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PRELIMINARY STUDY OF THE ON-AXIS SWAP-OUT INJECTION SCHEME FOR THE SOUTHERN ADVANCED PHOTON SOURCE*

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Abstract

The Southern Advanced Photon Source (SAPS) is a project under design, which aims at constructing a 4th generation storage ring with emittance below 100 pm.rad at the electron beam energy of around 3.5 GeV. The extremely low emittance will result in a very small dynamic aperture for the storage ring which makes it difficult to use the conventional off-axis accumulation injection. In this case, it is probably necessary to consider the transverse on-axis injection or the longitudinal injection. In this paper, the transverse on-axis swap-out injection scheme for the SAPS storage ring is presented. The preliminary parameters of the septum magnets and fast kickers are carefully evaluated.

INTRODUCTION

The Southern Advanced Photon Source (SAPS) is a mid-energy fourth generation synchrotron light source which is proposed to be built neighboring the China Spallation Neutron Source (CSNS) in Guangdong Province, the south of China [1]. The aim of this project is to provide extremely high quality photon beam to promote the progress of science and industry.

The Storage Ring (SR) is the most important part of a synchrotron light source facility. The quality of the SR determines the final performance of the light source. In the current preliminary design, the beam energy in the storage ring is 3.5 GeV and the natural emittance is only 31.8 pm [2], which makes SAPS an advanced fourth generation light source in the world.

In order to ensure the high performance of the light source, the electron bunches from the upstream injectors should be properly injected to the SR. In third generation light source facilities, the electron bunches are normally injected to the SR off-axis from the SR ideal orbit, like in the ALBA [3], Diamond light source [4], SSRF [5] and so on. This kind of conventional injection scheme normally includes some septum magnets and four linear kickers. The required dynamic aperture should be larger than 10 mm.

For the SAPS, the extremely small emittance leads to a momentum aperture of about 4% and the dynamic aperture of about 5 mm in the horizontal plane and 4 mm in the vertical plane. The few millimeter level of dynamic aperture makes it difficult to inject the electron bunches to the storage ring using the conventional accumulation injection scheme.

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In recent years, several novel injection schemes are proposed and are being developed. The injection scheme with non-linear kicker can make the accumulation injection more transparent to the stored beam which will improve the performance of the radiated photon beams [6, 7]. However as an off-axis injection scheme, the required dynamic aperture is still in the level of 10 mm. Longitudinal injection scheme can allow electron bunches be injected on-axis which hence requires very small dynamic aperture [8, 9]. The challenge of this injection scheme is the fast injection kicker with the state-of-art technology. The transverse on-axis injection scheme allows the electron bunches to be injected to storage rings with very small dynamic aperture at the cost of no-accumulation [10, 11]. As a result, the upstream injector should provide electron bunches with a total charge required by the storage ring.

The small dynamic aperture of the SAPS makes it difficult to use the transverse off-axis injection. Hence, the transverse on-axis swap-out injection scheme and the longitudinal off-momentum injection scheme are considered at present. In this paper, the transverse on-axis injection is presented.

THE FILLING PATTERN

The circumference of the current storage ring is 1080 m and the RF-frequency in the ring is 166.7 MHz. In the preliminary design, the beam current in the storage ring is assumed to be I =200 mA. If 90% of rf buckets in the ring are filled, there will be 540 electron bunches in the storage ring, as shown in Fig. 1. The bunch charge in the ring should be about 1.33 nC. The bunch space between two bunches is 6 ns.

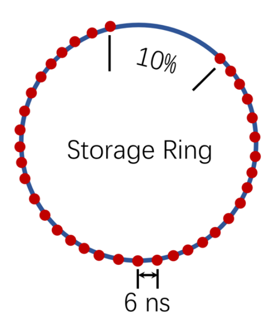

Figure 1: The illustration of the filing pattern.

Assuming an injection efficiency of 60% from the booster to the storage ring, the bunch charge extracted from the booster is about 2.22 nC.

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In the current design, the booster will work at 1 Hz. During one circulation, 10 bunches from the linac injector are injected to the booster and boosted to the nominal energy. These bunches are extracted with 50 Hz fast kicker system at the end of the circulation. Using such a design, the entire storage ring can be filled in less than one minute from initial state.

During the operation, some bunches with lower performance in the storage ring need to be replaced by fresh bunches from the booster (the swap-out). The booster during this phase can work on the same mode as the initial phase, or it can work on a mode with lower bunch rate.

INJECTION SCHEME

The on-axis swap-out injection is one reasonable injection scheme for the SAPS storage ring. The horizontal natural emittance of bunch from the booster is about $\epsilon_x = 40$ nm. The beta function in the injection straight section is in the level $\beta = 5$ m. Thus the r.m.s beam size is about $\sigma_{\text{inj,x}} = \sqrt{\epsilon_x \beta} = 0.45$ mm. Given the dynamic aperture 5 mm in the horizontal plane of the storage ring, there is about 10 $\sigma_{\text{inj,x}}$ space for the injection in the horizontal plane. This space is sufficient for the on-axis injection.

The vertical natural emittance can be about 10% of the horizontal one, i.e. $\epsilon_x = 4$ nm. Using the $\beta = 5$ m, the r.m.s beam size is about $\sigma_{\text{inj,y}} = \sqrt{\epsilon_y \beta} = 0.14$ mm. The vertical dynamic aperture 4 mm is about 28 times of the vertical beam size. So it is better to push the electron bunch on-axis in the horizontal plane and inject the bunches in the vertical plane.

For the vertical injection, the bunches at the end surface of the septum magnet should be separated from the reference line of the storage ring like $S = 5 \times \sigma_{\text{inj,y}} + D + T$, where D is the distance from the reference orbit to the septum magnet and T is the thickness of the septum blade. It is rational to assume $T = 2.5$ mm and $D = 2.5$ mm. In this case, the vertical separation space is 5.7 mm. This is shown in Fig. 2.

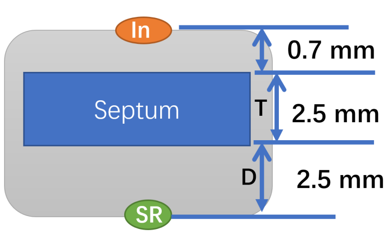

Figure 2: The illustration of the vertical separation.

In order to give the vertical separation of 5.7 mm, three fast kickers and a 2.83 m long drift space is used. The total length of the fast kicker system is 1.1 m and the deflection angle is 1.71 mrad. The distance from the injection point to the end surface of the septum magnet is 3.93 m. This is illustrated in Fig. 3.

In the current storage ring design, the length of the straight section is 5 m, which means the space left for septum magnet is about 1 m.

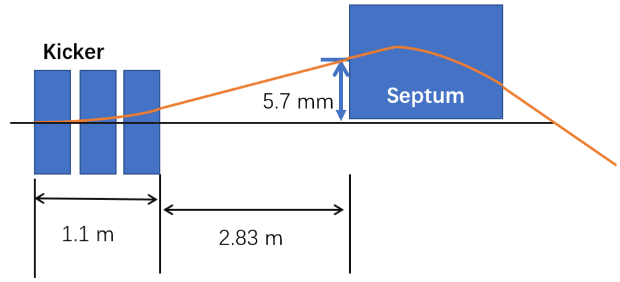

Figure 3: The layout of the vetical injection.

STRIPLINE KICKER

The full width of the fast kicker pulse should be less than two times of the electron bunch space in the storage ring for proper bunch injection without touching other stored bunches. The electron bunch space in the storage ring is 6 ns, so the full width of the kicker should be less than 12 ns. At the same time, the fast kicker should provide long enough flat-top field for bunch deflection (the bunch length from the booster ring is about 50 ps). Here, we assume the flat-top should be longer than several nanoseconds.

The HEPS project has developed and tested a 750 mm long fast stripline kicker [12] with full width about 15 ns, which is a little larger than our requirement. This team is also developing another 300 mm long stripline kicker with shorter pulse width which is compatible with our case So at present, we will assume the same fast kicker parameters as the HEPS project. The main parameters are listed in Table 1.

Table 1: Parameters of the Fast Stripline Kicker from HEPS

Parameter	Values	Values
Length	m	0.3
Voltage	kV	>17.5
Repetition	Hz	50
Angle@6GeV	mrad	0.33
Angle@3.5GeV	mrad	0.57
Full Width	ns	< 10
FWHM	ns	> 4.5

SEPTUM

The lambertson type septum can reach the requirement of our storage ring injection, and it has the advantage of simple structure, high reliability and low cost. So at present, it is chosen as our setpum magnet.

The septum magnet should bend the electron bunches to the reference orbit in the horizontal plane. In the vertical plane, the bunch should be located at 5.7 mm from the central orbit.

The length of 5 m long straight section leaves about 1 m long space for the septum magnet. Given the maximum magnetic field 1 T for the septum, the 3.5 GeV electron bunch

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will be bent about 86 mrad and the horizontal separation at the entrance of septum is about 10.7 mm.

In the vertical plane, the septum magnet should be rotated a little to provide the proper bending angle.

SUMMARY

The SAPS is synchrotron photon facility under design. The ultra-low transverse emittance makes it difficult to use the conventional off-axis injection scheme. In this paper, the preliminary consideration of the on-axis swap-out injection for the SAPS storage ring is presented, including the filling pattern consideration, the injection layout, the fast stripline kicker and the septum magnet. More work has to be done in the future: the injection simulation, the hardware design and so on.

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