STUDY OF A NEW INJECTION SCHEME FOR THE SSRF STORAGE RING*

M. Z. Zhang#, S.Q. Tian, B.C. Jiang, Q.L. Sun and L.H. Ouyan
Shanghai Institute of Applied Physics, Shanghai 201204, P. R. China

Abstract

A small emittance mode of the SSRF storage ring had been designed and commissioned. As well as reducing the emittance, the dynamic aperture decreases quickly. The aperture requires of the normal injection scheme is not reached anymore and the injection efficiency is lower. The pulsed multi-pole magnets give the opportunity to overcome the smaller dynamic aperture. Pulsed quadrupole and sextupole both are study for the injection scheme. With and without the orbit bump kickers are also considered in this study. An injection schemes are finally presented.

INTRODUCTION

The Shanghai Synchrotron Radiation Facility (SSRF) [1] is a dedicated third generation synchrotron light source with nominal energy of 3.5 GeV. A small emittance mode of the SSRF storage ring had been designed and commissioned to increase the brightness [2]. The emittance has reduced from 3.9nmrad to 2.9nmmrad. Strong chromatic sextupoles generate higher order aberrations which limit the dynamic aperture available for injection and the momentum aperture, reducing the Touschek lifetime. The dynamic aperture of nominal mode is more than 15mm, but the one of low emittance mode is 6mm only. The injection efficiency is decreased from more than 95% to less than 60% with orbit bump and beta bump. Injection schemes to reduce the aperture requirement should be studied. There are mainly 3 scheme considered in the world: 1) Injection from the vertical plane employing Lambertson magnet. 2) “swap out”, fast dipole kickers for bunch replacement between accumulator and storage ring. 3) Pulsed multipole magnet in place of traditional closed-bump kicker magnets.

On the other hand, top-up injection requires suppressing the oscillation of stored beam. However, it is difficult to provide the complete closed bump because of the magnetic field errors, timing jitters, and nonlinear effects such as from sextupole magnets inside the bump. The unclosed bump generates the coherent dipole oscillation of the stored beam, which degrades the quality of the photon beam for the SR experiments in top-up injection.

CONVENTIONAL INJECTION

The injection scheme for the SSRF storage ring was designed with a conventional local four-kicker injection bump in a long straight section, as shown in Fig.1. The gap between bumped beam and central of injection beam is 10mm. As shown in Fig.2, the injection beam size can be varied from 3-7mm (6σ), and the stored beam size is 1.4mm（$\pm 5\sigma$）. The septum thickness is 3 mm. After the injection bump, the injected beam is in the acceptance of the storage ring. It proceeds to damp down while it oscillates around the stored beam with a transverse damping time of several ms. There is no sextupole either quadrupole in the local bump. If the timing and kicker strength are carefully tuned, the closure of the bump and oscillation of stored beam will be very small, less than 30 um in each plane are measured. The tilts of kicker introduce the vertical residual oscillation, and it’s a little big for the users. For the nominal mode, the dynamic aperture covers the gap and the injection beam at the same time. But in the low emittance mode, 6 mm dynamic aperture only covers a part of the injection beam.

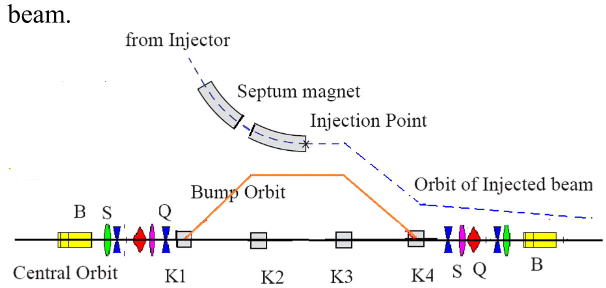

Figure 1: The injection scheme of SSRF.

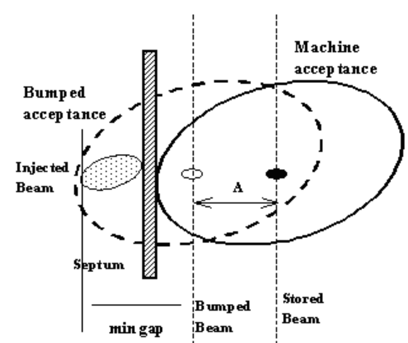

Figure 2: The schematic diagram of injection.

Top-up injection with a four kicker injection bump cannot be made entirely transparent. Furthermore, as stability criteria become tougher in newer storage ring designs, this method of injection becomes less favorable. Therefore, several labs have started investigating alternative injection schemes.

*Work supported by SSRF
#zhangmanzhou@sinap.ac.cn

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PULSED MULTIPOLE INJECTION

The new injection scheme employing a single pulsed quadrupole magnet (PQM) or pulsed sextupole magnet (PSM) was developed and demonstrated at the Photon Factory Advanced Ring [3]. Since the PQM and PSM have a linear field gradient along the horizontal axis, it can give an effective kick to the injected beam in a distant position from the magnetic center. The stored beam passes the pulsed multipole magnet (PM) through the magnetic center, it sees approximately zero fields. The only synchronization requirement is between the PM and the injected beam. Alignment also becomes easier than in conventional four-kicker bump injection.

Theory

Starting with the coordinates of the injected bunch at the injection point in the injection region, and taking into account the storage ring's horizontal acceptance A_{req}(since capture occurs in the horizontal plane this is the plane of interest here), an optimum location for a PM can be derived. The trajectory of the injected beam in PM injection is illustrated schematically using a normalized phase space in Figure 3. The ideal location of the pulsed magnet is given by the injection invariant A_{inj} and reduced invariant A_{req} alone. After several phase advances, the injection beam move to the position of A, B, C or D, a kick by PSM is introduced to kick the injection beam into the required acceptance. The kicker strength is decided by:

$$|\Delta P| = A_{inj}\left|\sin(\phi_1+\phi_0)\right| - \sqrt{A_{red}^2 - A_{inj}^2\cos^2(\phi_1+\phi_0)} \quad (1)$$

The relationship of normalized ΔP the real strength of the PM θ is $\Delta P = \sqrt{\beta}\theta$.

For a PQM, the strength is:

$$K_1 = \frac{A_{inj}\left|\sin\phi_1\right| - \sqrt{A_{red}^2 - A_{inj}^2\cos^2\phi_1}}{\beta X_1}, \quad (2)$$

For a PSM, the strength is:

$$K_2 = 2\frac{A_{inj}\left|\sin\phi_1\right| - \sqrt{A_{red}^2 - A_{inj}^2\cos^2\phi_1}}{\beta^{3/2} X_1^2} \quad (3)$$

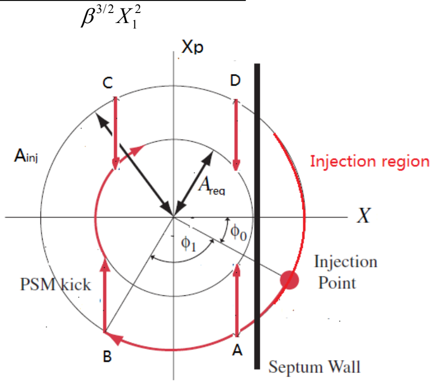

Figure 3: A trajectory of an injected beam in PSM injection on a normalized phase space [3].

Figure 3 and equation 2 and 3 shows that the PM strength is strongly depend on the required acceptance, and the required acceptance should not be very small to avoid not realized magnet strength. If the orbit bump is used at the same time, the A_{inj} and then the PM strength can be reduced very much. When we provide the same field for the injected beam at a horizontal position of to both the magnets, both the field gradient and the field strength on the stored beam of the PSM are smaller than those of the PQM. But the PSM strength is much stronger than the PQM at the edge of magnet aperture. On the other hand, ideal placement cannot necessarily be achieved because the lattice might not leave space for the pulsed magnet at that location. The injection point can be changed to help the placement. Furthermore, due to the strong nonlinearity in betatron motion, especially at the large amplitudes of injected beam, the actual pulsed magnet solution has to be derived from tracking.

Injection Scheme

There are mainly 2 injection schemes have been considered: 1) Remove the four-kicker, move the septum closer to the store beam. 2) Employing four-kicker bump and PM at the same time. The injection direction can be changed in these two schemes to help get suit PM position and strength. The required aperture at the injection section is set to 5mm, corresponding to A_{req} = 2.02. The dynamic aperture of nominal mode is about 15mm, so the lowest septum position is set to 15 mm, and then the injection height is 21mm. The position only reduces 3.6 mm.

A Single PM

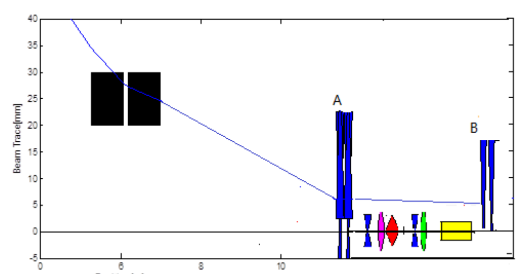

Figure 4: The Injection scheme of a single PM.

The simplest way for the injection is employing only one single PM. The length of PM is supposed as 0.4m. Figure 4 shows the two suitable places for the PM. For the scheme A, there are no other element between the septum and PM, that's a very simple scheme. The injection direction and injection height can be changed to satisfied the aperture require at PM. The required PQM and PSM strength for injection height 21mm is -2 m^{-1} and 800 m^{-2}, that's a very huge strength for a pulsed magnet. The other selection is move the septum back to the edge of the 12 m long straight section. In order to install the high energy transport line, another septum is needed. Then employing one longer PM, the strength can be reduced to one quarter, and the PQM will be possible.

For the scheme B, the PM locates at the short straight section. Carefully choose the PM's location, the required PQM and PSM strength is -2.49 m^{-1} and -1295 m^{-2}

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without injection direction change. Changing the injection direction can reduce the PM strength slightly, but not very much.

Bump with PM

Due to the results of a single PM is not very good, the combine of PM and four-kicker bump is considered. Because of the long straight section, the distortion of four-kicker inconformity can be reduced to a small value. One doesn't worry about it when running at top-up mode. Same as the single PM mode, there are 3 position can be chosen for the PM: A) between the last 2 kickers; B) after the last kicker; 3) at the short straight section. In order to decrease the workload and the installation, the septum position is at the original position, and the injection height is 24.6mm.

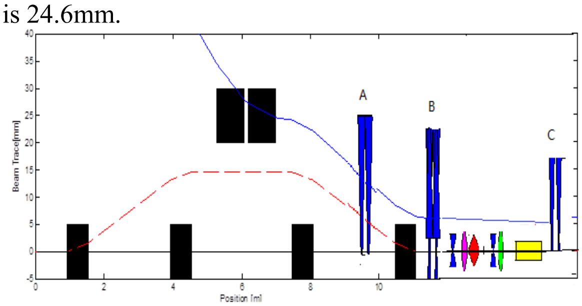

Figure 5: The Injection scheme of PM and four-kicker bump.

In plan A, the PM will disturb the store beam, the kicker strength should be carefully tuned, and the synchronization between PM and kicker should be perfect. The PM should be a multi-turn waveform, due to the kicker is a 4 um's long half sinusoid. But, due to the injection beam pass a large offset through the PM, the strength, especially the PSM, will be reduced. The required PQM and PSM strength is -1.1 m^{-1} and -50 m^{-2}, that's much smaller than the others in above section.

The plan B is similar to the plan A of a single PM. After change the injection direction, the required PQM and PSM strength is -0.52 m^{-1} and -220 m^{-2}.

The plan C is similar to the plan B of a single PM. the required PQM and PSM strength is -1.09 m^{-1} and -587 m^{-2} without injection direction change. If the injection changed to +0.8mrad, the strength is reduced to -0.96 m^{-1} and -445 m^{-2}.

Calculation results show that, the plan B of combines of PM and four-kicker is the easiest scheme, and the magnet is chosen as PQM.

Multiturn PM

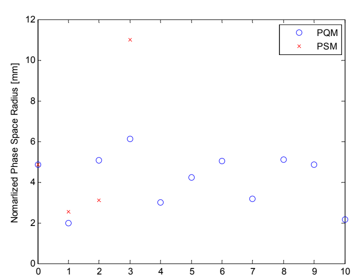

Figure 6: The multi-turn effect.

The single turn PM is much harder than a multi-turn one. In order to design a less difficult magnet, multi-turn tracking was studied. In SSRF low emittance mode, the tune is 23.31, the one turn phase advance is nearly 2*pi/3. As figure 3 shown, the phase after injection is closed to 0 or pi, after one turn, the X is not very small. The second turn effect must be considered. Figure 6 shows, for PQM, after 2 turns, for PSM, after 3 turns, A will increase. Single turn injection must be chosen for this mode.

Beam Size Change

The beam size change can be nicely demonstrated by tracking the stored beam through the PQM and PSM and comparing the effect of any residual kick received by the stored beam. The effect of PSM is less than PQM. Figure 8 shows the beam profile change along the ring using PQM. The change will be quickly damp down due to damping. As well known, if PSM is used, the beam profiles don't change very much.

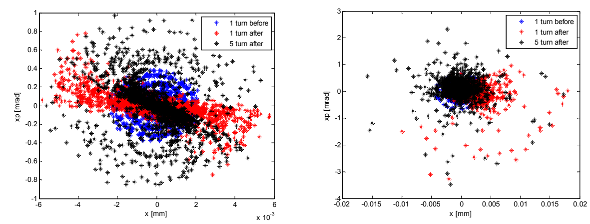

Figure 7: The beam before and after injection using PQM and PSM.

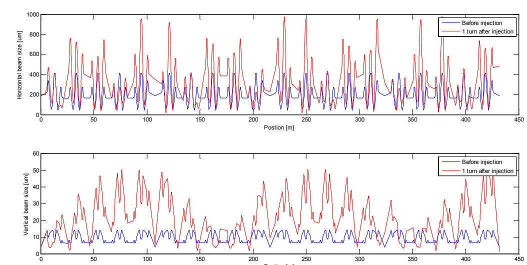

Figure 8: The beam profile before and after injection using PQM.

CONCLUSION

A new injection scheme employing PQM and four-kicker bump is studied for the SSRF low emittance mode. For this scheme, lowest difficulty and workload are needed. And the dynamic aperture requirement of nominal mode is also satisfied.

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