocathode gun for the FEL) is under consideration as well. As for the accelerating structure, 3 m long, 2998 MHz S-band accelerator tubes are currently considered to accelerate the electron bunches up to 4 GeV. In phase I, 30 such accelerator tubes are needed for the 1.5 GeV storage ring. Proper space is kept in between the LINAC at 300 MeV to install a bunch compressor for the future FEL. At the 1.5 GeV exit of the LINAC, the relative energy spread of the electron bunches should be below 0.05%, the normalized RMS emittance better than 5 mm.mrad, the bunch charge higher than 1.0 nC, and the repetition rate 10 Hz.

At present, detailed design of the LINAC is ongoing, and a R&D project of advanced photocathode materials is in progress. The emphasis is now put on the bialkali antimonide photocathode, taking advantages of its much higher quantum efficiency compared to metal photocathode, low intrinsic emittance, moderate lifetime, and vacuum requirement.

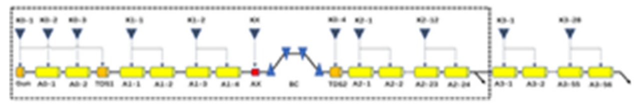
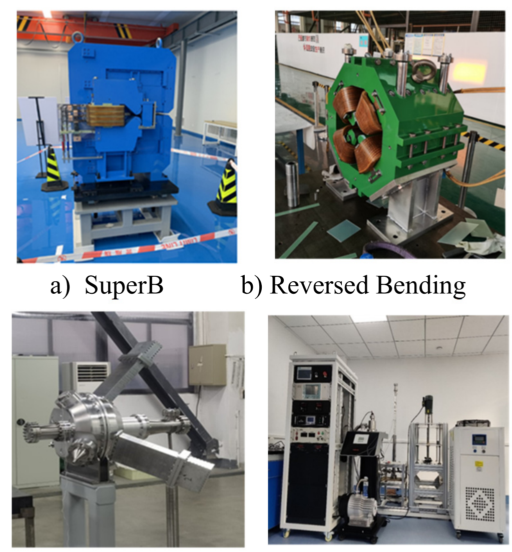


Figure 8: WHPS LINAC system diagram.

R&D PROGRESS

Three prototypes, a superB dipole, a reversed bending and an aluminum RF cavity, have already been built, as shown in Fig. 9. The maximum field of superB reaches 3.67 T, which is higher than expected 3.5 T. The Q value and HOM absorb property of the RF cavity match the requirement and the simulation results.



a) SuperB b) Reversed Bending

c) Aluminum cavity d) Vacuum coating facility

Figure 9: The injection and extraction system layout.

FUTURE PLAN

WHPS phase I project is planned to start in next few months. A prototype of half standard cell, which includes all magnets, vacuum systems with at least 3 BPMs, girders and power supplies, will be built this year. In the meantime, a copper RF cavity with solid state amplifier and LLRF, a strip line kicker system and a photocathode gun will be developed, too. The whole project will be constructed in about 4 years.

REFERENCES

[1] P. Raimondi, "The ESRF low emittance upgrade", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 2023-2027. doi:10.18429/JACoW-IPAC2016-WEXA01

[2] C. Pappas *et al.*, "Prototyping for ALS-U fast kickers", in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, pp. 2962-2964. doi:10.18429/JACoW-IPAC2016-WEPOW051

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB092

[3] F. Lenkszus *et al.*, “Fast injection system R&D for the APS upgrade”, in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 1797-1799. doi:10.18429/JACoW-IPAC2015-TUPJE069

[4] L. Shang *et al.*, “Status of the R&D for HALS injection system”, in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 2335-2337. doi:10.18429/JACoW-IPAC2019-WEPMP015