DESIGN STUDY OF A NEW LARGE APERTURE FLUX CONCENTRATOR*

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Abstract

For high luminosity electron-positron colliders, intense positron beam production is one of the key issues. Flux Concentrator (FC) is a pulsed solenoid that can generate high magnetic field of several Tesla and is often used for focusing positrons emerged from a production target. It works as an optical matching device in a positron capture section. With this device, high capture efficiency is achieved. In this paper, we will introduce a new design of a FC for the SuperKEKB positron source. The advantages of the new design are that the aperture is larger than the previous design, and the transverse components are much smaller. The new FC modeling has been done in CST Studio and we will report the results of new FC field evaluation. In order to calculate the positron yield and capture efficiency, a tracking simulation to the end of capture section has also been carried out, which is also included in this paper.

INTRODUCTION

Flux Concentrator (FC) is a pulsed solenoid that can generate high magnetic field of several Tesla and is often used for focusing positrons emerged from a production target. It consists of primary coil and conductor core. A pulsed current in the primary coil induces an eddy current in the conductor. Due to the skin effect, induced current is directed into the inner surface through a slit to produce a high magnetic field in small area. A matching device such as flux concentrator could transform the phase space distribution from the target so that it is appropriate for the solenoid focusing field in the accelerating section: this improves the capture efficiency. It works as an important part of adiabatic matching device (AMD) in a positron capture section. The detailed modeling and simulation work could be found in the paper [1]. The spiral slit FC is a preferred choice because of its small transverse component and relatively high peak field. The detailed comparison between straight slit FC and spiral slit FC has been discussed in paper [1]. In this paper, I will introduce a new design of FC which is developed based on the SLAC spiral slit FC design [2]. It could have a much larger aperture with similar level of peak field accompanying with smaller transverse component. The advantages of using a large aperture FC are: (1) the positron target could be immersed in the FC to improve the capture efficiency and then positron yield, (2) the positron target could have a larger radius to contain an electron beam with large spot size, which could reduce the peak energy deposition density to avoid damaging the target, (3) positron beam could benefit from a smaller transverse field strength preventing to be deflected. In the following section, we will perform a detailed field comparison between spiral slit FC and the new FC. And then apply the field distribution to the tracking code to evaluate positron yield at the end of the capture section.

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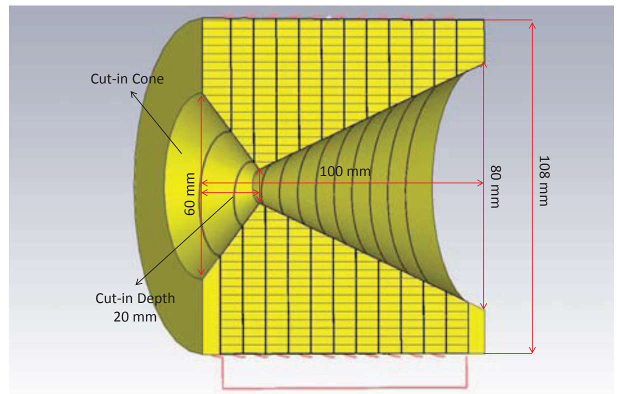

Figure 1: CST Model of the new designed Flux concentrator.

NEW FC MODELING AND FIELD EVALUATION

The new FC has been modeled in CST as shown in Fig.1. The copper coil length is 100 mm, 11 turns and assuming a current of 12 kA. The copper core has an outer radius of 54 mm and a conical inner radius growing from 7 mm to 40 mm. The entrance cone depth is 20 mm with the bottom radius of 30 mm. The cut-in depth is an important parameter that could influence the field distribution. Fig.2 shows the peak longitudinal field as a function of cut-in depth. When the cut-in depth changes from 5 mm to 40 mm, the peak field increases from 3.7 T to 4.6 T. After that, further cut can cause a field reduction. Overall, the peak field boost is about 1 T. However, a deeper cut-in depth is equivalent to a shorter FC, which is end up a steep field ramping up and reduction, so that the energy acceptance is smaller. The detailed discussion regarding FC parameters and acceptance could be found in the paper [3]. Furthermore, a deeper cut-in can also bring challenge to design an immersed positron target and its cooling system.

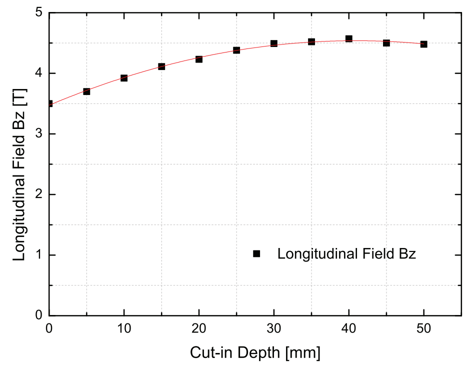

Figure 2: Peak longitudinal field as a function of cut-in cone depth.

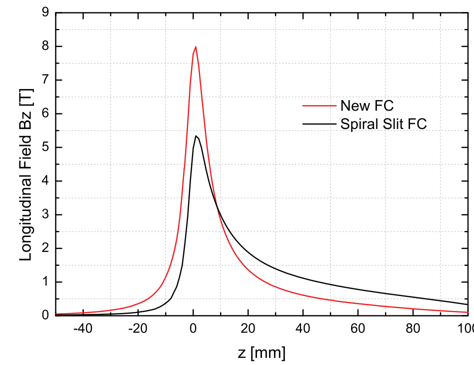

Figure 3: Longitudinal field distribution as a function of position z. The black line and red dots represent the new FC and spiral slit FC respectively.

The new FC design research is from all aspects. Other than the cut-in depth, there are a few parameters could change the field distribution. For example, when tungsten target is immersed in the FC, an eddy current is induced on the surface of the target, which leads to a field reduction. The eddy current effect is under investigation, so we will not go into details in this paper. In general, when the target size gets larger, the field will be reduced more. And after taking into account the copper cooling system, the situation could get even worse. A new target and its cooling system design are undergoing. The goal is to fit the target into the cone shape without reducing peak field too much.

New FC longitudinal Field on Axis

The FC longitudinal field strength is one of the most important figures to judge the performance of a design. Fig.3 shows the calculated longitudinal magnetic field as a function of longitudinal position on the central axis for the spiral slit FC and new FC, which are represented by the red curve and the black curve respectively. In this figure, z=0 is where FC has the minimum aperture (for new FC it means after 20 mm cut-in cone). As we can see, with same input current of 12 kA and radius of 3.5 mm, new FC could produce a peak field about 8 T, whereas the spiral slit FC could only do a 5.4 T. The field distribution shape is slightly different. New FC field reduce rapidly after achieving the peak and the spiral slit FC's field change is gradually. Hence, we could conclude that the new FC can produce higher field but with steep field shape. The adiabatic condition can be improved by introducing an additional DC coil around FC. The performance of positron capture has been investigated by using tracking simulation, which will be discussed and shown in the later section

New FC Transverse Field on Axis

In previous plot we have compared the field distribution with same aperture for two FC designs. In this section, a further investigation regarding correlation between field

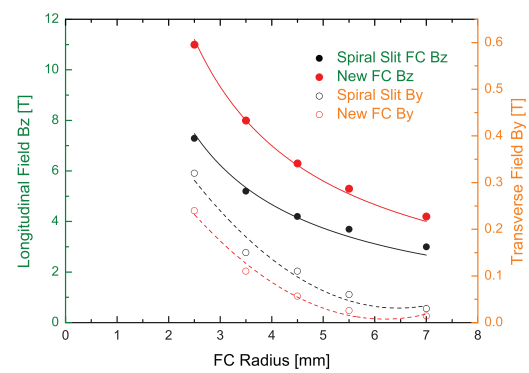

Figure 4: Longitudinal (left y-axis, green color) and transverse (right y-axis, orange color) peak field as a function of FC radius. The longitudinal field and the transverse field are represented by the solid dots and the circles respectively. New FC is shown in red and Spiral slit FC are shown in black.

(longitudinal and transverse) and FC radius will be carried out. Fig.4 shows the longitudinal and transverse field as a function of FC radius for both designs. In the figure, solid dots and circles represent the longitudinal peak field value and transverse peak field value respectively. The red dots and circles are the results of new FC. The black dots and circles are calculated from spiral slit FC. First of all, let's compare the transverse field between two designs. In fact, with the new design, we do not only get a higher peak longitudinal field, but also get a lower transverse component. When the radius increase from 4.5 mm to 7 mm, both designs show a similar pattern. The new FC's transverse field strength is about half of the spiral slit design's. The transverse component of the magnetic field is crucial to achieve high capture efficiency, because it could deflect positrons off the axis causing positron yield reduction.

From Fig.4 we can see that for both designs, the longi-

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tudinal field is sensitive to the inner radius changes. The strength of the longitudinal field along the axis is inversely proportional to the FC inner radius. But the new FC could produce the peak field about 1.5 times higher than the spiral slit FC in nearly all radii. If we look into it from another angle, we could keep the same peak field but benefit from a larger aperture. For example, the standard spiral slit FC needs an inner radius of 3.5 cm producing 5.2 T field, whereas the new FC could achieve same value with a much larger inner radius of 5.5 mm. According to Fig.4, spiral slit FC has a 0.118 T transverse field accompanying with the 5.2 T longitudinal field, and the value for the new FC with a radius of 5.5 mm is 0.026 T which is about 4.5 times lower than the spiral slit FC's. The new FC put us in a very good position that we could either trade off the aperture to obtain higher field or keep same field strength to have an immersed target in large aperture FC.

From the calculation results and discussion showing above we can conclude that the new FC performance is promising. With the same size as the spiral slit FC, it produces similar level of longitudinal peak field with large FC aperture. On top of that, the transverse component is only about 1/5 of the spiral slit FC.

TRACKING SIMULATION

The motivation of a tracking simulation is to compare the capture efficiency of the new FC with the spiral slit FC. The capture section layout is based on the SuperKEKB design. Positrons generation simulation is carried out by GEANT4 assuming a 3.5 GeV electron strike on a 14 mm thick tungsten target. The generated positrons go through the adiabatic matching device consisting of FC and bridge coil. Downstream of the matching section is the accelerating structures include six 2 m large aperture S-band accelerating units who have apertures of 17.5 mm. The whole accelerating structure is surrounded by a 0.4 T solenoid. Fig.5 shows the positron yield as a function of FC radius in the end of capture section. The red and black curves shows the tracking results by using spiral slit FC and new FC field distribution respectively. As the Fig.5 suggested, when FC radius increases (at the same time field is reduced), the positron yield has a peak at radius of 3.5 mm. For the case of smaller radius (2.5 mm), although a higher peak field can be achieve, which can increase the angular acceptance, the losses due to the reduction of energy acceptance and smaller entrance are greater and vice versa when the large radius FC is implemented. The results indicate that a 3.5 mm radius FC may be the best balance amount energy acceptance, angular acceptance and lateral acceptance. Comparing two FC designs, the red line is above the black in all radiuses. When the radius is between 2.5 mm and 4.5 mm, the positron yield for the new FC is improved about 20%∼30%. After enlarging the radius more than 5.5 mm, the differences start to be smaller and results are converged. So far the positron yield improvement is based on the condition of same radius and input current but different peak field. If we compare the new FC with radius of 5.5 mm with the spiral slit FC with radius of 3.5 mm, we will have some ideas of aperture contribution to yield, because both of them have a peak field about 5 T. When the radius increase by applying new FC, the positron yield increased about 7%. The tracking simulations have returned promising results indicate that the positron yield could be benefit from large radius and high peak field new FC configuration.

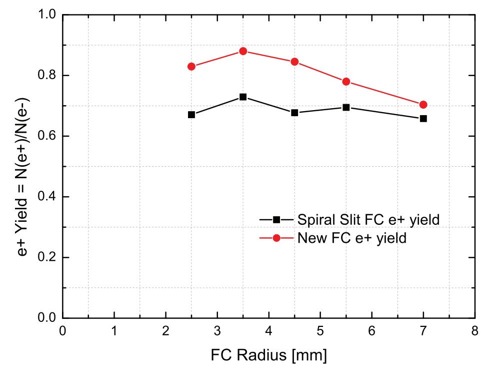

Figure 5: Positron yield as a function of FC radius in the end of capture section. The red and black line represents the new FC and spiral slit FC respectively.

CONCLUSIONS

Flux Concentrator plays an important role between production and acceleration section. There are several designs has been proposed such as the straight slit FC and spiral slit FC. In KEK, we have made a few of similar kind of prototype for test. In this paper, we have introduced another alternative option. The new design could either have a 1.5 time higher peak field or 1.5 times larger radius than spiral slit FC. Due to the enlarged aperture, the transverse components will be much smaller so that the positrons could avoid large deflection. Furthermore, the tracking results shows the new FC could give a 20%∼30% of yield improvement. In the future, we would like to manufacture a prototype of the new FC in KEK. A field measurement will be carried out before installing it into a vacuum chamber for high voltage operational test.

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