Prototyping of the Flux Concentrator for SuperKEKB Positron Capture*

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Abstract

The SuperKEKB requires higher positron intensity. We will upgrade the capture system of the injection linac by introducing a Flux Concentrator type of a pulsed solenoid that can generate several Tesla solenoid field to focus the positrons emerged from a conversion target. Due to the high temperature environment during brazing, we proposed to use a high strength copper material (HRSC) for FC which has a much better mechanical strength than Oxygen-free Copper (OFC). The experiment is designed to measure and compare the field distribution of two FC prototypes made of HRSC and OFC to evaluate the possibility of using HRSC for FC. Furthermore, in this paper, we will also introduce the different FC geometries: a simple straight slit FC and a SLAC type of spiral slit FC. The measurement results of these two geometries prototypes will be presented and discussed.

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 works as an important part of adiabatic matching device (AMD) in a positron capture section. With the help of this device, high capture efficiency could be achieved. Detailed modeling of the FC is sufficiently complex that there is significant uncertainty in the results of simulation. The detailed modeling and simulation work could be found in paper [1]. In order to benchmark the simulations, and provide a solid basis for understanding the issues and optimizing the design, experimental studies are necessary. Such studies have been performed at KEK, using several full-scale FC prototypes as shown in Fig.1. And the experimental station has been set up as shown in Fig.2. The experimental instruments and control software has been described in paper [2]. In this paper, experimental results of field measurements for various FC prototypes will be presented and compared.

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Figure 1: Four flux concentrator prototypes are manufactured and tested in KEK. From left to right: HRSC straight slit FC, OFC straight slit FC, OFC spiral slit FC and HRSC spiral slit FC.

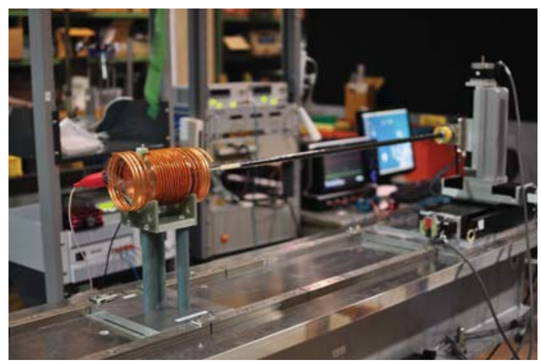

Figure 2: A straight slit FC made of OFC was set up on the experimental station.

FC GEOMETRY AND MATERIAL

FC Geometry: Straight Slit and Spiral Slit

When we manufactured the FC prototypes, there are two kinds of proposed geometries: straight slit and spiral slit. The straight slit FC is 10 cm long with a cylindrical outside radius of 4 cm and a conical inside radius growing from 0.35 cm to 2.6 cm. A 0.02 cm straight slit links the inner and the outer surface as shown in Fig.2. This design is easy for machining, and it could generate higher longitudinal field, but the transverse components are large. Whereas the spiral slit design have smaller transverse components due to the 12 turns of 0.02 cm of spiral cutting. The drawbacks of this geometry are the lower longitudinal peak field and its rather complicated geometry.

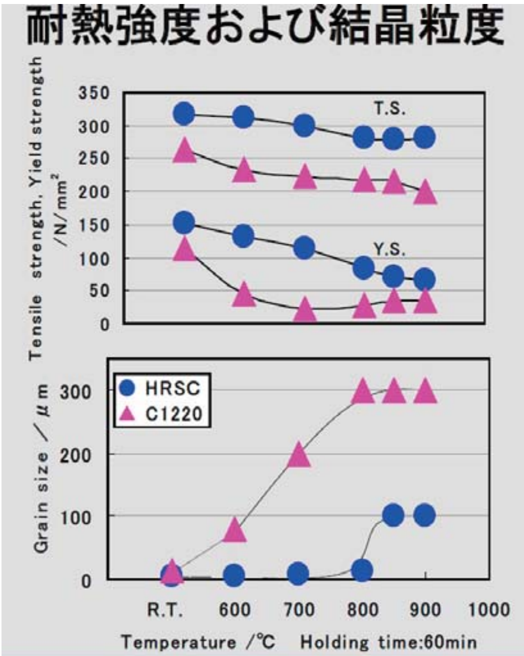

Figure 3: The comparison of the grain size, tensile strength and yield strength for HRSC and OFC at various temperature.

A New FC Material: HRSC

Other than the geometry, a new material (HRSC) has been used for FC. The HRSC is a high heat resistance copper alloy [3], which could maintain a fine grain and high strength during brazing process. Its outstanding physical properties in high temperature make it as an excellent candidate material for FC. Actually, after heating at a temperature of $800\,^{\circ}\mathrm{C}$, the fatigue characteristics of HRSC is about 8 times of the OFC that FC was made initially. During our HRSC prototype brazing process, $750\,^{\circ}\mathrm{C}$ was applied. The choice is based on the weight and balance amount grain size, tensile strength and yiield strength at various temperatures as shown in Fig.3 [4]. The disadvantage of HRSC is its lower electrical conductivity, which is about 80% of OFC. One of the goals of the FC prototype experiment is to compare the performance of FC that made of these two materials.

Totally there are four FC prototypes, as shown in Fig.2, have been made with two kinds of material (HRSC and OFC) shaping into two geometries (Straight slit and Spiral slit). In the following section, the results of measured longitudinal and transverse field will be presented and compared.

MEASUREMENT OF FIELD PROFILES

Longitudinal Field Distribution on Axis

Fig.4 shows the measured longitudinal magnetic field Bz as a function of longitudinal position z on the central axis ($x = y = 0$ mm). There are black, red, blue and green

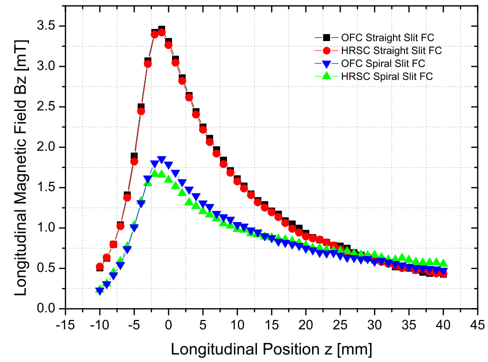

Figure 4: Longitudinal magnetic field Bz as a function of longitudinal position z for four FC prototypes. Black: OFC straight slit FC, red: HRSC straight slit FC, blue: OFC spiral slit FC and green: HRSC spiral slit FC.

lines represent the OFC straight slit FC, HRSC straight slit FC, OFC spiral slit FC and HRSC spiral slit FC respectively. As we can see, with the same input power source, which at this stage is about 6 A, the straight slit FC could produce a peak field that is about 1.75 times higher than the spiral slit FC. The field of straight slit FC increases steeply from 0.5 mT to 3.5 mT in a short distance less than 10 mm, and then reduce to 0.5 mT in distance of 40 mm, which could be characterized by taper parameter. After a rough calculation, the taper parameters for straight slit FC and spiral slit FC equals to 150 /m and 75 /m respectively. In fact, taper parameter is an important parameter that determines the energy acceptance. The smaller the taper parameter is, the larger the energy acceptance will be. The investigation is discussed in paper [1] regarding the distribution that will return higher capture efficiency.

Fig.4 has also shown us that the field distributions are identical for OFC and HRSC in both geometries. Although the HRSC's electric conductivity is only 80% of the OFC's, the measurement has shown negligible differences.

Transverse Field Distribution on Axis

The transverse component of the magnetic field in FC is crucial to achieve high capture efficiency. The transverse magnetic field could flick positrons off the axis causing positron yield reduction. We have measured the transverse magnetic field B_x along the central axis ($x = y = 0$ mm), and the results are presented in Fig.5. There are black, red, blue and green lines represents the OFC straight slit FC, HRSC straight slit FC, OFC spiral slit FC and HRSC spiral slit FC respectively.

The effect of the FC shape on the magnetic field profile could be observed. Straight slit FC produced a much stronger B_x, and it peaked near the FC entrance, then gradually decrease along the longitudinal direction. Whereas spiral slit FC had a weaker B_x. The peak B_x only maintain a short distance before rapidly reducing to nearly zero.

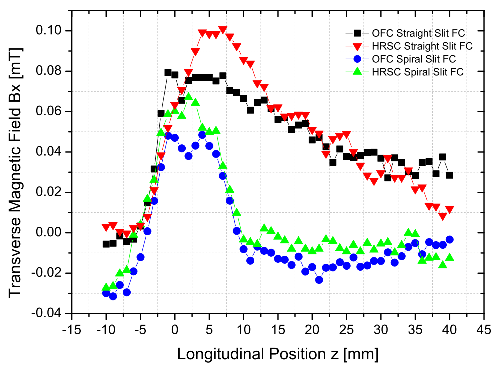

Figure 5: Transverse magnetic field B_x as a function of longitudinal position z for four FC prototypes. Black: OFC straight slit FC, red: HRSC straight slit FC, blue: OFC spiral slit FC and green: HRSC spiral slit FC.

The length of relatively high B_x region will depend on the length of cutting-in edge which is a short straight slot before going into spiral cutting trajectory.

Fig.5 has also shown us the field distribution differences between materials. Both geometries' field measurement results indicate that HRSC FC produce a stronger B_x which is 1.25 times of OFC's.

2D FIELD MAPPING AND FIELD OFFSET

As we have discussed in previous sections, the transverse field could deflect positrons leading to capture efficiency reduction. In general, a perfect cylindrical axial symmetric geometry should have the field center locate in the center of axis, where has the minimal transverse component. However, all of the FC prototypes are sort of asymmetry because of the slit. It is important task to investigate how much the slit affects the field center, and find out the ideal path for positron beam, from where they can suffer the minimal transverse kick.

Straight Slit FC Field Offset

Fig.6 shows the contour plot of the transverse field B_x in the xz plane when $y = 0$ mm. From the figure we can see the strong transverse components in front of the FC entrance with opposite polarity, so that the positrons going through either of them will receive a kick toward to the central axis following a cyclotron motion. Positron's trajectory and radius of cyclotron motion depends on its energy and FC field strength. The transverse field polarity is reversed inside FC, in which case, the transverse field deflects the positron off the central axis. That's one resource of capture efficiency reduction. In order to find out the field center with minimal transverse kick, we integrated the B_x magnitude along z for certain x position. We assumed the position with lowest integration value should be the new field center.

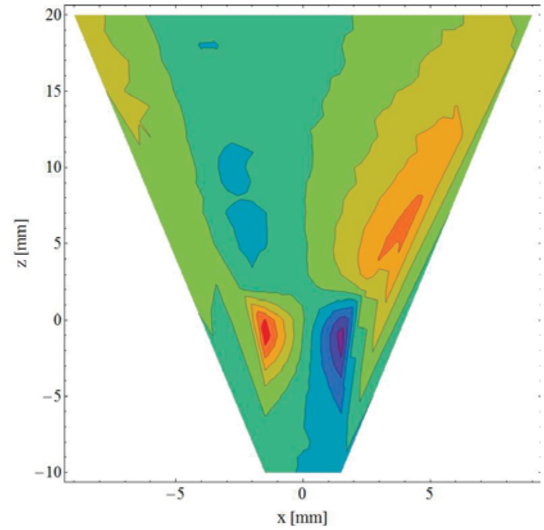

Figure 6: Contour plot of the transverse magnetic field B_x in xz plane for straight slit FC.

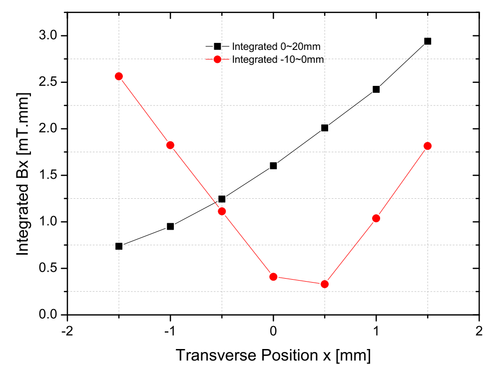

Figure 7: Integrated transverse magnetic field B_x along z for straight slit FC.

The integration results for straight slit FC have been shown in Fig.7. The black curve shows the integration from entrance of FC to 20 mm inside FC, red curve shows the integration from 10 mm ahead to FC entrance. There are few test point have been picked up from $x = -1.5$ mm to $x = 1.5$ mm with a step size of 0.5 mm. From the Fig.7 we can see the transverse field in front of the FC provides strong deflection to a direction pointing to central axis. Inside the FC, the field center is shifted about 1$\sim$2 mm off the axis due to the straight slit.

Spiral Slit FC Field Offset

The same measurement and analysis has been done for spiral slit FC as well which are shown in Fig.8 and Fig.9. Fig.7 shows the similar field distribution near FC entrance. However, inside the FC, thanks to the spiral structure, the magnitude of B_x is relatively small even in the region away from axis. There is nearly no field offset. The strong transverse component is associated with the pole face between

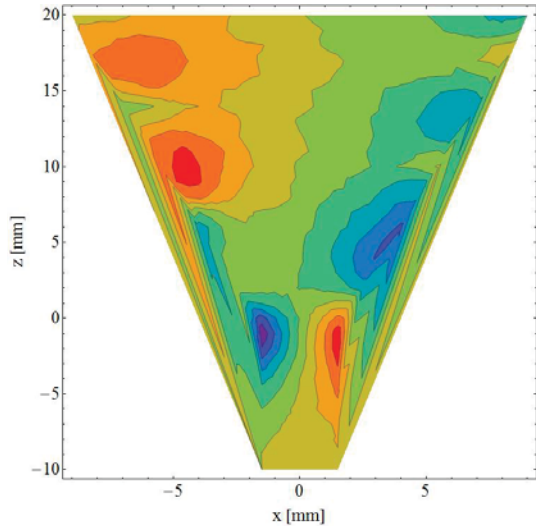

Figure 8: Contour plot of the transverse magnetic field B_x in xz plane for spiral slit FC.

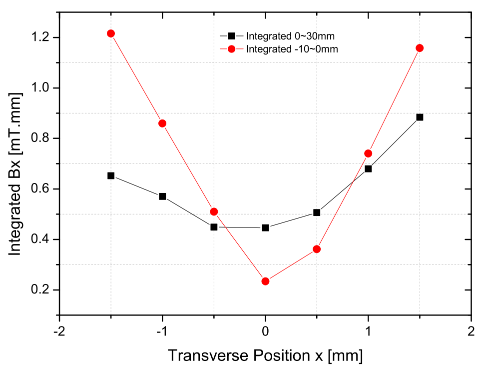

Figure 9: Integrated transverse magnetic field B_x along z for spiral slit FC.

slit gaps near inner surface of FC.

The integrated B_x along z in Fig.9 proved the advantages of applying slit cut to FC that the field shift is well reduced to a negligible level. By comparing the integrated B_x with the straight slit FC, if the positron beam injects into FC on the central axis, the results show a reduction from 1.6 mT·mm to 0.44 mT·mm.

CONCLUSIONS

Four FC prototypes have been successfully manufactured. Each of them represents a unique configuration of geometry and material. After a successful field measurement, the longitudinal and transverse field has been evaluated. By comparing the results from each prototype, we could have a few conclusions. Firstly, straight slit FC produce higher longitudinal field which accompany with high and long lasting transverse field, whereas spiral slit FC's transverse field is lower and effective in a shorter region. The drawback is the relatively low longitudinal field. Secondly, HRSC FC and OFC FC show some identical performance, which let the HRSC be the potential candidate material due to its outstanding physical property in high temperature. And finally, the investigation of the transverse field distribution on the xz plane has shown us that the field offset appear inside straight slit FC is about 1∼2 mm. Comparing to straight slit FC, spiral slit FC's field offset is nearly zero, which lead to the integrated transverse field on the central axis is only about $1/4$ of the straight slit FC.

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