DESIGN STUDY OF BEAM INJECTION FOR SUPERKEKB MAIN RING

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Abstract

The SuperKEKB project is in progress toward the initial physics run in the year 2015. It assumes the nano-beam scheme, in which the emittance of the colliding beams is $\varepsilon = 4.6$nm. The emittance of the injected beam is $\varepsilon = 1.46$nm. To achieve such a low emittance, it is vitally important to preserve the emittance during the transport of the beam from the linac to the main ring (MR). One of the most difficult parts is the injection system. We are considering the synchrotron injection for the electron-line to avoid a beam blowup in the ring after injection, which is caused by a beam-beam interaction with the stored beam. The optics study for electron injection and the current R&D status for the septum magnet is reported in this paper.

INTRODUCTION

In KEKB accelerator, the beam injection had been performed with the betatron injection scheme which inevitably induces betatron oscillation [2]. However, this scheme may not be available for the SuperKEKB accelerator, since the very low survival rate of injected beam is expected, especially for the electron ring. In the nano-beam scheme, the transverse position translates to the longitudinal shift of the interaction point. Since the beta-function is strongly squeezed in the vertical plane at the interaction point, a particle which has a finite vertical amplitude experiences a very strong beam-beam effect during the horizontal oscillation. A transient blowup of the injected beam due to this effect is expected to make the injection efficiency very low, specifically in the electron ring because of its narrow dynamic aperture. The result of the tracking simulation is shown in Figure 1, where the survival rate of the injected beam is supposed to be 24%. Therefore, another injection scheme has been considered: an injection to the synchrotron phase space, or shortly the synchrotron injection.

SYNCHROTRON INJECTION

The synchrotron injection [3, 4, 5] is free from the strong beam-beam interaction, since it does not cause the horizontal betatron oscillation. Figure 2 shows diagrams of the betatron and synchrotron injection schemes. In the betatron injection scheme, the injected beam has the same energy as the stored beam, thus the injected beam has the betatron oscillation according to the distance Δx between the injected and stored beams at the injection point. On the other hand, in the synchrotron injection scheme, the injected beam has the energy difference ΔE from the stored beam; if ΔE has the proper value, Δx is converted to the synchrotron oscillation.

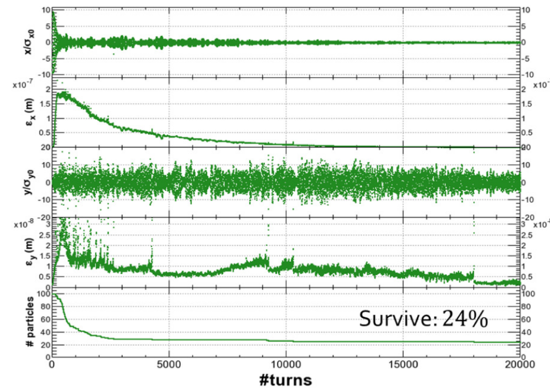

Figure 1: The tracking example of the betatron injection are shown. From above, the horizontal beam spread x/σ_{x0}, the horizontal emittance ε_x, the vertical beam spread y/σ_{y0}, the vertical emittance ε_y and the number of surviving particles are represented as the function of the number of turns.

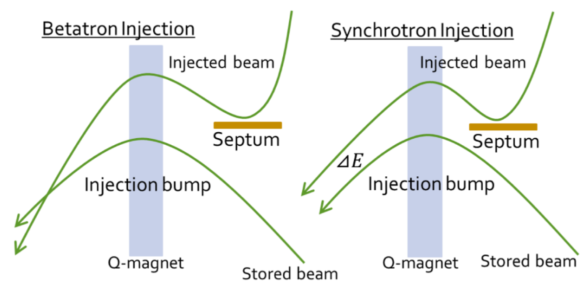

Figure 2: Schematic view of injection schemes.

Requirements for Synchrotron Injection

To perform the synchrotron injection, it is necessary that the sum of Δx and the radius of injected beam is less than the radius of the dynamic aperture of the stored beam. And also the Δx should be greater than the physical acceptance including the effective septum width w_S. The criterion is expressed as the following equations:

$$\begin{aligned} \Delta x &= \eta_{xR}\delta_0 \\ &= n_I\sqrt{\beta_{xI}\varepsilon_{xI} + (\eta_{xI}\sigma_{\delta I})^2} \\ &\quad +w_S \\ &\quad +n_R\sqrt{\beta_{xR}\varepsilon_{xR} + (\eta_{xR}\sigma_{\delta R})^2} \qquad (1) \\ &\quad \delta_0 + 2\sigma_{\delta I} = \delta_{\max}, \qquad (2) \end{aligned}$$

where

- η_{xj}: the horizontal dispersion of the stored beam for the injected beam $j = I$, for the stored beam $j = R$,

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- δ_0: the energy difference of the injected beam from the stored beam,
- $\delta_{\max}$: the maximum energy acceptance of the ring,
- n_j: how much part of the beam is considered in the σ unit,
- β_{xj}: the horizontal beta function,
- ϵ_{xj}: the horizontal emittance.

In Equation (2), $\delta_{\max}$ of 0.65% is assumed, which has been confirmed by the optics study. Figure 3 shows allowed w_S to the horizontal dispersion in the each energy spread value. The assumed values are following:

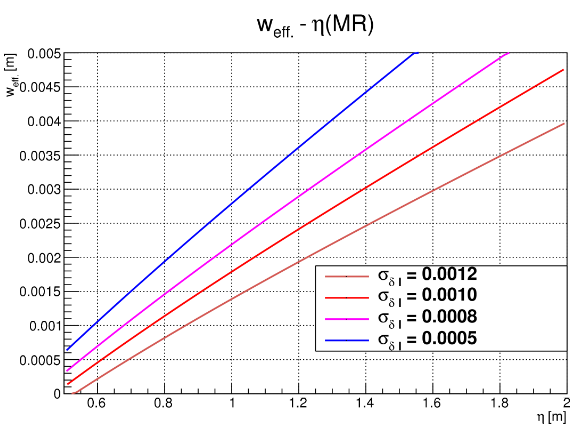

Figure 3: The allowed w_S to the horizontal dispersion on some cases of energy spread.

$$
\begin{aligned}
n_I &= 2.5 && (3)\\
\beta_{xI} &= 20[\mathrm{m}] && (4)\\
\varepsilon_{xI} &= 1.46[\mathrm{nm}] && (5)\\
\eta_{xI} &= 0 && (6)\\
n_R &= 3.0 && (7)\\
\beta_{xR} &= 60[\mathrm{m}] && (8)\\
\varepsilon_{xR} &= 4.6[\mathrm{nm}] && (9)\\
\sigma_{\delta R} &= 0.059[\%]. && (10)
\end{aligned}
$$

The parameters w_S, η_{xR}, $\sigma_{\delta 0}$ in equation (1) have greater effects to Δx than the others; making w_S or $\sigma_{\delta 0}$ smaller or making η_{xR} greater helps to perform the effective injection. It is important to control these three parameters, studies about them are described from the next section.

SEPTUM UPGRADE

According to the above discussion, smaller w_S derives more effective injection. We have designed the new septum magnet and have calculated the transient magnetic field.

Table 1: The KEKB and SuperKEKB parameters constructing w_S are represented.

Part	KEKB	SuperKEKB
Septum conductor	1.5	1.0
Si-steel sheet(s)	2×0.5	0.5
Wall of MR beam duct	1.0	0.5
Gaps in total	1.0	0.5
Bad uniformity field	1.0	1.0
Total	5.5	3.5

Design & Field Calculation

In KEKB, w_S is 5.5mm including bad uniformity field region; according to Figure 3, very large η_{xR} or very small $\sigma_{\delta 0}$ is required, though it is impossible. Therefore, the design study of the septum magnet was performed to reduce w_S. The contents of $w_S = 5.5\mathrm{mm}$ and their reduced values for SuperKEKB are shown in Table 1. In association with the decreasing of w_S, the increasing of the leak field is expected. To suppress that, the MR beam duct is planed to be made of a magnetic material with the copper or silver coating. The core gap is also reduced from 11mm to 6mm, intending to compensate the strength of the thinner septum conductor than before and to reduce the leak field. The schematic view of the design of the SuperKEKB septum magnet is shown in Figure 4. We confirmed that the leak field from the designed septum magnet into the MR beam duct is sufficiently suppressed to the same level as the KEKB septum magnet, using the OPERA-2D software. We have determined to prepare the prototype to confirm experimentally.

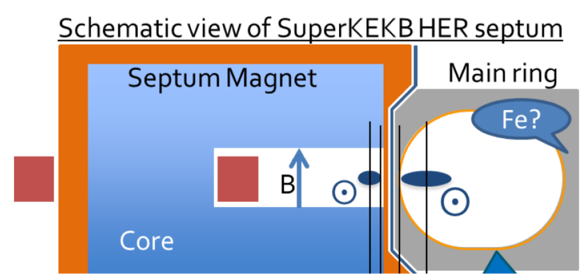

Figure 4: The schematic view of the SuperKEKB septum is shown.

Construction

To obtain the prototype, it is easy and low-cost way to improve the backup septum magnet for KEKB. The 1.0mm-width septum conductor had been produced successfully, then the exchange had been done without any big problem. The prototype of the MR beam duct is also produced.

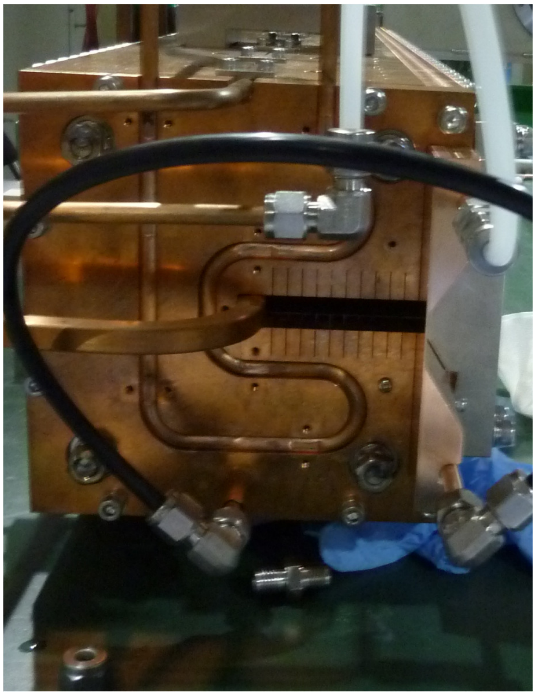

Figure 5: The picture of septum magnet is shown. The direction of view is the longitudinal along the beam line. The septum conductor is seen in the right-side of the core gap which is the pass for the injected beam; a vacuum duct for stored beam is placed on the right-side of the septum magnet.

Preparation for Field Measurement

We plan to measure the transient magnetic field with the pickup coil. The properties of the coil is: the wire turns are 20 and the outer and inner radii are 0.6 and 0.5 mm, respectively. We will compare the leak field outside of the septum conductor in the KEKB septum conductor and 1.0mm conductor case.

OPTICS FOR SYNCHROTRON INJECTION

This section describes the study about η_{xR} which is decided by the MR optics. To obtain the maximum absolute value of η_{xR}, the optics study was performed with the SAD program[6]. Figure 6 shows the result, where the top and middle rows indicate the beta functions and the dispersions, respectively. The obtained result is $\eta_{xR} = -1.6[\mathrm{m}]$ with $\varepsilon = 4.64[\mathrm{nm}]$. It satisfies the SuperKEKB design.

ENERGY SPREAD OF INJECTED BEAM

The last one of the three parameters is $\sigma_{\delta 0}$. It is decided by the injector linac. Assuming the beam bunch which has the Gaussian distribution with 3mm(10ps) FWHM, after the bunch is accelerated by the 2856MHz field, the energy spread is $\sigma_{\delta 0} = 0.4[\%]$. In the rectangular shaped bunch case, the energy spread is $\sigma_{\delta 0} = 0.12[\%]$. The study to reduce the energy spread is on going in the linac group and our requirement is $\sigma_{\delta 0} = 0.1[\%]$.

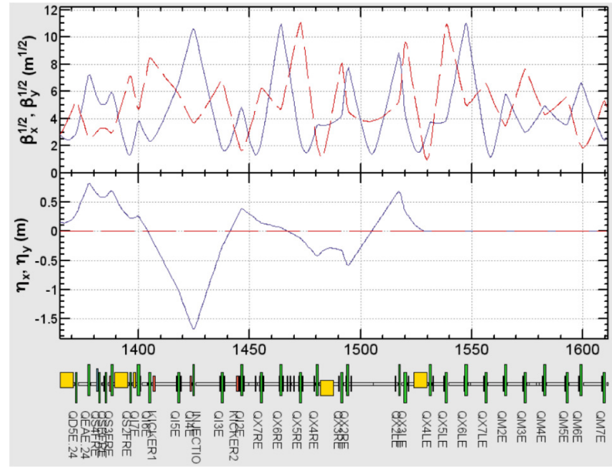

Figure 6: The result of optics study is shown. The top and middle rows indicate β_R and η_R, the blue and red color represent the horizontal x and vertical y axes, respectively. The bottom part shows a part of a number of magnets on the beam line. The injection point is named as 'INJECTIO', where η_{xR} takes the minimum.

CONCLUSION

It has become clear that the synchrotron injection is possible on the SuperKEKB accelerator, and the injection efficiency mainly depends on the effective septum width, the horizontal dispersion of the MR optics and the energy spread of injected beam. The parameters on synchrotron injection are preliminarily designed as follows:

$$w_S = 3.5[\mathrm{mm}] \quad (11)$$
$$\eta_{xR} = -1.6[\mathrm{m}] \quad (12)$$
$$\sigma_{\delta 0} = 0.1[\%], \quad (13)$$

where the injection efficiency is roughly estimated as 70 to 90 %.

The magnetic field measurement of the septum magnet is in progress, the values are officially decided after it is confirmed that the leak field is sufficiently suppressed.

REFERENCES

[1] M. Masuzawa, "Next Generation B-Factories," Proceedings, IPAC'10, Kyoto, Japan (2010).

[2] M. Kikuchi, *et al.*, "Beam-Transport System of KEKB," Nucl. Instr. and Meth. A 499 p.8-23 (2003).

[3] P. Collier, "Synchrotron Injection," Proceedings, Fifth LEP Performance Workshop, Chamonix, France, 1995.

[4] P. Collier, "Synchrotron Phase Space Injection Into LEP," Proceedings, PAC-95 Conference, Dallas.

[5] P. Collier, G. Roy, "Injection and Acceleration with Physics Optics in LEP," 5th European Particle Accelerator Conference, pp.e-proc. 292-294 (1996).

[6] The SAD is a computer program for the accelerator design. `http://acc-physics.kek.jp/SAD/`

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