CONSIDERATIONS OF THE HALS INJECTION SYSTEM AND A NEW NON-LINEAR KICKER DESIGN*

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Abstract

Hefei Advanced Light Source (HALS) is a newly designed diffraction-limited synchrotron radiation source with an energy of 2GeV and a natural emittance of 18.4 pm. A project to build test facility of this new light source has been approved and funded in 2017. Among many key subsystems, the injection system of HALS is a very important one. Both on-axis swap out, on-axis longitudinal accumulation and off-axis single multipole kicker injection are considered. For on-axis fast kicker injection, basic parameters of the system are given. Layout of kickers and septums are presented.

For off-axis multipole injection, non-linear kickers (NLK) draw much attention in recent years, various studies have been carried out in many laboratories. But it suffered from low injection efficiency and has not been used in routine operation. In this paper, we propose a new ferrite-loaded non-linear kicker (FNLK) and a prototype FNLK has been developed and tested. Compared to the air bus design of NLK, the FNLK not only improves the flat region of magnetic field but also reduce the error sensitivity of bars' position.

INTRODUCTION

Hefei Advanced Light Source (HALS) is a newly designed diffraction-limited synchrotron radiation source with an energy of 2GeV，a circumference of 648 meters and a natural emittance of about 18.4 pm. [1] The latest lattice design of the storage ring use 32-6BA structure and employ a full energy Linac as the injector. In 2016, a conceptual R&D program funded by Ministry of Science and Technology of china, was initiated to design the MBA lattice and investigate key technologies demanded by the new light source. In 2017, a new project with more funding of about 350 million Chinese yuan are granted by the local government of Anhui province to build a test facility of HALS. The formal construction of HALS is estimated to begin in 2020.

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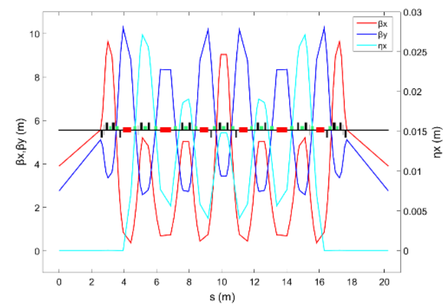

Figure 1: Optical function of 32-6BA lattice of HALS.

Injection is important issue for ultra-low emmitance light source. Because of the small dynamic aperture of the storage ring, traditional injection method cannot be used. Several new schemes have been proposed and investigated by some laboratory, including the on-axis swap-out [2][3], on-axis longitudinal accumulation [4] and off-axis single multipole kicker injection [5][6]. Table 1 lists various schemes chosen by different laboratories.

Table 1: Injection Schemes of Ultra-Low Emmitance Rings

	kicker	on-axis/ off-axis	pulse duaration
MAX-IV	multipole kicker	off-axis accumulation	～μs
SIRIUS	multipole kicker	off-axis accumulation	～ μs
ESRF-II	multipole kicker	off-axis accumulation	～ μs
APS-U	Stripline kickers	on-axis swap out	～20ns
ALS-U	Stripline kickers	on-axis swap out	～50ns
SLS2.0	Stripline kickers	on-axis logitudinal accumulation	<10ns

For off-axis single multipole injection, various studies have been carried out in many laboratories. Pulsed sextupole, quadrupole were firstly used. The nonlinear kicker concept seems to be attractive in recent years [7][8].
It has a flat zero magnetic field in the center and a maximum value off-axis in the path of the injected beam.

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Despite the encouraging results, the NLK has not yet been adopted for routine operation due to the reduced injection efficiency compared to conventional local bump approaches. The main cause for reduction in efficiency is the non-linearity of the kick at the injected beam position.

Normally 8 current bars are employed in a NLK to generate the desired field. But the field profile is sensitive to the position of current bars. Precise installation is required. Further the imbalance of current also generate error if two current loops are used.

In this paper，we proposed a new ferrite-loaded non-linear kicker (FNLK). A prototype FNLK has been developed and tested. Compared to the air bus design of NLK, the FNLK not only improves the flat region of magnetic field but also reduces the error sensitivity to bars' position. The outside vacuum design make alignment easier and the fabrication of ferrite cores has very high size precision.

ON AXIS FAST INJECTION

On-axis swap out or on-axis longitudinal accumulation share the same hardware. The new lattice has 5 meters straight section between two cells. We attempt to put all the necessary elements in one straight section to obtain a lattice independent character.

Table 2: Specifications of the Injection System

Beam Energy	2.0GeV
Injection straight length	5.1 m
Deflection of septum magnet	135 mrad
Deflection of stripline kicker	4 mrad
Total length of stripline	1.6 m
Kicker aperture	8*10 mm (H*V)
Kicker pulse voltage	±10kV
Pulse duration (swap out)	～50ns
Pulse duration (longitudinal accumulation)	<10ns

Figure 2 shows the layout of the injection straight. If the injection efficiency of longitudinal accumulation is proved to be high and technical problems can be solved, the longitudinal accumulation is a better choice, and downstream septum for swap out is then not needed.

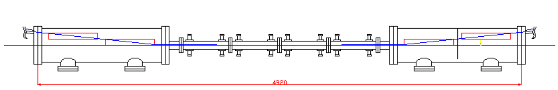

Figure 2: Layout of on axis fast kicker injection.

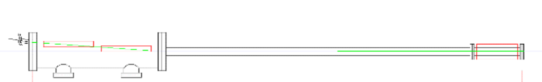

Figure 3: Layout of off axis NLK injection.

OFF AXIS SINGLE KICKER INJECTION

A high-beta function is required for off-axis single kicker injection because the dynamic aperture is proportional to square root of beta. Present lattice has small beta in the midpoint, and therefore special injection section need to be designed to enlarge beta function at injection point. But it breaks symmetry of lattice and causes reduction of dynamic aperture and momentum aperture. So, the final decision will depend on more study of lattice design.

A NEW FERRITE NON LINEAR KICKER DESIGN

Principle of the New FNLK

The new FNLK consists of two C type cores made by Mn-Zn ferrite. A traditional window frame structure is adopted with a free aperture of 50 mm wide and 18 mm high as shown in Figure 4. The difference from traditional dipole kicker is the direction of the current inside window and application of two eddy current plates. The copper plates are inserted between two cores in order to the cancel the interference of two cores. By eddy current effect it prevents the flux line go through from one core to the other.

Besides the two vertical plates, two additional shorter horizontal plates will shield the field and lower the center region field.

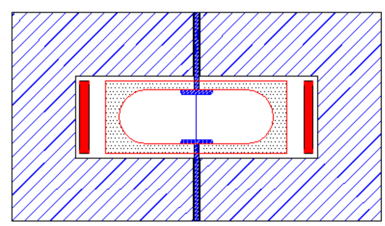

Figure 4: Cross section of the prototype FNLK.

Table 3: Specifications of the Test FNLK

length	140mm
aperture	50*18 mm (H*V)
inductance	1.53 μH
Shielding plate width	10 mm
peak current at test	612 A
Pulse width of current	2 μs
Max field at flat part	428 Gauss

The ceramic chamber is included in real application. But the prototype FNLK is measured without chamber. The inner surface should be coated with a titanium layer. The thickness of the coating should be carefully chosen to keep the deformation of the field within the error allowance and in the meantime minimize the contribution to the beam coupling impedance.

Field Measurement

The FNLK is driven by a pulsed power. The power is based on a simple RLC resonant discharging circuit. The thyratron, damping R and the high voltage capacitor are placed inside a coaxial structure to reduce the stray inductance.

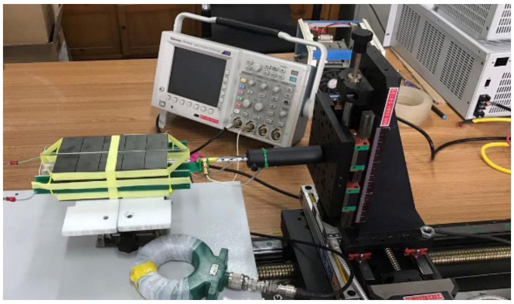

Figure 5: Bench measurement of the prototype FNLK.

For magnetic field profile measurement, a long sensor coil is used. It is a single-turn coil with a width of 1.6mm and a length of 180 mm. Long probe can facilitate the measurement of integration field along z-axis and is quick to find the field distribution at different horizontal position in the window.

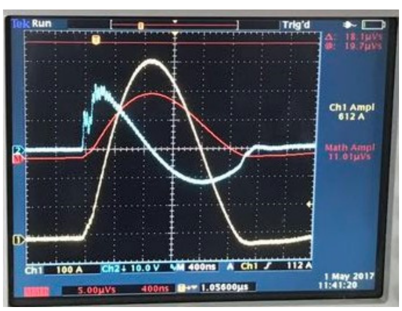

Figure 6: Pulse current (yellow), sensor coil voltage (blue) and digital integration of coil voltage (red).

The coil signals are integrated by either a RC integration circuit or the digital integration inherent of oscilloscope. The RC integrator can be calibrated by the digital integration data.

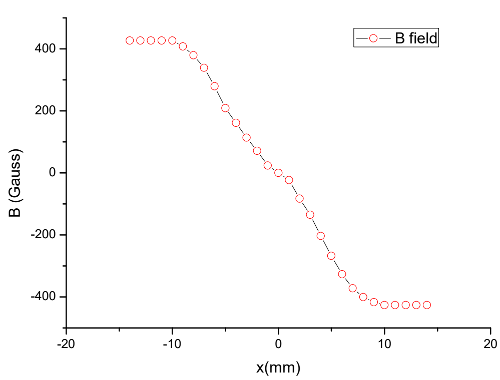

Figure 7: Magnetic field along horizontal direction.

Figure 7 shows the profile of field along horizontal direction. At the injected beam position which is 10mm away from the stored beam center, the field is like dipole. With a peak current of 612A, the magnetic field is 428 Gauss, which almost same as a half C shape dipole.

Discussion

The coil is 1.6 mm wide and cannot obtain a good resolution of the field near center region. We will make a narrow one of 0.25 mm wide.

The position of dipole high field can be closer to the center if the shielding plate is smaller. There is a compromise between bring high field closer to the center and keeping small field gradient in the center.

A thick coating of ceramic chamber in the center can act as the shielding film to replace the copper plates.

The field near center need to be measured carefully with better accuracy. And the influence to the stored beam by a small gradient of the field should be studied further. And all these ideas call for more optimization work

CONCLUSION

The HALS test facility has been approved and funded. Design of injection system is now in progress. Both onaxis fast kicker injection and off-axis single multipole kicker injection are evaluated.

For off-axis single kicker injection, a new ferrite-loaded non-linear kicker (FNLK) is proposed and a prototype FNLK has been developed and tested. Compared to the air bus design of NLK, the FNLK not only improves the flat region of magnetic field but also reduces the error sensitivity to the installation. We plan to improve the FNLK performance by more optimization with 3D modeling software. Even if the off-axis NLK injection is not chosen by HALS finally, the new design concept of FNLK can be used in other low emittance rings.

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