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ELECTRON BEAM INJECTION SYSTEM FOR SUPERKEKB MAIN RING

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Abstract

The SuperKEKB project [1] is in progress toward the initial physics run in the year 2015. It assumes the nano-beam scheme, in which the horizontal emittance of the colliding beams is $\varepsilon_x = 4.6$[nm]. The horizontal emittance of the injected beam is $\varepsilon_x = 1.46$[nm]. To achieve such a low emittance, it is vitally important to preserve the emittance during the transport of the beam from the linac [2] to the main ring (MR). One of the most difficult sections is the injection system. It has been pointed out that the injected beam has possibility of leading to blowup in the ring, which is caused by a beam-beam interaction with the stored positron beam. To avoid the beam blowup, the synchrotron injection [3–5] is adopted as a backup option. The orbit of the electron injection beam has been designed and the septum magnet prototype has been constructed. The optics study for electron injection and the current R&D status for the septum magnet will be reported in this paper.

INTRODUCTION

In KEKB accelerator [6], the beam injection had been performed with the betatron injection scheme which inevitably induces betatron oscillation [7]. For SuperKEKB, the synchrotron injection is adopted as a backup option since the possibility of the beam blowup has been pointed out with the betatron injection in nano-beam scheme [8].

The SuperKEKB project contains an upgrade of the KEKB accelerator, thus the old KEKB systems will be reused for the SuperKEKB accelerator as many as possible. Regarding the injection system for the electron ring (HER) of SuperKEKB, only the half of injection septum magnets are totally reconstructed to be capable of the injection of very low emittance beam on the nano-beam scheme. Therefore, new septum prototype has been designed and constructed according to the study of the injection orbit.

INJECTION ORBIT CALCULATION

Both the design orbits for betatron and synchrotron injections are described in this section. A study of the MR optics decides the ring parameters at the injection point. For the betatron injection, the MR horizontal dispersion $\eta_{x\mathrm{R}}$ around the injection region is set to be $\eta_{x\mathrm{R}} = 0$; on the other hand, larger $|\eta_{x\mathrm{R}}|$ makes the margin for the synchrotron injection larger.

Betatron Injection

The criteria at the injection point is shown in Table 1. The required acceptance of the stored beam is calculated as the function of the beta-function of the injected beam ($\beta_{x\mathrm{I}}$) and the stored beam ($\beta_{x\mathrm{R}}$) in Fig. 1. $\beta_{x\mathrm{R}} = 100$[m] is given by the HER optics study, therefore $\beta_{x\mathrm{I}} = 15.3$[m] is optimum. Injection parameters are defined as $\Delta x = 7.8$[mm], $\Delta x' = -0.62$[mrad], where Δx and $\Delta x'$ are the horizontal position and angular difference of the injected beam from the stored beam center at the injection point.

Table 1: Betatron Injection Parameters

Parameter	Value
$\alpha_{x\mathrm{R}}$	7.93
$\beta_{x\mathrm{R}}$	100m
$\varepsilon_{x\mathrm{R}}$	4.6nm
$\varepsilon_{x\mathrm{I}}$	1.46nm

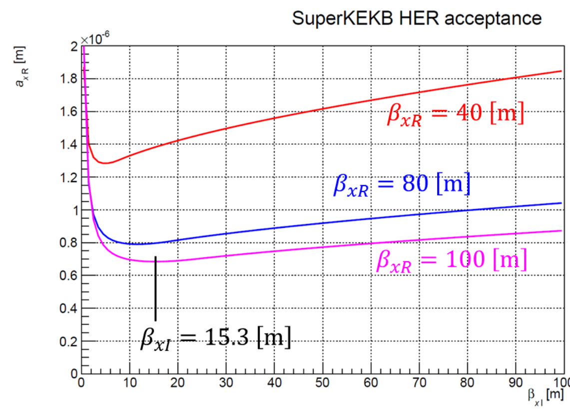

Figure 1: Acceptance of the betatron injection.

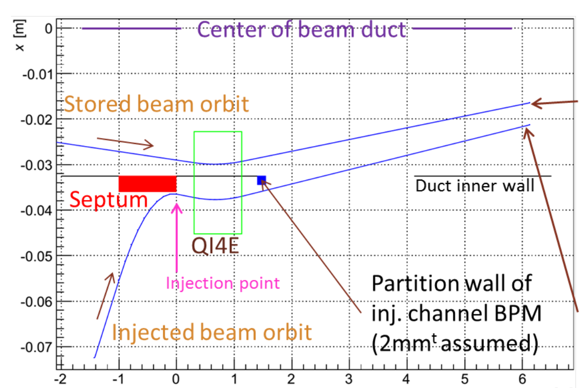

Figure 2: The betatron injection orbit for SuperKEKB is shown. As for the downstream of the septum magnet, the injected beam is controlled by the HER system. Thus a point at $z = 0$ is defined as the injection point.

Synchrotron Injection

The parameters for the synchrotron injection are shown in Table 2. The synchrotron injection orbit shown in Fig. 3

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Table 2: Parameters Related to the Synchrotron Injection

Parameter	Value
$\beta_{x\mathrm{R}}$	100 m
$\beta_{x\mathrm{I}}$	20 m
$\varepsilon_{x\mathrm{R}}$	4.6 nm
$\varepsilon_{x\mathrm{I}}$	1.46 nm
$\eta_{x\mathrm{R}}$	-1.6 m [8]
Momentum spread of the stored beam $\sigma_{\delta\mathrm{R}}$	0.059 %
Momentum spread of the injected beam $\sigma_{\delta\mathrm{I}}$	0.1 % [2]
Number of deviations of the stored beam n_R	3.0
Number of deviations of the injected beam n_I	2.5

is also designed in the same way as the betatron injection orbit.

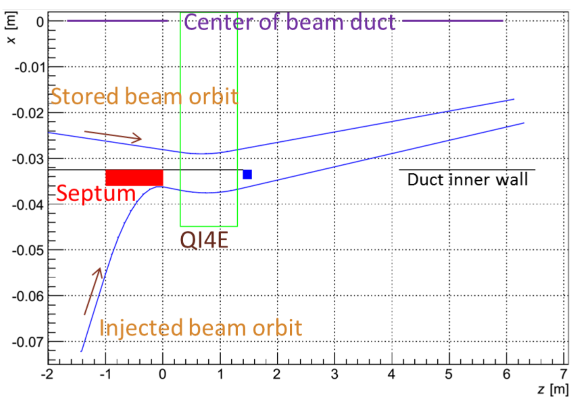

Figure 3: The orbit for the synchrotron injection are shown.

Injection Parameters

Parameters listed in Table 3 are derived from the design orbits. The allowed effective septum width w_eff is w_eff = 5.32[mm] for the betatron injection and w_eff = 3.34[mm] for the synchrotron injection. Therefore, w_eff < 3.34[mm] is required; the septum magnet has to be reconstructed to be capable for the SuperKEKB injection system.

Table 3: Injection Parameters are Listed. Betatron and Synchrotron Injection Parameters are in the center and right columns respectively.

Parameter	Betatron	Synchrotron
Kicker height	28.5 mm	28 mm
Slope angle	-1.88 mrad	-1.89 mrad
K_1 (QI4E)	0.1498	0.1437
Height at QI4E	29.5 mm	29 mm
$n_\mathrm{R}\sigma_{x\mathrm{R}}$	2.1 mm	3.49 mm
$n_\mathrm{I}\sigma_{x\mathrm{R}}$	0.374 mm	0.37 mm
Δx	7.8 mm	7.2 mm
$\Delta x'$	-0.62 mrad	-0.52 mrad
Allowed w_eff	5.32 mm	3.34 mm

SEPTUM DESIGN FOR SUPERKEKB

The concept design is shown in Fig. 4. The effective width of the septum is 3.3 mm; it means the 1.7 mm reduction from the KEKB septum. Ideas of that achievement are that the septum conductor thickness is reduced from 1.5mm to 1.0mm, the 0.5 mm^t magnetic shield plates are reduced from two to one and instead the pipe for the stored beam consists of the magnetic material with the copper coating to the inner wall.

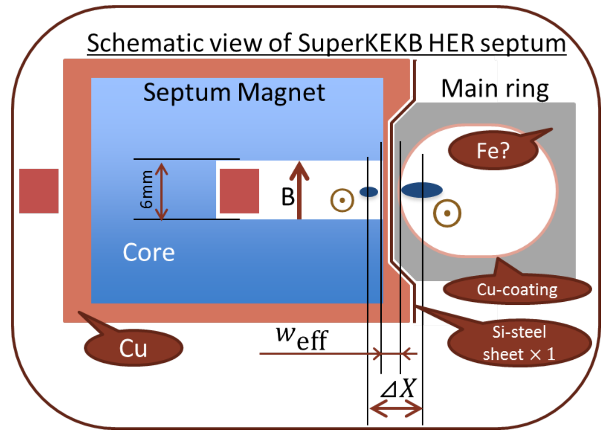

Figure 4: The concept design of the septum magnet.

CONSTRUCTION OF SEPTUM PROTOTYPE

In this section, the construction and field measurement of the septum prototype are reported. The effect of the non-uniformity of the field is also discussed.

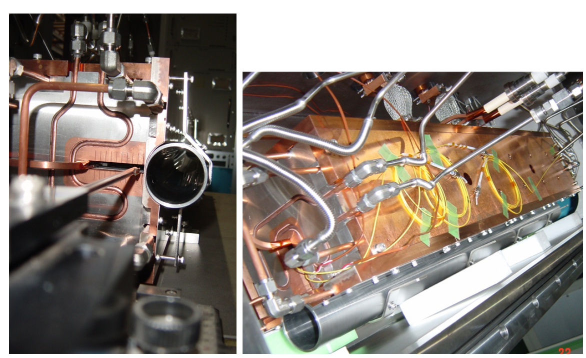

Figure 5: The pictures of the septum prototype are shown. The mock-up beam pipe for the HER is fixed on the septum conductor.

Field Measurement

The magnetic flux density of the prototype is mapped with the pickup coil which has the 20 × 0.5mm^2 of area and 10 −turn coil.

Beam Tracking with Practical Septum Field

The non-uniformity of the septum field affects the beam quality. The change of the divergence angle through the sep-

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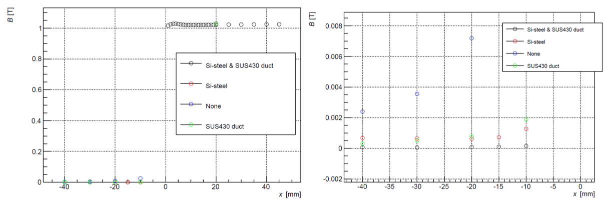

Figure 6: The measured septum fields are represented. The vertical axes indicate the magnetic flux density and the horizontal axes indicate the transverse position where the $x = 0$ point is on the inner surface of the septum conductor, the $x < -1$ region represents outside of septum and the $x > 0$ region represents inside of the septum core. The left and right plots represents the whole and outside ($x < -1$) range of the measurement.

tum field is obtained by the tracking simulation. In Fig. 7, the angular difference are plotted as the function of the transverse position from the beam center. The angular difference

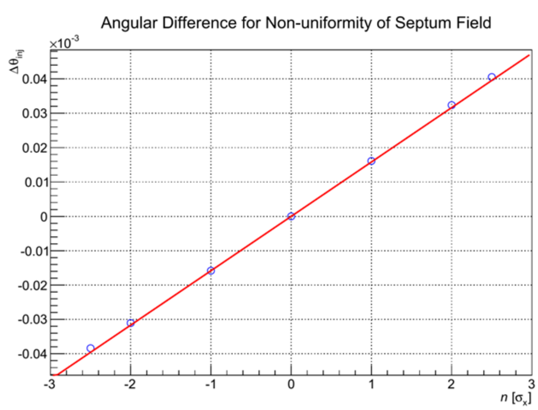

Figure 7: The angular difference for non-uniformity of the septum field. The vertical and horizontal axes represent the angular difference and the transverse position from the beam center. The red line represents the fitting result with the straight line.

in Fig. 7 is fitted with a straight line and the difference of the angular difference from the fitted line is plotted as the function of the transverse position from the beam center in Fig. 8. Since the first order component originates from the quadrupole field which can be cancelled with the upstream beam transport line, it is important that the higher order components are small enough not to affect the original horizontal divergence of the injected beam x'. In Fig. 8, the maximum angular distortion is 1.2μrad and the original horizontal divergence angle of the injected beam is

$$n_{\mathrm{I}}\sqrt{\frac{\varepsilon_x}{\beta_x}} = 24.4[\mu\mathrm{rad}], \quad (1)$$

thus the rate of unrecoverable distortion is about 5%.

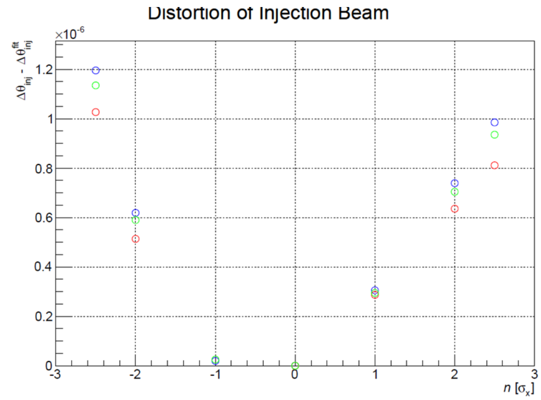

Figure 8: The distortion of injection beam.

SUMMARY AND CONCLUSION

The HER injection system capable for the nano-beam scheme for the SuperKEKB accelerator is studied and the injection orbit are designed. It is found out that the KEKB/HER septum should be reconstructed, since the KEKB/HER septum has no margin for the betatron injection and is not capable for the synchrotron injection. Therefore the septum magnet for SuperKEKB is designed with the 3.3 mm effective width. Other KEKB/HER components of the injection system is confirmed to be capable of being used for SuperKEKB.

The prototype of the septum magnet has been constructed and the field has been measured. The leak field to the HER beam pipe is $o(10^-3)[\mathrm{T}]$; it is restrained enough. The effect of the non-uniformity of the septum field on the injected beam is calculated to be about 5% at maximum for the horizontal divergence angle. No critical issue for constructing the actual septum magnet has been found.

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