DEVELOPMENT OF A PULSED SEXTUPOLE MAGNET SYSTEM FOR BEAM INJECTION AT THE PHOTON FACTORY STORAGE RING

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Abstract

We have developed a pulsed sextupole magnet (PSM) system to demonstrate a new scheme of a beam injection at the Photon Factory storage ring (PF-ring) in KEK. We are going to install the PSM in this winter shutdown. Since a sextupole magnet has a characteristic of the parabolic magnetic field with no field at the magnetic center, it can give an effective kick to the injected beam at a distant position from the magnetic center and suppress effects on the stored beam at the beam injection. This enables us to inject the beam using the single PSM without a conventional pulsed local bump. The new injection scheme has a great advantage to achieve the top-up injection for a synchrotron radiation light source because it is not necessary to prepare a long straight section for the pulsed local bump system. The designed PSM has a length of 0.3m, a field gradient of about 13T/m^2 at a peak current of 3000A, and a pulse full width of 1.2µsec in a half-sine waveform. In this paper, the current status of the development for the system is described.

INTRODUCTION

In a conventional beam injection at synchrotron radiation sources, a pulsed local bump handled by several kicker magnets is used to reduce a coherent dipole betatron oscillation of the injected beam as shown in Fig. 1(a). However, it is difficult to make a closed bump completely because of their field errors, timing jitters and non-linear effects of the magnetic field like sextupole magnets inside the bump [1]. This unclosed bump causes a large coherent dipole oscillation of the stored beam and may reduce a quality of the synchrotron radiation light at the top-up injection.

A new injection scheme by use of a single pulsed quadrupole magnet (PQM) was developed and demonstrated at the Photon Factory Advanced Ring (PF-AR) [2-3]. In this scheme, we used only one PQM and did not need to make the local bump (see Fig. 2(b)). Since the PQM has 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. On the other hand, the stored beam which passes through the magnetic center with no field is not kicked. The injection scheme using the PQM could reduce the dipole oscillation of the stored beam compared with the conventional injection scheme. However, another oscillation (like a coherent quadrupole oscillation) was clearly observed at the injection of the PF-AR. It produced the beam profile modulation of the stored beam.

In order to stabilize the beam profile modulation and to improve the injection performance, we introduce a pulsed sextupole magnet (PSM) for the injection system. In the following section, we are going to describe about the detail design of the PSM system.
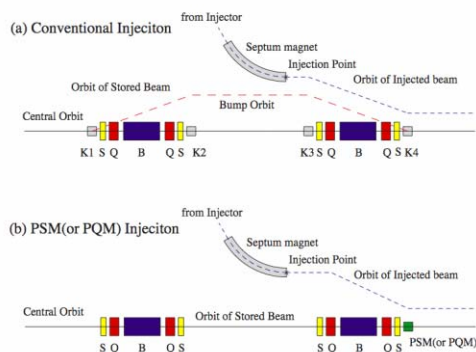

Figure 1: Schematic view of a beam injection. (a) Conventional injection scheme using a local bump by four pulsed dipole kicker magnets (K1-K4). The trajectories of the injected beam (dotted), the local bump (dashed) and the central orbit of the ring (solid) are shown. (b) New injection scheme using a PSM (or PQM) without the local bump.
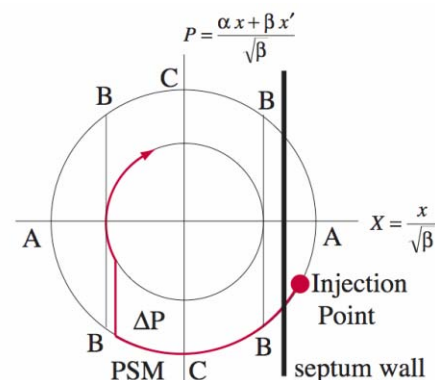
BEAM INJECTION USING PSM

Figure 2: Trajectory of the injected beam on the normalized phase-space. The outer circle shows an injection emittance and the inner circle shows a reduced emittance with the kick by the PSM in order to avoid colliding with the septum wall.
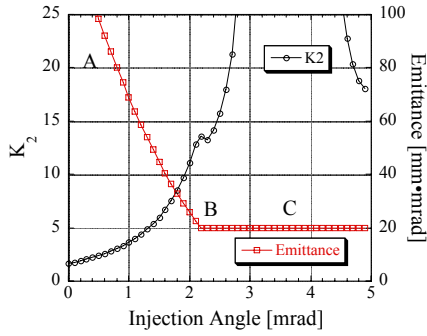
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Figure 3: The required strength K_2 of the PSM and the reduced injection emittance are shown as a function of the injection angle *x'*. Since the reduced emittance is required to be 20mm·mrad, the injection angle is needed to be more than of2.2 mrad. The points *A-C* are corresponding to the points indicated in Fig. 2.

First, we consider the location where we install the PSM to effectively reduce a coherent betatron oscillation of the injected beam. The trajectory of the beam on the normalized phase-space is shown in Fig. 2. The normalized coordinates are represented by $X = x/\sqrt{\beta}$ and $P = (\alpha x + \beta x')/\sqrt{\beta}$, where x and x' are a horizontal position and an angle, α and β are Twiss parameters. The injected beam has a large emittance of the coherent betatron oscillation represented by the outer circle, which is called the injected emittance, and is kicked by the PSM in order to reduce the emittance to the required emittance (inner circle). Then, the beam is captured into the ring. The kick strength is expressed by $\theta = \Delta P/\sqrt{\beta} = \beta K_2 X^2/2$, where ΔP is the deviation of the normalized angle, K_2 ($=B''L/B\rho$) denotes the sextupole strength and β is the horizontal betatron function at the location of the PSM. When the PSM locates between point *A* and point *B* in Fig. 2, there is no solution to reduce the injection emittance toward the required emittance. On the other hand, when the PSM locates at X~0 (point *C* in Fig. 2), a strong strength of K_2 is required because of a very small X^2 value. So, the adequate location of the PSM on the phase-space is the just inside of point *B*, where X^2 has the
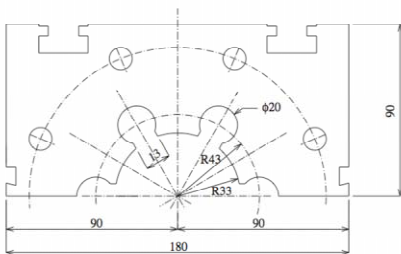
Table 1: Principal parameters of the pulsed sextupole magnet system

Core Length	[mm]	300
Bore diameter	[mm]	66
Turn # of coil		1
Field gradient @x=15mm	[Gauss]	400
Peak Current	[A]	3000
Inductance	[μH]	6.5
Pulse width	[μsec]	1.2 (2.4*)

maximum value in order to reduce the emittance toward the required emittance. As the optimum location for the PSM installation at the PF-ring, we selected a free space in the downstream of the long straight section of the undulator #02 (U#02), which is located about 25m from the injection point.

Next, the fine-tuning of the phase-space position of the PSM is made in order to decrease the K_2 value. Once the optics of the ring is fixed, the phase advance from the injection point to the PSM is also determined and cannot be changed. Then, the normalized angle P is controlled by adjusting the injection angle *x'*. When the injected beam is kicked toward the outside direction ($x' > 0$) in Fig. 2, the normalized P increases and the phase advance between the injection point and the PSM are slightly rotated to counter-clockwise direction on the phase-space. Fig. 3 shows the required strength K_2 and the reduced injection emittance as a function of the injection angle *x'* when the injection position is 27mm. Because the position of the PSM with the injection angle of 0mrad is near the point *A*, the reduced emittance is larger than 20mm•mrad. When the injection angle is 2.2mrad, the location of the PSM on the phase-space is at the point *B*. Moreover, it shifts to the point *C* when the injection angle is 3.6mrad. When we require that the reduced emittance is 20mm•mrad, the injection angle should be more than 2.2mrad. The K_2 has the optimum strength of 13m^{-2} to achieve the reduced emittance of 20mm•mrad as shown in Fig. 3. Since the horizontal position of the injected beam at the PSM is 15mm from the central orbit, the field strength is corresponding to be 400G at the beam energy of 2.5GeV.
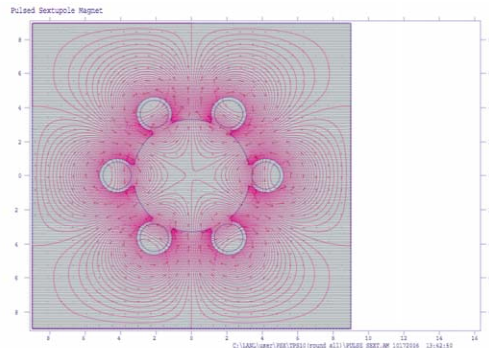

Figure 4: Designed cross sectional view of the PSM.

Figure 5: Two-dimensional magnetic field distribution of the PSM calculated by the Poisson code.

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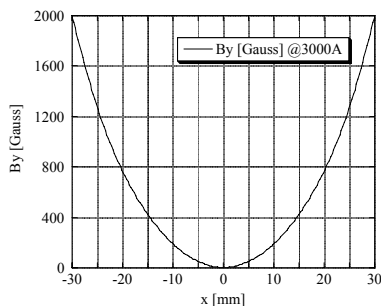
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Figure 6: Magnetic field strength as a function of a positive horizontal position from a magnetic center of the PSM. There is no magnetic field at a magnetic center where the stored beam passes. At the horizontal position of 15mm from the magnetic center where the injected beam passes, the field strength is realized to be grater than 400G.
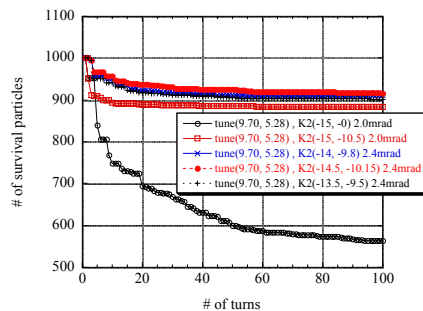

Figure 7: The numbers of survived particles as a function of the circulating turn number after the injection into the PF-ring are represented. By changing the conditions such as the K_2 of the PSM and the betatron tunes of the ring, it is plotted how particles is survived in the beginning after 100 turns of injection. Injection efficiency of about 95% is obtained by the current state (red line).

DESIGN OF PULSED SEXTUPOLE MAGNET

In order to reduce eddy current effects, a ceramic chamber is used for the PSM. In addition, a Cu absorber with water-cooling is attached in upstream of the chamber to protect the ceramic from synchrotron radiation produced in an upstream bending magnet. The beam clearance of the absorber is determined by the geometrical relation between the bending magnet and the PSM, and then the downstream of the U#02 undulator is a suitable place compared with the upstream of it. The bore diameter 66mm of the PSM is determined so that the ceramic chamber does not limit the physical aperture. The thickness 3mm of the ceramic chamber is adopted.

The head of the magnetic pole has a round shape along to the chamber as shown in Fig. 4. Since the PSM gives a just single kick to the beam, it is not essential to have a precise sextupole field. The round pole shape has the relatively stronger field among several different pole shapes.

The principal parameters of the PSM system are listed in Table 1. The core length of the magnet is 0.3m. The magnetic core is laminated using the silicon steel with a thickness of 0.15mm. The required strength is 400G at a horizontal position of 15mm from a central orbit.

Fig. 5 show the magnetic distribution calculated using two-dimensional magnetic field calculation code Poisson [4]. When the current is 3000A, the magnetic field of 400G is achieved at the position of 15mm as shown in Fig. 6 and has an enough performance for our purpose.

2-TURN INJECTION

Unfortunately we cannot prepare a pulsed power supply with a pulse width of 1.2µs at the present, but we have the existing power supply with a pulse width of 2.4µs and an excitation current of 3000A. Thus, we have to accept the

second kick of the PSM in order to put this new injection scheme in practice at the PF-ring since the revolution period of the ring is 0.624µs. We call this injection scheme "2-turn injection".

In the 2-turn injection, the first kick is generated at a peak of half-sine waveform, and the second kick is generated at the timing after 0.624µs from the peak. The kick strength becomes about 70% strength of the peak. It is essential to choose a betatron tune in order to avoid increasing the coherent oscillation of the injected beam by the second kick. We find that the beam loss is less than about 5% by choosing the appropriate betatron tune as shown in Fig. 7. This is estimated by the multi-particle tracking simulation using a code SAD [5].

SUMMARY

We have developed the PSM system to demonstrate a new scheme of a beam injection at the PF-ring in KEK. We are now in the production stage of the system. In the next stage, we are going to measure the field strength and install the PSM in this winter shutdown, and then conduct a test experiment using a real beam.

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