POSITRON YIELD OPTIMIZATION BY ADJUSTING THE COMPONENTS OFFSET AND ORIENTATION*

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Abstract

The SuperKEKB's design luminosity is 40 times greater than that of KEKB. In order to achieve this goal, we need to keep the injection electron beam emittance small and let the primary electron beam generates high positron yield. The design is challenge but fulfilled after introducing a pulse-to-pulse switching system for electron and positron injection. During the operation, the injection electron beam is on axis to preserve emittance and the primary electron beam will be steered to strike on the offset target to generate positrons. The flux concentrator as a part of the matching device in capture section plays an important role in yield improvement. It is offset due to the constrain of small aperture. As a result of the straight cut-in slit section the FC has an unsymmetric field distribution, so that the orientation could lead to a positron yield variation. In this paper, we will discuss this issue and find out the ideal trajectory for the positron beam.

INTRODUCTION

From KEKB to SuperKEKB, the luminosity is required to be 40 times higher, which demands the injection linac to provide beams of higher charges. [1]. The positron source principle configuration has been shown in Figŕeflayout. The primary electron beam would be guided off the central axis by the pulsed steering coil before striking on the target. To avoid damaging the target by the extremely small size electron beam, a beam spoiler will be placed between the quadruple and the target. The beam spoiler is made of aluminum attaching with a screen monitor, so that it could not only scatter the beam to protect the target but also measure the beam size. More detailed spoiler discussion could be found in paper [2]. When the primary electron beam strikes on the target, the beam spot size can be as large as 0.7 mm. The positron conversion target is made of tungsten whose radius is 2 mm and length is 14 mm. In the other hand, to optimize the injection electron beam, it needs to be placed on a common central axis of the DC solenoid.

A hole of 1 mm radius for electron beam passage is bored 0.5 mm away from the edge of the target. Considering the target radius is 2 mm, then the target center is 3.5 mm off

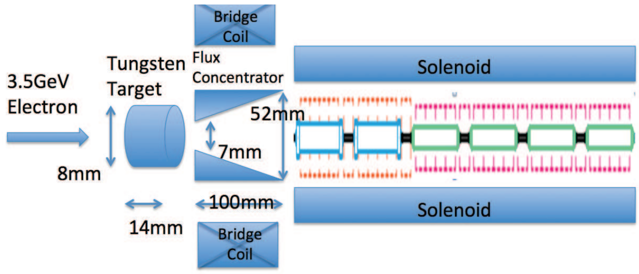

Figure 1: Schematic view of SuperKEKB positron source configuration [4].

from the central axis. The generated positron beam has a very large divergent angle but small lateral dimension. Hence, a flux concentrator (FC) would be installed to improve the capture efficiency [5]. The FC has an aperture of 7 mm, in which should contain the target and the passage hole. As a consequence, the FC center has to have a 2 mm offset from the beam line and the target center has a 1.5 mm offset from the FC center. The positron target and the FC layout are shown in Fig.2. After passing through the FC, the positron beam enters into the solenoid field with a few millimeters offset from the central axis moving as a cyclotron orbit. The captured positrons would be accelerated by the large aperture S-band accelerating structures before being delivered to the downstream of the linac [3].

In the following section, we will present the FC field distribution and discuss the positron yield reduction due to the offset layout of SuperKEKB positron source. The results are based on the simulation from the target to the end of the capture section. For the ideal scenario we assumed all the components are well aligned on the central axis. The maximum positron yield equals to 0.89. Whereas SuperKEKB layout could see 50% yield degradation because of the target and FC offset. We propose that by adjusting the FC slit orientation, the positrons can go through a path with relatively low transverse components. Combining with a new offset strike point on the target, the positron yield reduction because of the components offset will be recovered.

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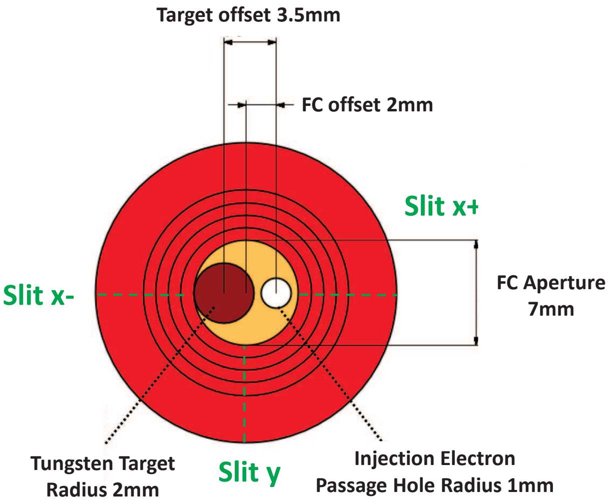

Figure 2: SuperKEKB positron target geometry. The red part represent the FC, yellow is the cooling copper and brown is the tungsten target. The injection electron passage hole is shown in white. The green dash lines are the three possible slit orientation directions.

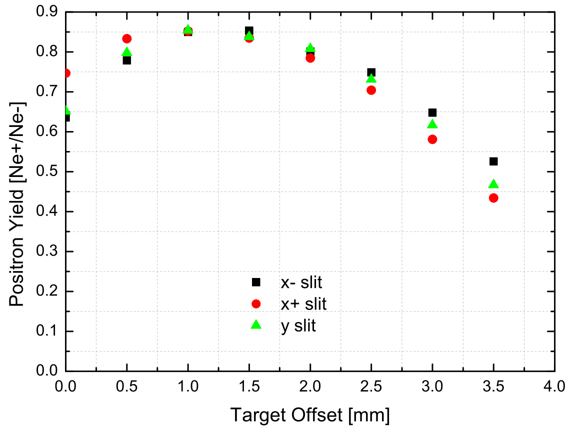

Figure 4: Positron yield (number of positrons per electron) as a function of target offset. The FC center is 2 mm away from the center axis. The black, red and green marks represent the slit orientation of x-, x+ and y respectively, as marked in Fig.2

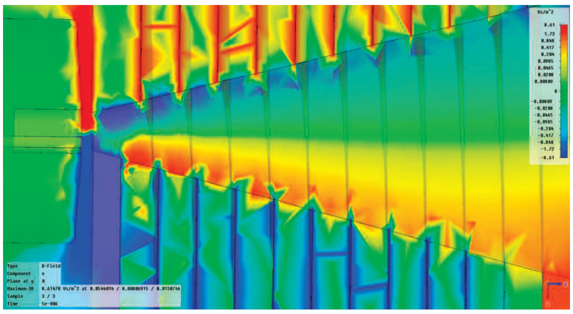

Figure 3: CST 2D FC transverse field distribution.

FC FIELD DISTRIBUTION AND SLIT ORIENTATION

In KEK, we have manufactured and studied two kinds of FC: the spiral slit one and the straight slit one. The detailed introduction of these two models, prototyping and experiment could be found in paper [5]. One of the advantages for the spiral slit FC is low transverse component. The transverse component of the magnetic field in FC is crucial to achieve high capture efficiency. It could flick positrons off the axis causing positron yield reduction. The Fig.3 shows the 2D transverse field distribution on the plane that parallel to the slit direction. The main source of the transverse component is due to the straight cut-in slit section. The field could be divided into three sections:

1. Between FC and target: the field is symmetric.
2. Cut-in straight slit region inside FC: the field is offset.
3. Further deeper of FC: field is symmetric again.

This indicates that the transverse field strength is lower on the slit side. A detailed simulation has been done to investigate the influence of transverse field by scanning the positron's injection trajectory. The simulation started from the target and ended at the last accelerating structure in the capture section. The results have been presented in Fig.4. In the figure, we show the positron yield at the end of capture section as a function of the target position. Target offset equals to 0 means it's on central axis. When it equals 3.5 mm, it's the SuperKEKB setup. And the different colors represent the various FC slit orientation, which has been marked on the Fig.2 with the green dash line.

As we can see from the figure, when the target offset=0 mm (on axis), the target is close to x+ slit (because FC is 2 mm offset from central axis), the x+ slit positron yield is 15% higher than the x- slit one. Then as the target offset increases, which means the target is moved toward to the x- direction, the yield peak at the position of 1 mm$\sim$1.5 mm. The location in between central axis and FC center returns the maximum value. In this region, the positron yields are more or less the same with difference slit orientation. And then the x- slit start to have a better capture efficiency along with the target offset toward to the same direction as slit. For instant, when the target offset equals to 3.5 mm, and an x+ slit direction only has a yield of 0.43, but an x- slit can improve the yield to 0.53. This simulation has shown us that a higher yield could be achieved by adjusting the target offset and slit orientation to the same side.

OFFSET STRIKE ON THE TARGET

Although the FC orientation could recover the positron yield a little bit, it's still a dramatic reduction. The layout is restricted due to the small aperture of the FC. Therefore, we need to carry out a solution based on SuperKEKB positron source setup which has a 3.5 mm offset target and 2 mm off-

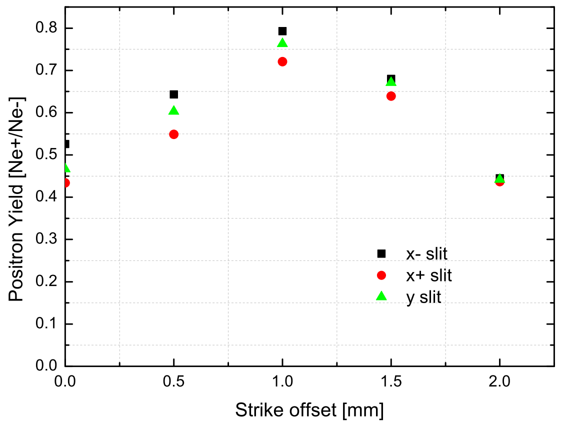

Figure 5: Positron yield as a function of electron bombardment position respect to the target center. Strike offset equals 0 is the target center and the primary electron beam's moving direction is toward to the central axis. The black, red and green marks represent the slit orientation of x-, x+ and y respectively, as marked in Fig.2

set FC. There is one clue we can find out from previous section is that the capture efficiency is better when the positron beam trajectory is in between central axis and FC center. This would encourage us to let the electron beam strikes the target's off center position to enhance the positron yield. The Fig.5 shows the simulation results of the positron yield as a function of the electron bombardment position. When x equals to 0, electron beam strikes on the target center. As we know that the target radius is 2 mm, so the x equals 2 mm means it's the edge of the target. The Fig.5 has also includes the influences of the FC slit. The x- slit, x+ slit and y slit represented by the black, red and green marks respectively.

From the Fig.5 we can see that the positron yield would increase along with the movement of the striking point. The peak appears when the primary electron beam moves away 1 mm from the target center, which corresponds to 2.5 mm offset from central axis and 0.5 mm from FC center. As we expected, the x- slit orientation returns a maximum yield of 0.79, and the y slit is slightly lower (0.76), then the lowest one is the x+ which equals to 0.73. If the striking point keeps moving further, although the trajectory gets closer to the FC center, the primary electron cannot develop sufficient cascade shower to generate positrons. Therefore, the positron yield is reduced to 0.45 when the offset equals to 2 mm, where is the edge of the target. One more thing has been reflected from this figure is that the slit impact has been confirmed again. The offset position equals to 2 mm represents the FC center. When x is less than 2 mm, the positron trajectory is always on the x- side, so that x- slit as expected would return a higher positron yield all the time. All in all, from this evaluation we can get one important results: The positron yield could be recovered from 0.53 to 0.79, if we apply an offset strike of 1 mm. It's about 91% of the ideal layout (everything is on axis)

CONCLUSION

The FC plays an important role as a part of matching device. We have found out that the cut-in slit would cause a field offset in the FC. In order to let the injection electron beam passes the center of the DC solenoid to avoid emittance dilution, the target is away from central axis. And the FC could only contain both target and passage hole if it is 2 mm offset duo to the restriction of the small aperture. This is an issue that will cause huge yield decrease. As we can see from the Table.1, if we assume an ideal layout of the positron source, which means there's no offset for any components and primary electron beam strike at the center of the target, the positron yield would be 0.87. For the proposed SKB positron source structure, FC offset is 2 mm and target offset is 3.5 mm. If the slit is the opposite direction of the offset direction, the positron yield could be reduced from 0.87 to 0.43. If the slit is the same direction as the offset direction, the positron yield will increase from 0.43 to 0.53. Therefore, we suggest letting the target offset and the FC slit on the same side to improve yield. Furthermore, the positron trajectory should close to the FC center by striking the primary electron beam off the target center. For example, if the strike position is 1 mm offset, which means 1 mm closer to the FC center, then the positron yield can be improved from 0.53 to 0.79, which is about 91% of positrons from the ideal layout. The positron yield is well recovered without changing the default layout.

Table 1: Positron yield for various calculation scenarios.

	FC/Target	Center-Strike	Offset-Strike
On-axis	Ideal	0.87	N/A
x+ Slit	Offset	0.43	0.73
x- Slit	Offset	0.53	0.79

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