14th International Particle Accelerator Conference,Venice, Italy JACoW Publishing
ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM086

STUDIES ON BEAM INJECTION SYSTEM FOR WUHAN ADVANCED LIGHT SOURCE STORAGE RING

Y. Zou†, H. H. Li, Y. Chen, Y. C. Nie, J. K. Wang, X. R. Hao, P. Xiang, X. T. Wu, Y. Wang, Y. H. Xu, J. M. Zhang, G. Wei, J. Li, H. Li, H. J. Wang, Y. X. Zhang, J. H. He, IAS, Wuhan University, Wuhan, China

Abstract

Wuhan Advanced Light Source is the low-energy 4th generation advanced light source, which is proposed by Wuhan University, China. It includes a 1.5 GeV full-energy LINAC injector, a 180 m circumference, 1.5 GeV low-emittance storage ring, and a series of state-of-the-art beam lines. The standard 7BA magnetic focusing structure is adopted for the storage ring to lower the beam natural emittance and the lattice has been well- designed and optimized by multiple-objective genetic algorithm to maximize the dynamic aperture and energy acceptance. The dynamic aperture of the storage ring at injection can reach up to 8 mm in the horizontal plane, which makes the off-axis beam injection method possible. An off-axis beam injection scheme based on the pulsed nonlinear magnet is to be employed for the storage ring. Detailed studies about the beam injection scheme, including the beam optical design, nonlinear magnet design and optimization, have been performed and multi-particle simulations have also been carried out to study the beam injection procedure. These will be presented in this paper.

INTRODUCTION

Wuhan Advanced Light Source (WALS) project was proposed by Wuhan University in 2016 [1], of which the accelerator includes a 1.5 GeV full-energy LINAC injector, and a 180 m circumference of low-emittance storage ring. The ring lattice is 8-fold symmetrical structure, of which each cell includes a 7BA structure and a 6.8 m of long straight section. The horizontal nature emittance is around 223 pm rad. Several measures have been taking into account to reach this target, e.g., employing bending magnets with both transverse and longitudinal gradients; employing two groups of the reverse dipoles, etc. A superbend magnet, of which the peak field strength reaches as high as 3.57 T, is adopted in the center of each cell to expand the application boundaries of the synchrotron radiation light source to the field of hard X-ray. Both permanent and electro- magnets are used in the storage ring. A serious of sextupoles are employed to correct the chromaticity, which would introduce nonlinear effects in the ring to reduce the dynamic aperture and momentum acceptance that finally would affect the beam lifetime. The multiple-objective genetic algorithm (MOGA) is introduced to optimise the lattice design in order to obtain the maximum dynamic aperture and energy acceptance. Two of the eight straight sections are reserved for beam injection system and RF system, respectively. Beam injection system is to bend the electron beam into the storage ring while RF system is to supplement the electron energy loss and stretch the bunches in the ring to increase the beam lifetime. The other straight sections are reserved for insertion devices. Figure 1 shows one eighth of the lattice and Twiss parameters for the WALS storage ring. Table 1 shows the main parameters of the ring.

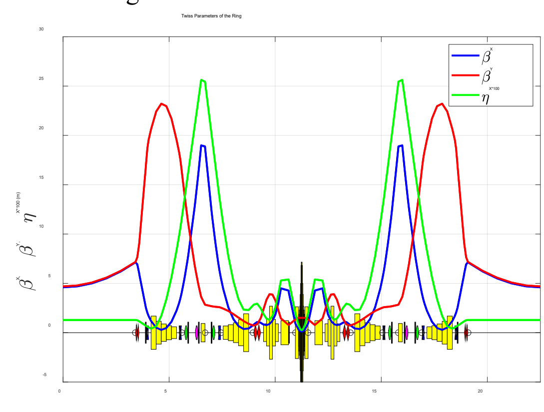

Figure 1: One eighth of the lattice and Twiss parameters for the WALS storage ring.

Table 1: The Main Parameters of The Storage Ring

Parameter	Value
Energy (GeV)	1.5
Circumference (m)	180
Revolution period (ns)	600
Harmonic number	300
Horizontal emittance (pm rad)	214.8
Damping time H/V/S (ms)	7.08/17.02 /28.52
Betatron tunes Hor./Ver.	20.279/10.155
Energy acceptance (%)	4.2
Momentum compact factor	0.00036
Radiative loss per turn (keV)	105.9
Synchrotron phase (deg)	169.8
Bunch length (ps)	16.37

BEAM INJECTION SYSTEM

The beam injection system is employed to bend the electron beam into the storage ring. Since the beam dynamics aperture is relatively large, the off-axis accumulate injection scheme is available. The philosophy of injection system design is to seek high injection efficiency while being transparent to the storage beam. The traditional off-axis injection is normally implemented by a local bump formed by two groups of bump magnets. This method needs a relatively long injection straight section and the local bump is difficult to be fully closed mainly due to the fields error of

† Email address: ye.zou@whu.edu.cn

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM086

the bump magnets. An alternative off-axis injection method based on pulsed nonlinear magnet (PNM) was firstly introduced at KEK [2, 3], and has been well studied and implemented at several facilities, e.g., BESSY [4], MAXIV [5], ALS-U [6]. The key of this method is the design of the PNM, which is used to "kick" the injection beam into the ring acceptance while not affect the storage beam.

Beam Injection Scheme for WALS Storage Ring

The off-axis accumulative injection scheme based on the PNM is proposed for the WALS storage ring. Figure 2 shows the layout of the injection scheme. A thick septum is used to bend the injected beam with 120 mrad, followed by a thin septum with the septum thickness of less than 1.5 mm to bend the injected beam with 45 mrad, while not affect the storage beam. Half sine-wave is adopted for both thin and thick septa with the wave width of 60 μs and 120 μs, respectively. The repetition rate is 10 Hz with the stability of 0.1% for both septa.

The PNM is employed after the septa to kick the injection beam into the ring acceptance, while ideally being transparent to the storage beam in the ring. The injection process is as follows: the beam from the exit of the thin septum (-11 mm, 2.5 mrad) drifts about 2.4 m to the entrance of the PNM (-5 mm, 2.5 mrad). The injection beam is then kicked by the PNM to the ring acceptance. To maximize the injection efficiency, the injection beam is being kicked to the center of the ring acceptance, as illustrated in Fig. 3. From Fig. 3, we can see that the injected beam will be kicked around 3 mrad and the maximum injection acceptance is about 1.6 μm rad. Table 2 summarizes the main parameters for the injection procedure. Since the normalised emittance of the injection beam is at the level of nm rad, which is smaller than the injection acceptance with around 3 orders of magnitude, so there is no need to match the Twiss function of the injection beam. Nevertheless, on-axis injection is essential for the first few turns of injection since there is no aperture at first. So, a normal kicker (KIK1) is set after the PNM for first step of commissioning. When the dynamic aperture comes to above 5 mm, the PNM starts to work and the KIK1 will be shut down, the on-axis injection will be changed to off-axis injection.

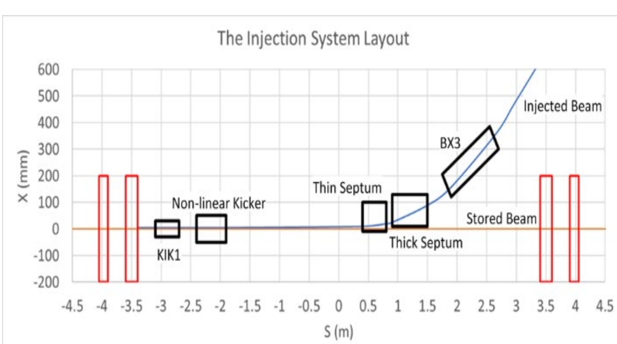

Figure 2: Layout of the injection system for the WALS storage ring

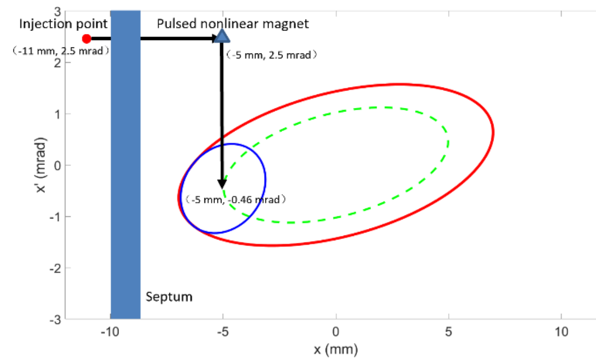

Figure 3: The beam injection procedure (Red ellipse: ring acceptance; blue ellipse: injection beam acceptance; green ellipse: C-S invariant of the injection beam)

Table 2: Main Parameters for Beam Injection Procedure

Parameter	Value
Beta function at the PNM H/V (m)	5.61/5.67
Injected beam position at thin septum exit H/V (mm)	11.0/0
Injected beam position at PNM entrance H/V (mm)	5.0/0
Injected beam angle at PNM entrance H/V (mrad)	2.5
Distance between thin septum and PNM (m)	2.4
PNM length (m)	0.5
PNM deflect angle (mrad)	3
Beam injection acceptance (μm rad)	1.6

Pulsed Nonlinear Magnet Design

The idea of using a customized spatial magnet field distribution for beam injection was first introduced and implemented at KEK, where a pulsed sextupole injection kicker was proposed and implemented. Then, an alternative configuration was proposed at BESSY and successfully implemented at MAXIV based on an iron-free pulsed nonlinear kicker that uses eight current-carrying wires, which were fixed to a precisely machined ceramic chamber that can produce multipole fields to bend the injected to the ring acceptance while with zero field at the stored beam position. Experience at MAXIV indicates that heating of the PNM ceramic chamber due to the image currents circulating in a thin titanium coating, which is required for electrical continuity would be a big issue. A thicker titanium coating can effectively address this issue [7].

Figure 4 shows an upper half geometry and the resulting field distribution with different coating thicknesses of the pulsed nonlinear magnet for the WALS storage ring. From Fig. 4, we can see that the magnetic field can reach around 250 Gauss at 5 mm and has slightly difference with 1 μm and 5 μm of coating thicknesses. In this case, 5 μm of coating thickness will be chosen for PNM to mitigate the heating issue. Figure 5 shows the field distribution at the position of stored beam. From Fig. 5, we can clearly see that the magnetic field at the stored beam position is much less than 1 Gauss, which is almost transparent to the stored beam. Table 3 shows the main parameters of the PNM.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM086

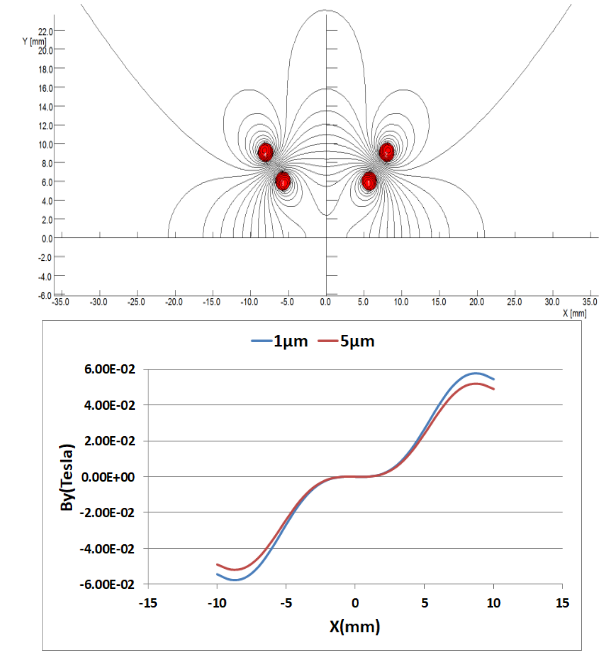

Figure 4: Upper half geometry (Upper) and the resulting field distribution with different coating thicknesses (Lower) of the pulsed nonlinear magnet for the WALS storage ring.

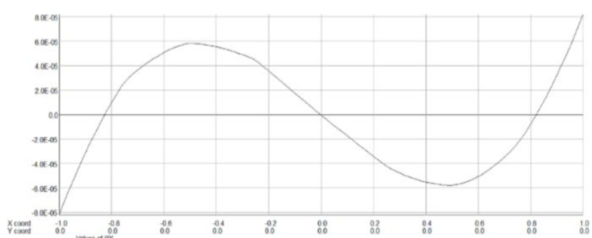

Figure 5: Field distribution at the position of stored beam.

Table 3: The Main Parameters of the PNM

Parameter	Value
Length (m)	0.5
Bending angle (mrad)	3
Beam stay clear Hor./Ver. (mm)	20/14
Field strength (Gauss)	250 @5 mm
Pulse duration half sine-wave (µs)	1.2
Repetition rate (Hz)	10
Amplitude variations (%)	<1
Pulse timing variations (ns)	±5
Field flatness (Gauss)	<5 @±5 mm

Multi-Particle Simulations

Multi-particle simulations have been performed with the AT code [8] to evaluate the beam injection scheme with PNM. Misalignment and field errors have been taken into account to calculate the horizontal acceptance for injection system. The PNM strength is chosen as 48000 T/m^3 with 0.1% error and the misalignment errors are chosen as 0.15 mm and 0.25 mrad. Figure 6 shows the injection acceptance in horizontal phase space with errors. From Fig. 6, we can see that the injection point at -5 mm is a good position for injection which has a quite large error tolerance. Nevertheless, if the dynamic aperture is large enough, the injection point can be moved to -5.3 mm, which has a larger error tolerance.

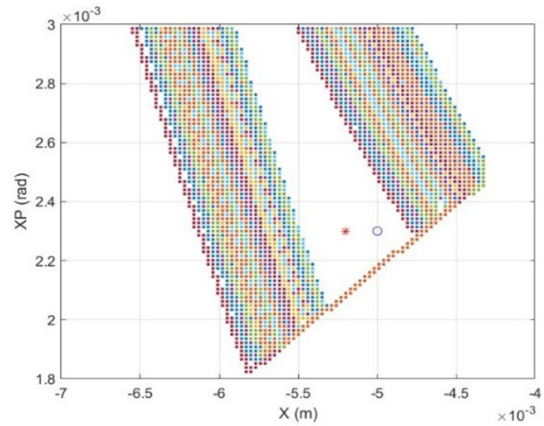

Figure 6: The injection acceptance in horizontal phase space with errors (black circle: current injection point; red star: optimal injection point)

CONCLUSION

The off-axis injection scheme based on PNM has been introduced for the WALS storage ring due to the quite large dynamic aperture. The injection acceptance is much larger than normalised emittance of the injected beam. The iron-free type of PNM that uses eight current-carrying wires can provide enough magnetic field at injection point to bend the injected beam into the ring acceptance while keep quasi-transparent to the stored beam. Multi-particle simulations show the choice of the injection point is quite reasonable.

ACKNOWLEDGMENTS

This project is supported by Science and Technology Major Project of Hubei Province (2021AFB001).

REFERENCES

[1] H. H. Li, Y. Deng, J. H. He, Y. Nie, L. Tang, J. Wang, Y. X. Zhu, “Project of Wuhan Photon Source”, *in Proc. IPAC’21*, Campinas, SP, Brazil, 2021, pp. 346-349. doi:10.18429/JACoW-IPAC2021-MOPAB092

[2] K. Harada, Y. Kobayashi, T. Miyajima, and S. Nagahashi, New injection scheme using a pulsed quadrupole magnet in electron storage rings, *Phys. Rev. Accel. Beams* 10, 123501 (2007).

[3] H. Takaki, N. Nakamura, Y. Kobayashi, K. Harada, T. Miyajima, A. Ueda, S. Nagahashi, M. Shimada, T. Obina, and T. Honda, “Beam injection with a pulsed sextupole magnet in an electron storage ring”, *Phys. Rev. Accel. Beams* 13, 020705 (2010)

[4] O. Dressler, T. Atkinson, M. Dirsat, P. Kuske, and H. Rast, “Development of a Non-Linear Kicker System to Facilitate a New Injection Scheme for the BESSY II Storage Ring”, in *Proc. IPAC'11*, San Sebastian, Spain, Sep. 2011, paper THPO024, pp. 3394-3396.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM086

[5] S. C. Leemann, "Pulsed sextupole injection for Sweden's new light source MAX IV," *Phys. Rev. Spec. Top. Accel Beams*, vol. 15, no. 5, May 2012, doi: 10.1103/physrevstab.15.050705

[6] C. Sun *et al*., "Optimizations of nonlinear kicker injection for synchrotron light sources," *Phys. Rev. Accel. Beams*, vol. 23, no. 1, Jan. 2020, doi:10.1103/physrevaccelbeams.23.010702.

[7] P. Alexandre *et al*., "Transparent top-up injection into a fourth-generation storage ring," *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 986, p. 164739, Jan. 2021, doi: 10.1016/j.nima.2020.164739.

[8] A. Terebilo, "Accelerator Toolbox for MATLAB", SLAC-PUB-8732, 2001. doi: 10.2172/784910.