

# DEVELOPMENT OF A HIGH RADIATION RESISTANT SEPTUM FOR JPARC MAIN RING INJECTION SYSTEM

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## Abstract

The J-PARC is a high intensity proton accelerator complex, which consists of a LINAC, a Rapid Cycling Synchrotron (RCS) and a Main Ring (MR). The MR injection system employs a high-field septum to deflect the incoming beam from the RCS, which has been used for the beam commissioning study with low beam intensity successfully. Relative large beam losses in the injection area have been observed, which is proportional to the injection beam intensity. In future, the beam intensity will increase about 100 times to realize high beam power ( $\sim$ MW) operation required from neutrino experiments. The beam loss at the injection region is expected increase greatly due to the space charge effects, which creates severe radiation problems. Since the present injection septum coil is organic insulated, which will be destroyed under such a severe irradiation quickly. To cope with this problem, a new high radiation resistant injection septum magnet is developed, which uses inorganic insulation material (Mineral Insulated Cable - MIC) to prevent the septum from radiation damage. This paper investigates different effects caused by the MIC and gives an optimization design.

## INTRODUCTION

The J-PARC accelerator complex is a high intensity proton beam facility, which consists of a 181 MeV Linac, a 3 GeV rapid cycling synchrotron (RCS) and a 50 GeV main ring (MR). High intensity proton beam is subsequently accelerated via the Linac, the RCS and the MR. The MR injection system employs a high-field septum and a low-field septum to deflect the incoming beam from the 3-50 beam transfer line. The main purpose of the MR is to provide high intensity proton beam for users. In future, the beam power will increase up to 0.75 MW, and the beam intensity can reach about  $4.2 \times 10^{13}$  PPP (8 bunches operation mode). Due to the strong space charge effect, the beam loss is expected very large leading to a severe radiation problem.

Beam commissioning with very low beam intensity ( $\sim 10^{11}$ ) was started from 2008. Relative large beam losses in the injection area and the collimator area have been observed. Fig. 1 compares the beam loss with different beam intensity. It shows that the beam loss is roughly proportional to the injection beam intensity. The beam power is planned to be increased to 0.75 MW within 5 years to meet the requirement from neutrino experiments. Consequently, the beam intensity will increase about 100 times, leading to severe radiation damage to injection system components.

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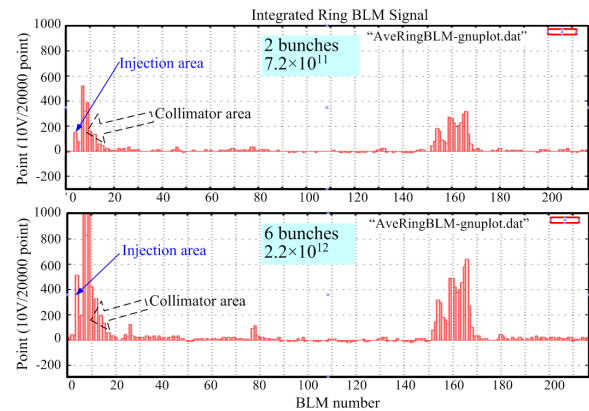


Figure 1: Beam loss distribution at different beam intensity along the ring.

To cope with the severe radiation, the components radiation resistance capability is crucial. However, the coil insulation material of the current using septa is conventional organic material. Its lifetime will be shortened quickly because of the severe radiation damage. Thus, a replacement high radiation resistant septum using Mineral Insulation Cable (MIC) has been proposed.

## SEPTUM COIL

In view of radiation resistant, the most crucial part of a magnet is the coil insulation. Compared with organic insulation material that used for conventional magnet, some inorganic materials such as ceramic has excellent ability of radiation resistant. Table 1 compares the radiation property.

Table 1: Radiation Resistant

Material	Radiation resistant
Epoxy	$>10^7$ Gy
Polyimide	$>10^9$ Gy
Ceramic (MgO)	$>10^{11}$ Gy

A MIC cable uses ceramic material as insulation so that it has extremely high capability of radiation resistant (see Fig. 2). KEK [1,2] and GSI [3] have developed several high radiation resistant magnets based on MIC coil. These magnets are normally DC dipoles or quadrupoles, which field quality do not dependant on coil.

However for a multi-turn septum magnet, the spatial field distribution is heavily dependant on septum coil design. Thus, some strict requirements have to be imposed on the MIC, such as the total MIC dimension, the insulation thickness, the sheath thickness. Since the magnet works in pulse mode, eddy current loss in the sheath needs to be concerned also. Collaborate with

Hitachi cable Company, several MIC pieces with different specifications have been developed for test.

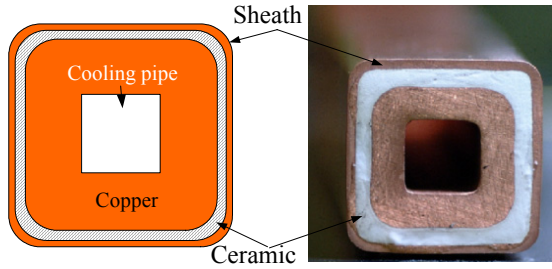


Figure 2: MIC septum coil structure.

### MAGNET DESIGN

#### Magnet aperture and MIC size

The current using injection septum has an acceptance of  $81 \pi \text{mm.mrad}$ . However when the injection beam intensity increases up to  $4.2 \times 10^{13} \text{PPP}$ , the beam halo will become significant occupying a large phase space volume. To accommodate the coming beam include halo without significant beam loss, the new magnet aperture increases to  $120 \pi \text{mm.mrad}$ .

Due to the technology restriction, only square shape MIC can be made. Thus, the total septum thickness, the MIC size and the magnet aperture must be optimized. Compared with conventional kapton insulation, MIC has large insulation thickness between individual conductor inside the septum stack, which will affect the spatial gap field quality. Several schemes have been studied. After optimization, the gap field uniformity can be better than  $10^{-3}$ , which satisfies the requirement from the beam optics study that beam injection without mismatch (see Fig. 3). Table 2 lists some basic parameters.

Table 2: Basic Parameters of Septum Magnet

Gap height	105 mm
Septum thickness	42 mm
Septum structure	4×5 (Hor. ×Ver.)
MIC size	10.5 mm (outer) 0.5 mm (sheath) 0.75 mm (insulation)

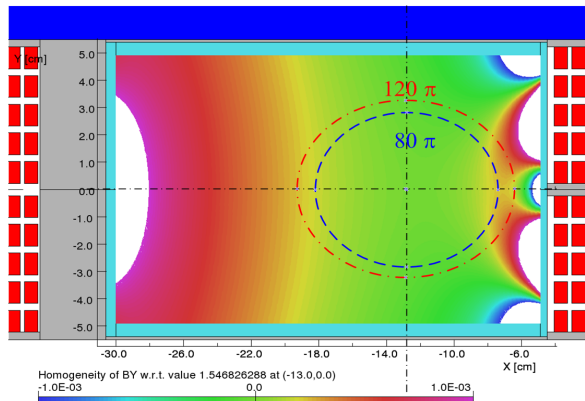


Figure 3: Gap field uniformity.

#### Magnet 3D structure

The new septum will be installed at the same position of the current one. So, the structure does not change much (see Fig. 4). The magnet core turns an angle of  $7^\circ$  at the middle point to deal with the large bending angle of the incoming beam. The circulating beam pipe at downstream is made of iron to guarantee a field free region for the circulating beam. The circulating beam pipe is not shielded at upstream because of the installation of some facilities related to vacuum system.

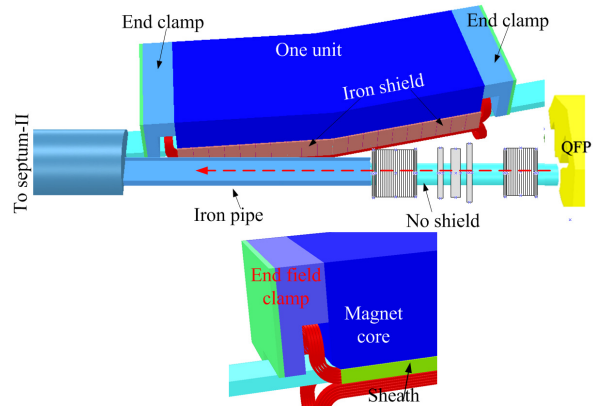


Figure 4: Injection septum-I with end field clamp.

#### End fringe suppression

The magnet has large aperture (both planes) leads to large end fringe field, which contains significant nonlinearities deteriorating the gap field uniformity. To improve the field quality, two end field clamp are installed at each magnet ends as shown in Fig. 4. The gap field integral distribution with and without end field clamp is compared in Fig. 5. Without end field clamp, the gap field contains significant Q field components, which will affect beta function match between the 3-50 BT line and the MR. The end field clamp can improve the uniformity to  $10^{-4}$ .

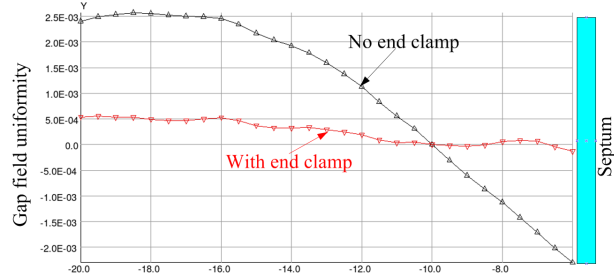


Figure 5: Gap field uniformity improvement by using end field clamp.

#### Leakage field

The leakage field along the circulating beam center is shown in Fig. 6, which indicates clearly that the end fringe field makes the main contribution. Two end field clamps can suppress the leakage field greatly from 0.48 mT.m to 0.055 mT.m.

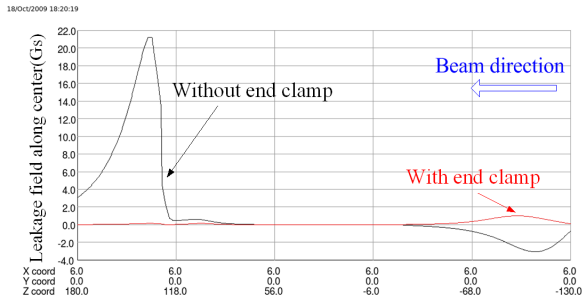


Figure 6: Leakage field suppression by end field clamp.

*End field clamp demerit*

The cost of using end field clamp is the degradation of gap field integral. Fig. 7 compares the gap field longitudinal distribution with and without end field clamp. Using end field clamp, the gap field integral will decrease about 1.6%.

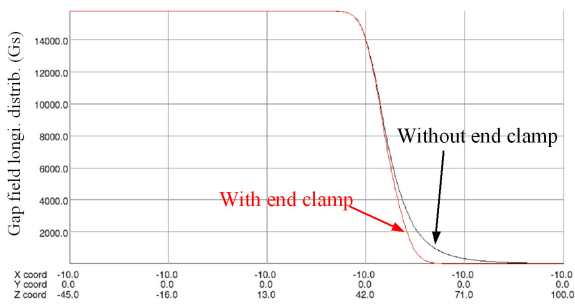


Figure 7: Gap field decrease by end field clamp.

*Eddy current effects*

To realize high beam power operation, the repetition rate of the MR will increase from 0.3 Hz to 1 Hz. Consequently, the eddy current effects will increase significantly. The eddy current induced in the injection beam pipe (SUS) and in the MIC sheath will not only consume energy causing thermal problem but also generate eddy field worsen the field quality. Fig. 8 shows the eddy current distribution in the SUS beam pipe and MIC sheath.

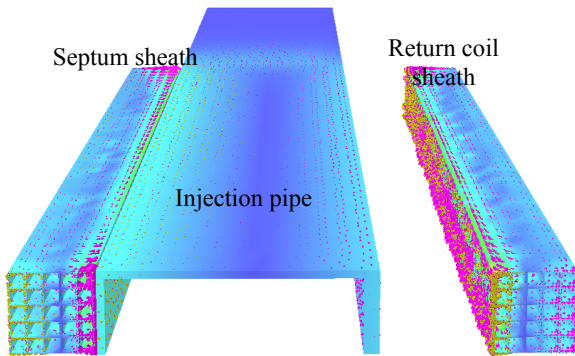


Figure 8: Eddy current distribution. (1/4 magnet)

The gap field top flatness will be deteriorated because the induced eddy field during the rise time of the field. Since the eddy current has long time const of decay, the

eddy field can still affect the top field flatness, which is shown in Fig. 9. The using of end clamp has the benefit that it can compensate the top flatness.

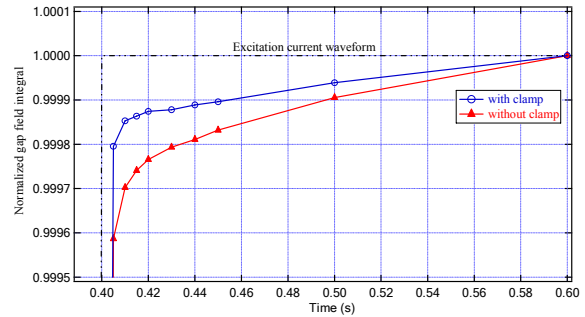


Figure 9: Top field flatness degradation due to eddy current effects.

The eddy current power loss in SUS beam pipe and in MIC sheath needs to be concern also. Fig. 10 compares their power loss. The main power loss is dissipated in the SUS pipe, however the power density of the copper sheath is much higher. So, low conductivity material is preferred to make sheath.

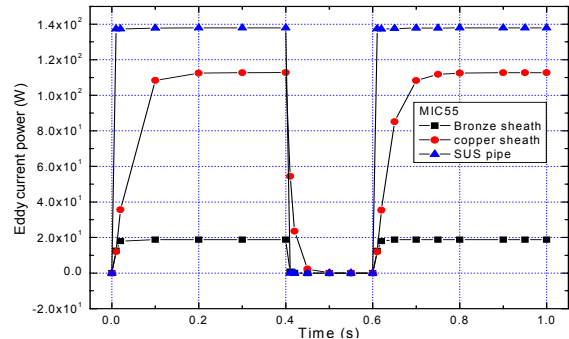


Figure 10: Eddy current power loss comparison.

**CONCLUSIONS**

To operate the JPARC with high beam power in future, the capability of high radiation resistant is crucial for the injection septum. Simulation indicates that the new septum using MIC cable can meet the requirements. Since it is the first trial in the world, a lot of design challenges are expected. Practical fabrication will be started soon.

**REFERENCES**

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