DESIGNS OF SEPTUM MAGNETS AT 3-GEV RCS IN J-PARC

M.Yoshimoto#, J.Kamiya, T.Takayanagi, M.Watanabe, O.Takeda, M.Kinsho, Y.Irie,
JAEA/J-PARC, Tokai, Naka, Ibaraki, JAPAN
H.Fujimori, S.Igarasi, H.Nakayama, KEK, Tsukuba, Ibaraki, JAPAN

Abstract

3 GeV RCS (Rapid Cycling Synchrotron) at J-PARC (Japan Proton Accelerator Research Complex) comprises with several septum magnets of different kinds. These include seven septum magnets for the beam injection and extraction at the RCS ring. Design requirements for these magnets often conflicts with efforts to minimize leakage magnetic field. Silicon steel sheets set outside of the septum magnets shield leakage magnetic fields so as to keep proper beam orbits in the ring in most cases. At the divergent duct areas, sufficient spacing is not available for installing thick magnetic shields. Vacuum chambers are made by the magnetic stainless steel to reduce the leakage field without a large shield. Results obtained from 3D field calculations by TOSCA indicate the magnetic leakage field is suppressed down to a few Gauss or less in the present design. In order to prove the field shielding capability of the magnetic stainless steel, a test duct has been assembled to measure the field intensity distribution. The structure was proved effective to diminish leakage magnetic field of the order of 100 Gauss.

INTRODUCTION

There are three main beam lines in the RCS ring [1][2]. The first is the injection line for H- beam into the RCS. The second line is the one to dump the part of the beam with their charge not changed from H^- to H^+ at the charge stripping foil. The third is the extraction line to transport H^+ beam from the RCS. The septum magnets are installed at each of these beam lines in order to separate the circulating beam from the incoming and outgoing beams. There are two to three septum magnets in each beam line because they need to deflect high energy proton beam. The design parameters for all of these septum magnets are summarized in table 1 together with their specifications. These septum magnets have some challenging issues as they are required to realize MW beam in the RCS ring. In this paper, we describe the design goals of the septum magnets at the RCS, and report the recent R&D status.

#yoshimoto.masahiro@jaea.go.jp

DESIGN OF SEPTUM MAGNETS

Requirements for Septum Magnets

The septum magnets of the RCS are required to deflect the high energy proton beam at the local beam ports. In designing the septum magnets, one of the most important requirements is minimization of beam loss at the septum magnet. Thus a DC field to realize a stable high field at the rapid repetition rate, and a large gap size to install a huge vacuum chamber to guarantee a large physical aperture are adopted as fundamental design concepts. However these requirements accompany difficulties in the actual design. One is the large leakage magnetic field outside the septum. The leakage fields form error fields at the ring as a source of the closed orbit distortion (COD). The local error fields have to be kept within a few Gauss-m or less in the integral of the leakage field along the beam orbit.

Field Shielding

In order to reduce the leakage field at the circulating beam orbit, a magnetic shield structure is set between the septum magnet and the vacuum chamber of the ring. The shield is made of laminated silicon steel sheets having an isotropic magnetic permeability. Thus, the magnetic shields reduce leakage magnetic fields effectively.

However three septum magnets, which are installed at the divergent duct in each beam line, do not have sufficient spaces for installing thick magnetic shields. Therefore, the vacuum chambers for the circulating beam near the septum magnets are made of the magnetic stainless steel (K-M36, TOHOKU STEEL Corporation [3]), and the leakage fields penetrating into the ring can be diminished inside the chamber. This magnetic stainless steel vacuum chamber is one of the most challenging technical issues in the septum magnet development. Figure 1 shows the schematic diagram of the injection septum 2, and the divergent duct in the injection line which consists of a titanium chamber inside the septum and magnetic stainless steel chamber outside the septum.

Table 1: The design parameters of septum magnets

	Injection line		Dump line		Extraction line		
	ISEP-1	ISEP-2	DSEP-1	DSEP-2	ESEP-1	ESEP-2	ESEP-3
Deflection angle	9.640deg	4.985deg	8.075eg	8.075deg	2.807deg	6.245deg	7.448deg
Radius of curvature	7726.7mm	7470.2mm	6386.0mm	6386.0mm	18370.5mm	9174.6mm	7726.7mm
Field length	1300.0mm	650.0mm	900.0mm	900.0mm	900.0mm	1000mm	1000mm

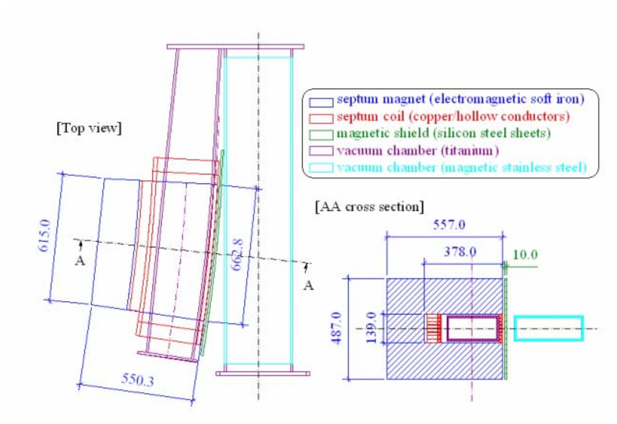


Figure 1: The schematic diagram of the injection septum 2 and the divergent duct in the injection line.

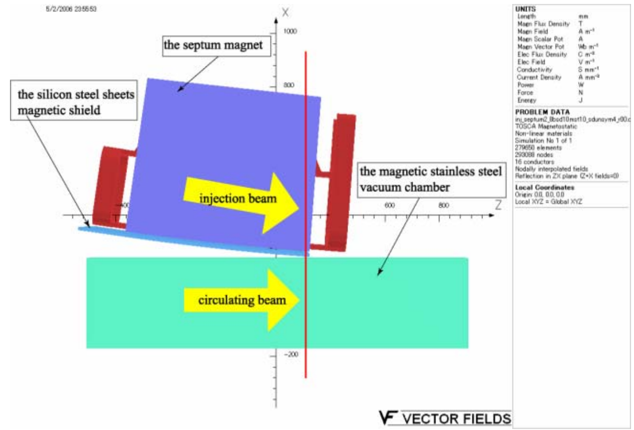


Figure 2: The typical 3D calculation model of the injection septum 2.

3D Field Calculation

In order to optimise the septum design, the magnetic field distributions of not only the main septum but also the leakage component are calculated by the 3-dimensional field analysis code (TOSCA). Figure 2 shows the typical 3D calculation model. Field calculation was performed on the following three conditions: (1) the septum magnet only, (2) the septum magnet with the silicon steel sheets magnetic shield, and (3) the septum magnet with a shield by silicon steel sheets with the magnetic stainless steel vacuum chamber.

Figures 3 show the result of the calculated field distribution along the line intersecting perpendicularly to the circulating beam orbit, which is indicated with the red line in figure 2. Figure 3-(a) shows the field intensity distribution, and figure 3-(b) expands the ordinate to emphasize the leakage fields. In the case of (3), the magnetic shield and the magnetic stainless steel chamber reduce the leakage field to almost zero Gauss.

Figures 4(a) and (b) show the field distribution in the circulating beam chamber. The field distributions along the beam orbit are shown in figure 4-(a), and the BL distributions, which are obtained by integrating each of By distribution in figure 4-(a) are shown in figure 4-(b). With the magnetic shield, peak leakage fields reduce, but the integral fields increase. The leakage field outside the septum can be reduced with the magnetic shield, but the fringing field from the magnet pole are not suppressed because there is no shield near the edge of the septum magnet. However with the magnetic stainless steel vacuum chamber, not only the peak field but also the integral field can be reduced. In the development of the septum magnets, this magnetic shielding structure is effective and adopted to design the vacuum chamber.

FIELD SHIELDING OF THE MAGNETIC STAINLESS STEEL

In order to prove the field shielding capability of the magnetic stainless steel, the test duct has been built to measure the field distribution.

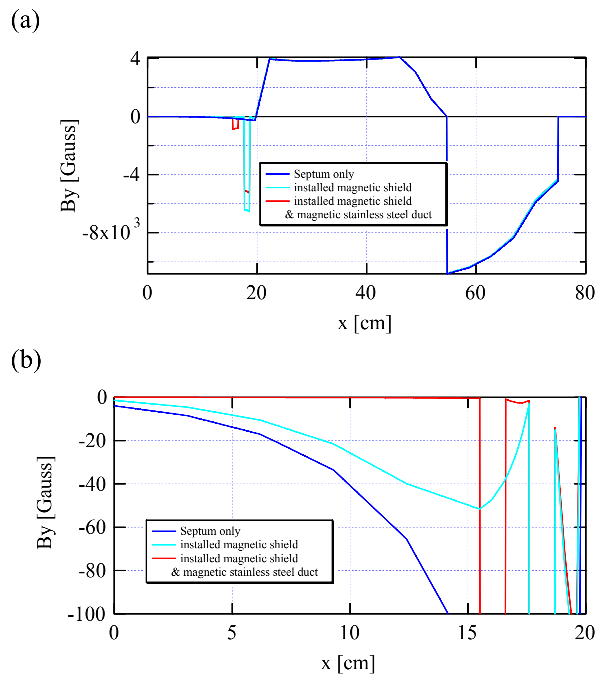


Figure 3: The result of the calculating field distribution along the intersect line with the circulating beam orbit perpendicularly in the position nearest to the septum magnet (refer the red line in the Fig.2).
(a): The field distribution along the all range.
(b): The leakage fields distribution outside the septum.

Figures 5 show the schematic diagram and photograph of the field measurement set-up. A Helmholtz coil was set and the magnetic field of the order of 100 Gauss was generated at the med-plane. Then the test duct was installed at the centre of the Helmholtz coil and the field distribution was measured by a hall probe. Field measurements were carried out with three coil current patterns. The results of the field measurement and 3D calculation are summarized in figure 6. The markers correspond with the measured results and the lines correspond with the calculation results. The blue lines show the field distributions by the Helmholtz coil without the test duct and the red ones show the field distributions in the test duct. It has been experimentally verified that the magnetic field of 125 Gauss can be diminished with the magnetic stainless steel duct.

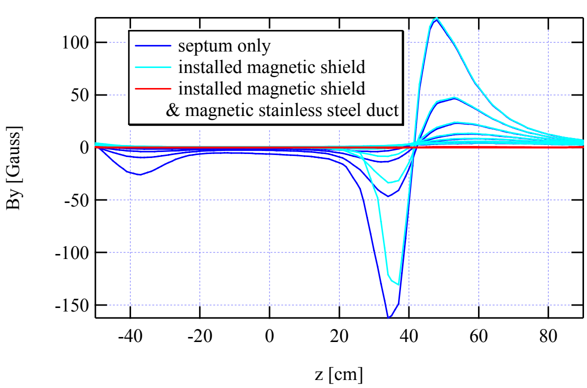
CONCLUSION

In the design of the septum magnets at the RCS, not only the silicon steel sheets magnetic shields but also the magnetic stainless steel vacuum chambers are adopted in order to reduce the leakage magnetic fields outside the septum. The magnetic stainless steel vacuum chamber is one of the key issues to develop septum magnets. Up to now, we prove experimentally that the magnetic stainless steel duct can shield the magnetic field of the order of 100 Gauss. There can be other constraints to realize the vacuum chamber made of magnetic stainless steel, and more R&Ds on this material are underway.

REFERENCES

[1] JAEA/KEK Joint Project Team, KEK Report 2002-13, Jaeri-Tech 2003-044, March 2003.
[2] I.Sakai *et al.*, 2003 PAC, Portland, p.1512.
[3] http://www.tohokusteel.com/

(a)



(b)

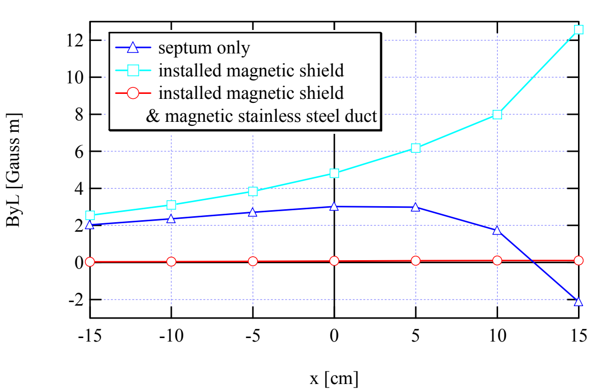
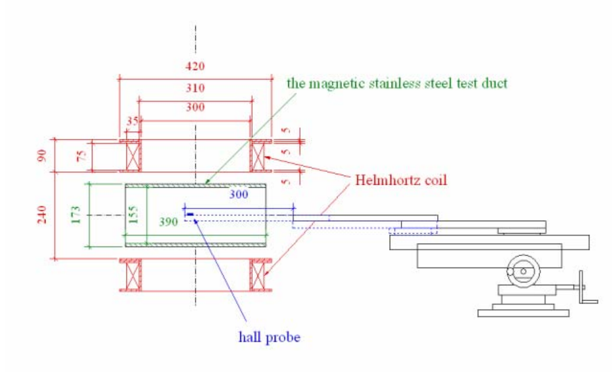


Figure 4: The field distribution in the ring.
(a): The magnetic field distribution.
(b): The integral field distribution.

(a)



(b)

Figure 5: The field measurement set-up with the magnetic stainless steel duct.
(a): The schematic diagram.
(b): The photograph.

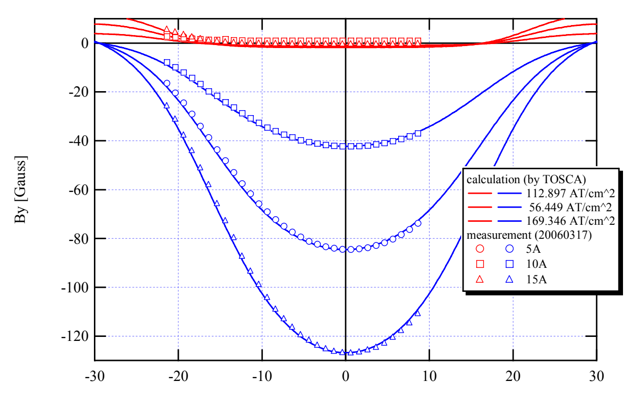


Figure 6: The results of the field measurement and 3D calculation. The blue lines show the field distributions produced by a Helmholtz coil without the test duct and the red lines shows the field distributions in the test duct.