DESIGN METHOD OF A LARGE APERTURE OPPOSITE-FIELD SEPTUM MAGNET

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Abstract

A novel design septum for Japan Proton Accelerator Research Center (J-PARC) delivers high intensity 3GeV proton beam to the 50GeV main ring is presented. The project requires the construction of the large aperture septum to accommodate the large size and high intensity injection beam. As there limitations due to the lattice size and restricted installation space, the septum must provide a large kick angle to the injection beam. Sufficient clearance between the circulating beam and the injection beam is also needed to reduce the beam loss to an acceptable level to avoid the serious radiation problem. To meet these challenging requirements, a large aperture, thin septum, opposite-field septum magnet has been developed. In this paper, we present the detail studies done for the optimization of the magnet, including DC and pulse magnet.

INTRODUCTION

The J-PARC, currently in the installation stage, will be a high beam intensity accelerator project. The space-charge effect of high intensity charged particle beam is very serious. In order to accommodate the high intensity proton beam, large aperture magnets are needed. As for the injection septum magnets, to separate the beam with enough clearance in a limited straight section, which is needed for suppressing the residual radiation, the magnet must has a thin septum and kick the beam with sufficient angle. These high requirements create challenging to the septum design. To deal with these difficulties, a novel, large aperture, opposite field septum magnet has been developed, which is shown in Fig.1. At injection side, the field is doubled by the two sub-bending magnets. On the contrary, for circulating beam the field will be cancelled completely. Detailed information can be found elsewhere [1,2]. The key features of the design are force free structure of septum conductor and easy pulse operation

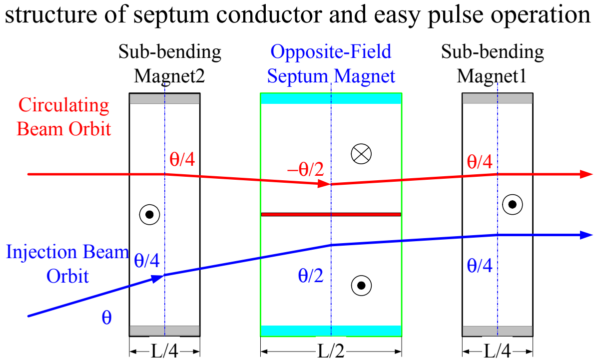

Figure 1: Principle of opposite-field septum magnet.

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MAGNET STRUCTURE

The general 3D view of opposite-field septum is shown in Fig.2. The basic geometry parameters are listed in table1. The two sub-bending magnets are conventional window type dipole magnets. The structure of the opposite-field septum depends on the constraints of vacuum. Concerning the out-gassing of the lamination, the magnet core has to be installed outside of the vacuum chamber, which is shown in Fig. 3. To include the inner cooling pipes, the two septum-conductors are installed vertically to keep a thin thickness. Since the field region is divided into two opposite-field regions along the septum, high order field components can likely appear near the field transition region.

The septum magnet system is divided into 3 sub-magnets, as a result, each sub-magnet becomes shorter and the ratio of magnet gap to magnet length becomes larger. The ratio of gap to length of the opposite-field septum 0.17, while the ration of the sub-bending magnet is two times high. Inevitably, the end field of both magnet core and coil may provide significant contribution, which may contain large high order field components. To eliminate the undesirable high order field, both magnet core structure and coil must be optimized.

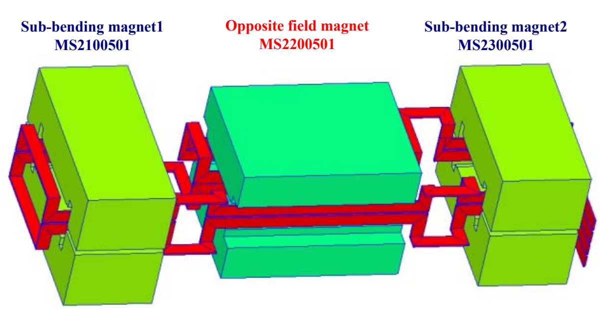

Figure 2: 3D view of the opposite-field septum.

Table 1: Basic parameters of the opposite-field septum

	Sub-bending Magnet1	Opposite field magnet	Sub-bending magnet2
Magnet length	350mm	700mm	350mm
Aperture height	120mm	120mm	120mm
Aperture width	374mm	355mm	272mm

In principle, this septum magnet can works in both DC mode and pulse mode. However, concerning the eddy current effects, the pulse magnet design is different from the DC one.

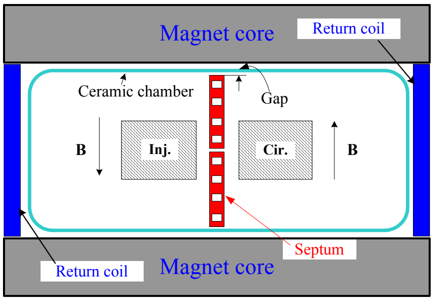

Figure 3: Cross section of opposite-field septum

DC SEPTUM MAGNET DESIGN

Septum Conductor Shape Optimization

Since the septum conductors are installed inside the vacuum chamber, the magnet core and the septum are separated, which causes leakage field at both side of the septum. To eliminate the leakage field, one way is to adjust the current distribution along the vertical position, which can be obtained by optimizing the shape of septum. Taking into account the inner cooling pipes, the septum conductor is optimized by OPERA-2D code. Fig.4 shows the comparison of field distribution at mid-plane with and without septum shape optimization.

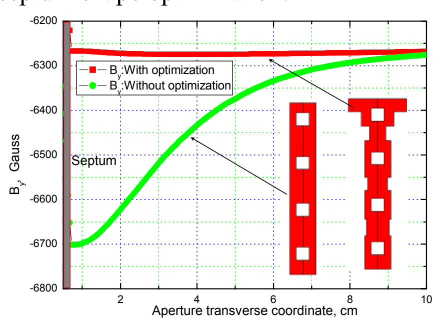

Figure 4: Septum conductor shape optimization

Septum Conductor Length Optimization

Due to the large aperture, the end field of each magnet provides significant contribution. Fig. 5 shows the 3D contour of end-field distribution between the opposite-field septum and the sub-bending magnet.

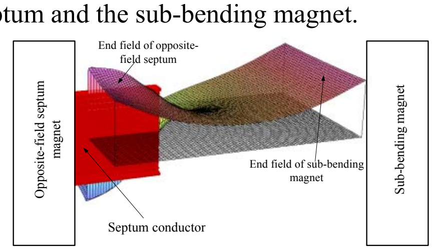

Figure 5: End-field of opposite-field septum magnet

One can find that the end-field of the sub-bending magnet is quite uniform in the useful aperture. However, the end-field of the opposite-field septum, which affects by the length of septum conductor, contains high order field components. Obviously, optimize the length of septum conductor can decrease the high order field components.

Actually, the current distribution on the septum conductor is not uniform, which can be simulated by OPERA-2D. At the middle part, the current distribution along the vertical direction close to uniform, but at the end part the current distribution changes greatly, which is shown in Fig.6.

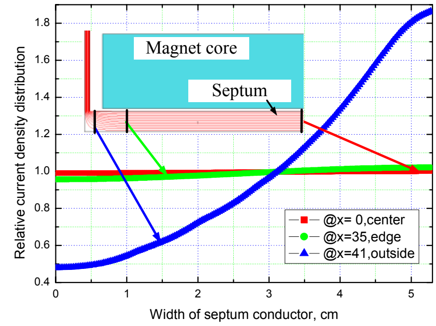

Figure 6: Current distribution in septum conductor

To simulate the septum exactly, the septum conductor is partitioned into many small pieces, in which the current is set depends on its position. Fig.7 illustrates the process. At the middle of septum conductor, where the current distribution closes to uniform, larger partitions are applied (A: 2cm), while at the end part, where the current distribution changes greatly, fine partitions are applied (B: 1cm, C: 0.5cm).

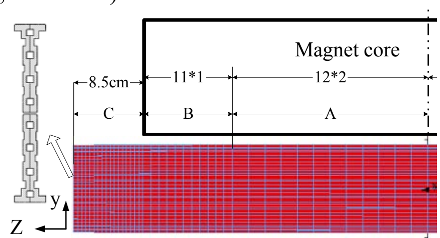

Figure 7: Partitioning of septum conductor

When the length of septum conductor changes from 90cm to 82 cm, the high order components decrease accordingly. Fig. 8 shows the integrated field distribution for circulating beam. If the septum length is 82cm, almost all of the high order field components disappear. The integrated field only contains dipole field, which can be easily compensated by sub-bending magnets.

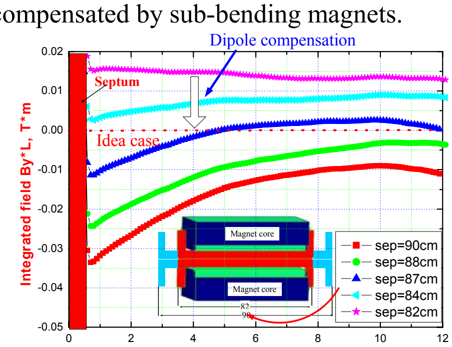

Figure 8: B_y*L with respect to the septum length

Sub-bending Magnet Design

In ideal case, the two sub-bending magnets can produce the same field as that of the opposite-field septum. So the field at the circulating beam side can be cancelled completely. Actually, due to the end-field, the integrated field of the sub-bending magnets is larger. Therefore, to balance the field of the opposite-field septum, the field of sub-bending magnets must be decreased. To this end, the sub-bending magnets are designed with adjustable gap.

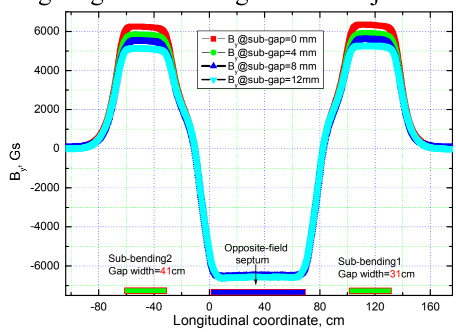

Figure 9: Longitudinal B_y distribution with different sub-bending magnet gap

Fig.8 shows the B_y longitudinal distribution at circulating side with different sub-bending magnet gap. Calculation shows that if the gap height is 9.4mm, the integral field at the center of circulating beam can be cancelled completely.

PULSE SEPTUM MAGNET DESIGN

The most important advantage of the opposite-field septum magnet is easy pulse operation because of the force-free structure septum. However, eddy current effects must be taken into consideration carefully.

Eddy Current Effects on Magnet Core

The power dissipation caused by eddy current on lamination can be suppressed greatly if thin laminated core is employed. However, at the end part, due to the magnetic field components norm to the lamination increase, large eddy-current losses may take place. Usually, cut the end plate and core with many narrow slits can reduce the eddy current losses.

In this septum, however, since the two sub-bending magnets have more ends, their power losses are larger. To balance the eddy current losses, additional power losses have to be introduced to the opposite-field septum, which can be fulfilled by employing a pair of back-leg winding circuits [2].

Eddy Current Effects on Septum Conductor

The eddy-current induced on the septum conductor will redistribute the current distribution and will change the field distribution near the septum. Certainly, shaping the septum conductor can improve the field distribution. In our case, the septum conductor shape was optimized based on the DC operation. If it works in pulse mode, higher order field components appear near septum.

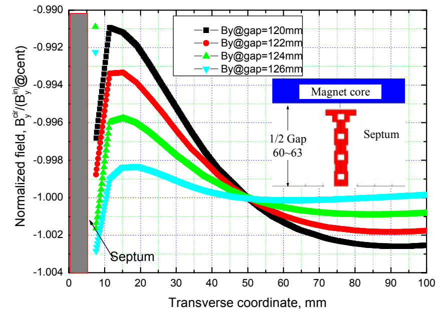

Figure 10: Eddy current effects compensation

Two methods can be used to compensate the eddy-current effect. One is to increase the opposite-field septum magnet gap, which is shown in Fig. 10. another method is tilt the sub-bending magnets [4].

MAGNET MEASUREMENTS

Initial measurements of both point field and integrated field have been performed. Measured data agree with the calculation well. Fig. 11 shows the integrated field distribution without compensation and with two different ways compensation. After compensation, the field uniformity for circulating beam is better than 0.5%.

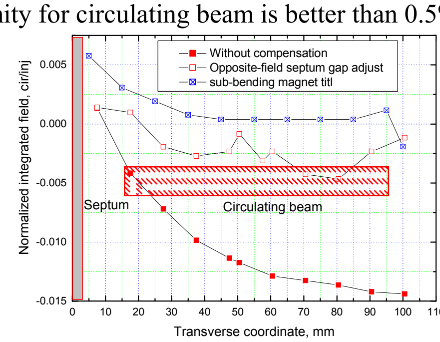

Figure 11: Integrated field distribution before and after compensation

SUMMARY

The opposite-field septum provides a new solution to make a large-aperture, thin-septum, high-field septum magnet. To realize this goal, much detailed calculations and experiments are needed. Further studies are currently underway to improve the performance of the magnet for the J-PARC, which also could be used for other high energy accelerators.

REFERENCES

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[2] A I. Sakai et al, Opposite Field Septum Magnet System for the J-PARC. Main Ring Injection, MT19

[3] Opera 2D/3D manual.

[4] I. Sakai, this proceeding.