R&D of a Septum Magnet Using MIC coil

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Abstract

The J-PARC that is under construction at JAEA will provide a high-intensity, high-power proton beam for experiments. A high-power beam will inevitably result in serious radiation, particularly at beam injection and extraction area, where the uncontrolled beam loss is large. The fast-extraction abortion system of the 50-GeV main ring comprises kickers and a group of septa, which includes low-field septa SM11/12/21/22 and high-field septa SM30/31/32/33. Since the beam clearance is very narrow at the upstream, the low-field septa coils are ceramic insulated to deal with the severe radiation damage. The high-field septa coils are polyimide insulated. In future when the beam power reaches 0.75 MW, very severe radiation damage is expected due to the high-intensity beam. Among these high-field septa, the SM30 suffers the severest radiation damage. To cope with this problem, a new septum coil using MIC (Mineral Insulated Cable) is proposed. However, the problems arising from the MIC coil are: large leakage field due to the thick insulation thickness, and eddy current effects due to the coil sheath. This study quantitatively investigates these effects and gives the solutions.

1. Introduction

The J-PARC that is under construction at JAEA is a joint project between KEK and JAEA, which comprises a Linac, a 3-GeV RCS and a 50-GeV main ring. The 50-GeV main ring will provide proton beam with power as high as 0.75 MW for different experiments, such as neutrino oscillation experiment and nuclear physics experiment. A high-power, high-intensity proton beam will inevitably result in serious radiation, particularly at beam injection and extraction area, where the beam clearance between the beam and the septum coil is very narrow and the uncontrolled beam loss is very large. The radiation will destroy the insulation material between individual coils and degrade the magnet performance. Thus, very strict requirements are imposed on the design of these septa.

The layout of the 50-GeV ring is shown in Fig. 1. It is a three-fold symmetric lattice, which has three 116.1 m long straight dispersion free sections. The straight sections are used of injection/dump, slow extraction and fast extraction/abortion, respectively. The fast-extraction abortion septa system is designed bipolar in order to deliver the extracted beam and the aborted beam inward and outward of the ring. Fig. 2 shows the septa system. At the upstream of the septa system, the low field septa coils are ceramic insulated to deal with severe radiation damage. The high field septa coils are polyimide insulated. In future, the MR will operate with beam power of 0.75 MW. The uncontrolled beam loss is expected very large, which will creates severe radiation damage to the polyimide coils. Among these high-field septa, the SM30 suffers the severest radiation damage. To cope with this problem, a new septum coil using MIC coil is proposed.

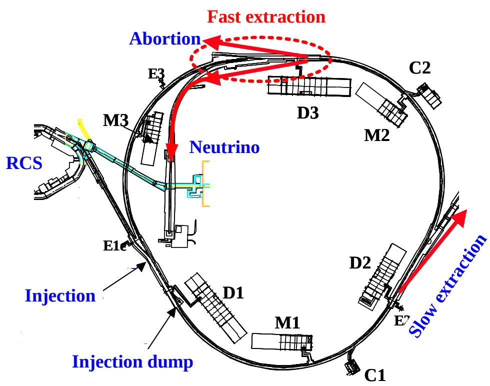

Fig.1 Layout of 50-GeV MR

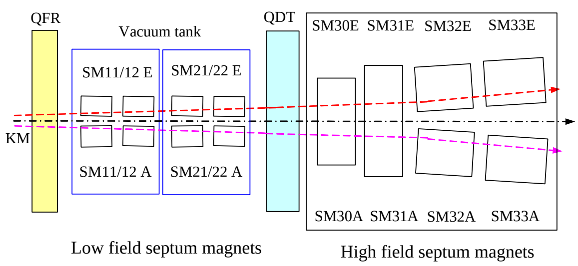

Fig.2 Fast-extraction abortion septa system

2. MIC coil

The cross section of MIC is shown in Fig.3. Ceramic material is filled in the between of the sheath and the conductor. Due to the inorganic insulation material, the

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MIC coil has higher radiation-resistant than the conventional organic insulation material. Table 1 compares the radiation-resistant ability among three different materials.

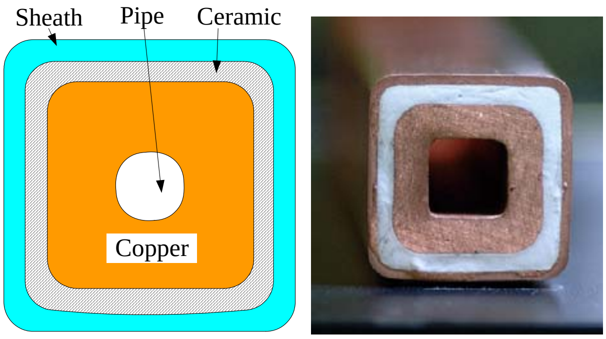

Fig. 3 Cross section of MIC

Table 1: Comparison of radiation resistant

	Organic		Inorganic
Insulation	Epoxy	Polyimide	MgO
Resistant	$>10^7$ Gy	$>10^9$ Gy	$>10^{11}$ Gy

Due to the excellent property of radiation resistance, MIC is widely and successfully used in the design of high radiation resistant magnet in J-PARC[1].

However due to the fabrication technology restriction, MIC has several demerits: the size of MIC cannot be determined precisely, the cross section shape is restricted to square, the insulation thickness cannot be very thin, the metallic sheath may induce eddy current in pulse operation.

The existing MIC magnets are normally DC dipole magnets and Q magnets, whose interesting gap field is determined mainly by the profile of the magnet yoke. The coil size, coil shape and the sheath have little effects on field quality.

For a pulsed septum magnet, using MIC coil may create several problems, such as: the leakage field increases due to the large coil-yoke separation, septum thickness increases due to the thick MIC insulation layer, eddy current effects due to the metallic coil sheath, and cooling difficulties due to the high temperature caused by high current density.

3. SM30 design study

The cross section of the high-field septum SM30 is shown in Fig. 4. It is a bipolar design so that the extracted beam and the aborted beam can go different direction. This geometry has a merit that the leakage field can be partly bypassed by the magnet yoke.

3.1. MIC Insulation thickness effects

The multi-turn septum conductor can be made by brazing individual MIC coils. However, the thick insulation layer, the fabrication and installation errors will increase the separation between the magnet yoke and the septum coil. Consequently, the leakage field increases.

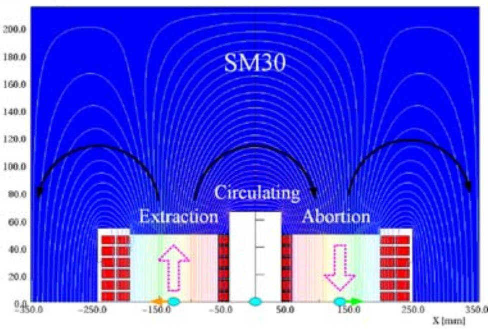

Fig.4 Cross section of SM30

To suppress the leakage field, the circulating beam pipe has to be shielded. Fig. 5 compares the leakage field along the circulating beam orbit with and without shield. The beam pipe can be partly shielded by embedding two 3-mm iron plates in a SUS pipe, or completely shielded by using an iron pipe. In both cases, the leakage field can be decreased greatly.

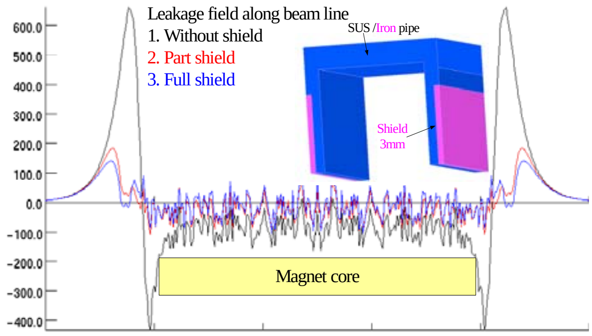

Fig.5 Comparison of leakage field with/without shield

However, the end fringe field is still as high as 150 Gs even with a fully shielded pipe. To suppress the end fringe field more, a thin shield plate can be placed in frond of the magnet yoke as shown in Fig. 6. The end fringe field can be shielded greatly.

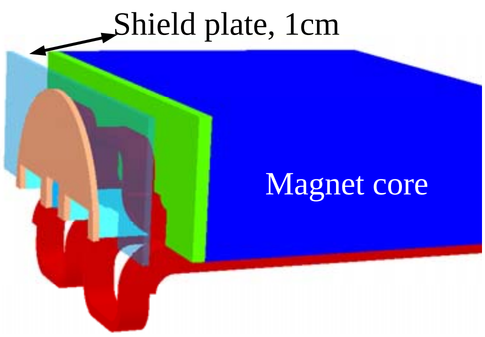

Fig.6 Shield plate to suppress end fringe field

3.2. Eddy current on beam pipe

The septum magnet works in pulse model to escape the thermal problem. The rise time is 1.9 s for 50-GeV operation. During the rise time, the eddy currents will be induced in the beam pipe, which may affect the circulating beam. Since all pipes are electric connected through the flanges, the eddy current can flow between circulating/extraction and circulating/abortion beam pipes, which enhance the leakage field a lot. Fig. 7 shows the eddy current flowing.

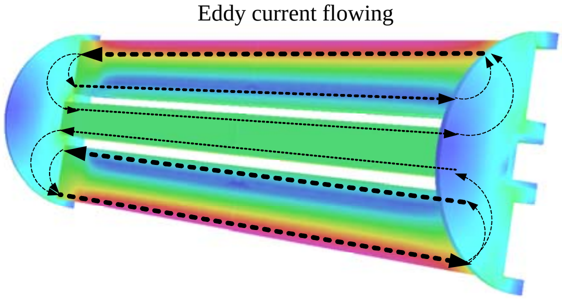

Fig.7 Eddy current flow between pipes

Without shield, the leakage field longitudinal distribution with and without eddy current is compared as shown in Fig. 8. It clearly shows that within the range of beam pipe, the leakage field increases; external of the beam pipe, where no eddy current exist, the end fringe leakage field in two different cases are the same.

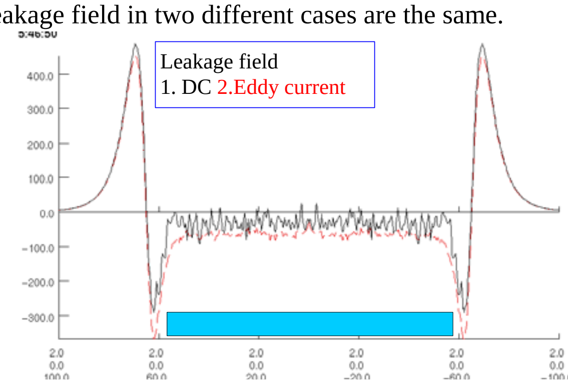

Fig. 8 Comparison of leakage with/without eddy current

When the circulating beam pipe is shielded as shown in Fig. 5, the leakage field integral transverse distribution is almost same in two different cases as shown in Fig.9. It means that the eddy-leakage field can be completely shielded.

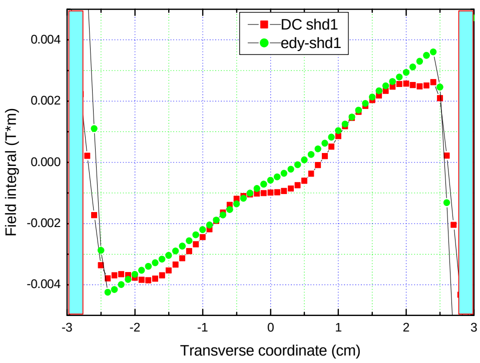

Fig.9 Comparison of leakage field integral after shield

3.3. Eddy current in sheath

Eddy current can be induced in the metallic sheath also. To study its effects on the leakage field, suppose only septum coil is made of MIC. During the rise time, the eddy current generated in sheath is shown in Fig. 10.

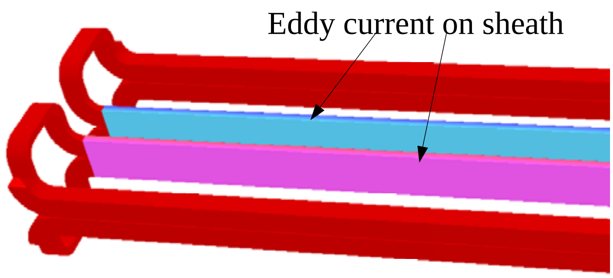

Fig.10 Eddy current in MIC sheath

The Sheath material is assumed to be copper or SUS, Fig. 11 compares the leakage field integral in the three different cases. It clearly indicates that the eddy current in sheath can be neglected no matter it is made of copper or SUS.

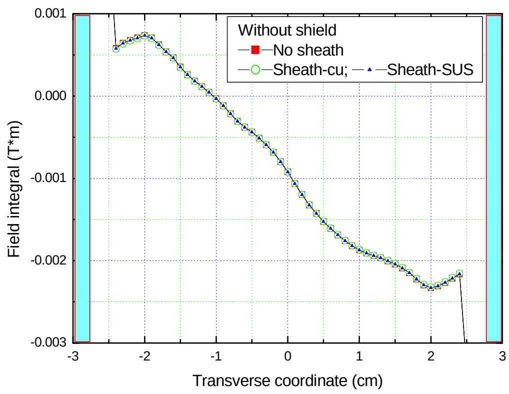

Fig. 11 Leakage field integral in different cases

Summary

The high-field septum SM30 of the fast extraction system will suffer very severe radiation damage in the future high-power beam operation. High radiation resistant septum is needed for the stable operation. Preliminary study shows that it is possible to design such a radiation resistant septum by using MIC coils. The problems arising from the MIC coil can be resolved and the field quality can satisfy the requirement. Detailed studies are needed and experiment will start soon.

Reference

[1] K. H. Tanaka, et al. "Development of radiation resistant magnets for JHF/J-PARC", IEEE Trans on applied superconductivity, Vol. 14, No. 2, June 2004