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BEAM INJECTION FOR THE PF-AR WITH A SINGLE PULSED QUADRUPOLE MAGNET

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Abstract

We have developed an innovative injection system by using a single pulsed quadrupole magnet (PQ-magnet) without any dipole kicker magnets in electron storage rings. Using a characteristic of a quadrupole magnet, we can easily reduce the amplitude of the oscillation of the injected beam without exciting the coherent dipole oscillations of the stored beam. During the summer shutdown of 2004, we installed the PQ-magnet in the PF-AR (Photon Factory Advanced Ring). The parameters of the PQ-magnet are the length of 0.30m, the field gradient of 3T/m at the peak current of 2000A, and the pulse width of the 2.4μsec that is the double revolution period. In this paper, we will describe the preliminary results of the machine study for the beam injection by the PQ-magnet at the PF-AR.

INTRODUCTION

Recently, a top-up injection has been adopted for the light sources. For the injection, it is critical to suppress the coherent oscillations of the stored beam during the beam injection in order to avoid the deterioration of the photon beam quality for the user experiments. For the conventional injection system, however, it is severe to suppress the oscillations since the several dipole kicker magnets are employed to make the pulsed local bump of the stored beam. Because of the field errors, timing jitters, and individualities of them, the leakage of the bump is produced. Moreover, if the nonlinear components are installed inside the bump, the oscillations of the stored beam are unavoidable for the multi-bunch operation. In order to solve the problem, the injection system with a single pulsed quadrupole (PQ) magnet has been developed [1].

The quadrupole magnet has zero field strength at the magnetic pole centre. As the stored beam passes through the magnetic pole centre, the dipole oscillation is not excited. On the other hand, because the injected beam has large amplitude, the magnetic field is finite and thus only the injected beam is kicked. By optimizing the location and the strength of the PQ-magnet, we can inject the beam by a single PQ-magnet.

The PF-AR is the 6.5GeV electron storage ring that has the circumference of 377m. The beam energy for the injection is 3.0GeV and is ramped up to 6.5GeV before the user operation. The PF-AR dedicates the single-bunch operation. For such the operation, however, we could not store the beam current of more than 65mA until now. The injection stagnated around the current. It seemed that the stored beam with a coherent oscillation generated the strong wake field in the RF cavities and the injected beam would be lost because of them [2]. Therefore, adopting new injection system, we may solve this problem since the coherent oscillation of the stored beam is not produced by the PQ-magnet.

We produced the system, which consists of the quadrupole magnet and pulsed power supply, in the FY 2003. The field measurements were conducted in the spring of 2004 [3]. After the design requirements were confirmed, the system was installed into the PF-AR during the summer shutdown of 2004. From the autumn, the machine study for the beam injection was started.

THE INJECTION EMITTANCE AND THE CONVENTIONAL INJECTION SYSTEM

When the motion of the injected beam is assumed to be linear, the invariant of the oscillation of the injected beam can be described by the Courant-Snyder invariant (we call the invariant as injection emittance),

$$\varepsilon_{inj} = \frac{1}{\beta}\left(x^2 + (\alpha x + \beta x')^2\right).$$

First, we give the brief description of the conventional injection system. The schematic view of the typical system with four dipole kicker magnets is shown in Fig. 1. For the PF-AR, the Twiss parameters and the coordinates of the injected beam are shown in Table 1. The initial injection emittance is ε_{inj}=125.9mm·mrad. In the present injection system, the coordinates of the stored beam with the pulsed bump is x=22mm and x'=3.4mrad at the injection point and this reduces the injection emittance to 37.1mm·mrad. For the optimization of the PQ-magnet, we set this injection emittance as the design goal.

For the usual operation at PF-AR, in order to increase the injection efficiency, the kicker jump is introduced. The basic concept of the kicker jump is shown as the beam orbits of the dotted line in Fig.1. For the conventional injection system, the minimum distance between the injected beam and the stored beam is determined by the thickness of the wall of the septum

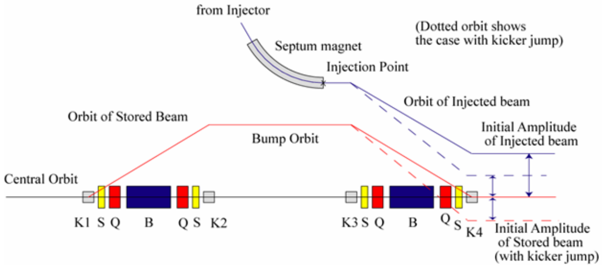

Figure 1 Schematic view of the conventional injection system.

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Table 1 Injection emittance of the ordinary injection system with the pulsed local bump (PB)

	injection point	change by Pulsed Bump	after Pulsed Bump
α	-2.9		-2.9
β [m]	18.3		18.3
x [mm]	48.0	-22.0	26.0
x' [mrad]	7.6	-3.4	4.2
ε_{inj} [mm·mrad]	125.9		37.1

magnet and the sizes of the stored beam and injected beam. Usually, after the local bump without kicker jump, we restore the orbit of the stored beam to the central orbit. Then, the minimum distance conceptually becomes the initial amplitude for the oscillation of the injected beam and determines the injection emittance. In order to reduce the initial amplitude of the injected beam and the injection emittance, we can make the orbit of the injected beam closer to the central orbit with the kicker jump shown as the dotted line in Fig. 1. With such the kicker jump, however, the orbit of the stored beam is not restored to the central orbit and thus the dipole oscillation of the stored beam is excited. Even with such the oscillation, we achieve much larger injection efficiency for the PF-AR. Now the kicker jump is indispensable for the operation at the PF-AR.

PARAMETERS OF THE PULSED QUADRUPOLE MAGNET

The pulsed quadrupole (PQ) magnet is installed in the PF-AR at the place about 16m downstream of the injection point. The parameters of the PQ-magnet are shown in Table 2. The length of the magnet is 0.3m, the field gradient is 3T/m, and the integrated field gradient is 0.9T. A quadrupole magnet reduces the angular divergence of the injected beam by $\Delta\theta = kx$, here x is 14.7mm, the amplitude of the injected beam at the place of the PQ-magnet. Thus Δθ= 1.3mrad. This reduces the injection emittance to ε_{inj}=36.8mm·mrad and the design requirement is satisfied as shown in Table 3. The picture of the PQ-magnet is shown in Fig. 2.

RESULTS OF THE MACHINE STUDY

First, we synchronized the excitation timing of the PQ-magnet with the beam injection. Comparing the excitation timing with the revolution signal of the stored beam from the beam oscillation detector (BOD) and the noise of the dipole injection kickers, we finally fixed the timing as shown in Fig. 3.

Once the timing was fixed, the injection could be successfully done only with the PQ-magnet without using four dipole kickers. After the COD (closed orbit distortion) correction in order to make the closed orbit pass through the magnetic pole centre of the PQ-magnet, the injection rate easily reaches about 0.18mA/sec at 5 Hz

Table 2 Parameters of the pulsed quadrupole magnet.

Length [mm]	300
Vertical bore [mm]	36
Horizontal bore [mm]	102
Turn number of the coil	1
Charging voltage [kV]	20
Field gradient [T/m]	3
Peak current [A]	2000
Pulse width [μsec]	2.4
Inductance [μH]	1.8
Color	Pink

Table 3 Injection emittance with the PQ-magnet

	at PQ before kick	kick by PQ	after kick
α	-1.7		-1.7
β [m]	17.9		17.9
x [mm]	-14.7		-14.7
x' [mrad]	-3.9	1.3	-2.6
ε_{inj} [mm·mrad]	124.3		36.8

Figure 2 Picture of the pulsed quadrupole magnet.

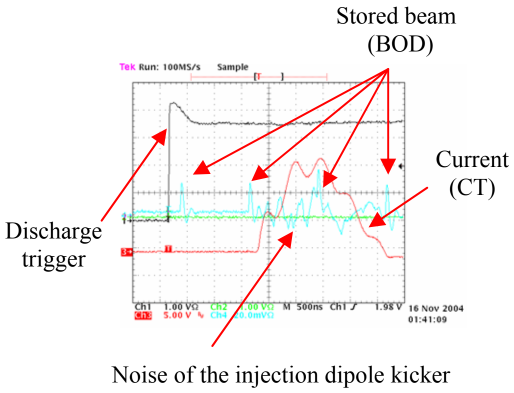

Figure 3 Timing of the excitation of the PQ magnet.

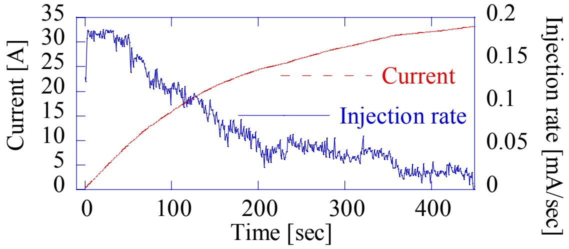

Figure 4 Injection history with the PQ magnet

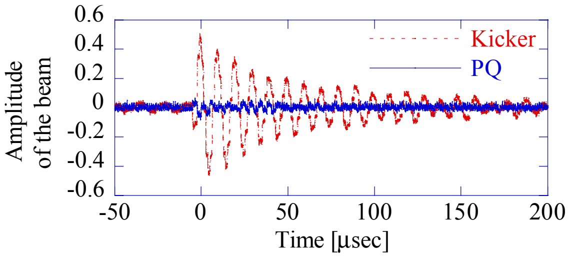

Figure 5 Oscillation of the stored beam.

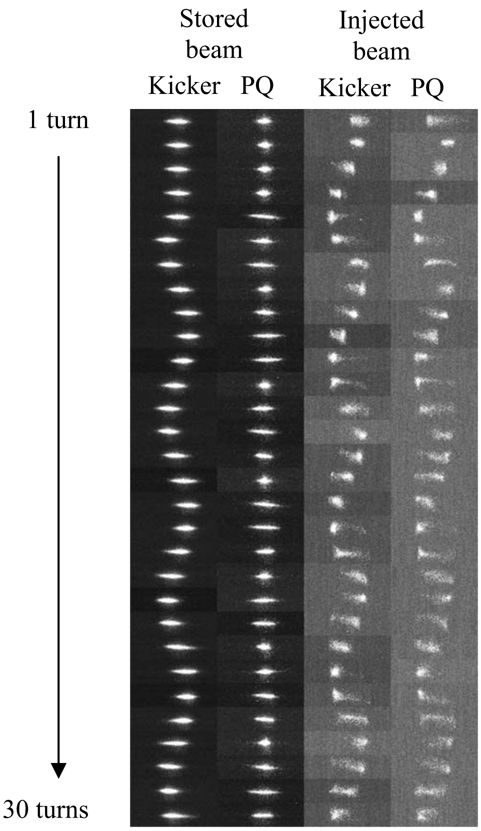

Figure 6 Oscillation of the beam.

repetition rate until the stored current reached at 10mA as shown in Fig. 4. As the stored current increased, the injection rate decreased. When the stored current reached about 30mA, the injection rate dropped to zero. Figure 5 shows the oscillation of the stored beam detected by the beam oscillation detector (BOD). Even after the COD correction, the small oscillation was remained. The resolution of the BPM was about 10µm, and we used the back leg coil of the bending magnet as the horizontal orbit corrector, which had large hysterisis. With these difficulties, we could not further fix the COD. After the adjustment of the injection parameters, finally the maximum stored current was increased to about 40mA.

Figure 6 shows the oscillation of the stored beam and the injected beam observed by the synchrotron radiation monitor [4]. The pictures of the stored beam show the beam profile of just 30turns after the excitation of the injection system. For the conventional injection system, the oscillation of the stored beam was excited mainly because of the kicker jump. We note that the horizontal betatron tune is 10.15 and the oscillation period is about 7 turns. In contrast with the conventional injection system, the coherent dipole oscillation of the stored beam was not observed for the case with the PQ-magnet. The stored beam, however, looks like blinking because of the quadrupole mode oscillation excited by the PQ-magnet. On the other hand, the behaviour of the injected beam with the PQ-magnet is very similar to that with the conventional injection system. The requirements for the beam injection are, however, very different. With the conventional injection system, for example, the transverse beam feedback system and the negative octupole magnetic field is indispensable. But they are unnecessary for the injection with the PQ-magnet. The beam dynamics and the beam instabilities at the PF-AR are very complicated problems and they have been the research subjects during the several generations. We may need much more machine studies, if we put the PQ-system to the practical use at the PF-AR.

CONCLUSION

We have developed the innovative injection system with a single PQ-magnet without any dipole kickers for the PF-AR. The beam injection has successfully conducted by the PQ-magnet. The problem of the stagnation of the beam injection was not solved so far and the maximum stored current with the PQ-magnet was about 40mA. In future machine studies, we will identify the reason of the stagnation of the injection rate with the PQ-magnet.

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