DESIGN STUDY OF EDDY CURRENT SEPTA FOR JPARC MR FAST EXTRACTION

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Abstract

The present low-field septa of the JPARC main ring fast extraction system are conventional design multi-turn septum magnets. The major problems of the septa are weak mechanical structure, poor gap field uniformity and large leakage field. These defects may have significant effects on high power operation and cause large beam losses. Eddy current septa have been studied to replace the present multi-turn septa. In order to generate sufficient flattop width for the beam extraction, the eddy current septum will be excited by a fundamental sinusoidal pulse with a superimposed third harmonic. The paper will discuss the methods to realize the superposition of third harmonic and to suppress the end fringe field.

INTRODUCTION

The fast extraction (FX) system of the J-PARC main ring is composed of five kicker magnets, four low-field septa (SM11/12, SM21/22) and four high-field septa (SM30/31/32/33). The layout of the septa system is shown in Fig. 1. All septa are design to have bipolar so that the FX system has two functions: normal extraction to the neutrino experimental target and abort extraction to the garbage to protect the superconducting magnets of the neutrino beam line in case of hardware failures.

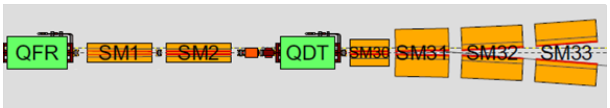

Figure 1: FX septa system

The beam orbit in the septa region is shown in Fig. 2. Due to the limited physical aperture of both the QFR and the QDT, the separation between the extracted beam and the circulating beam orbit is very narrow. Thus the leakage field from the septa will have significant effects on the circulating beam.

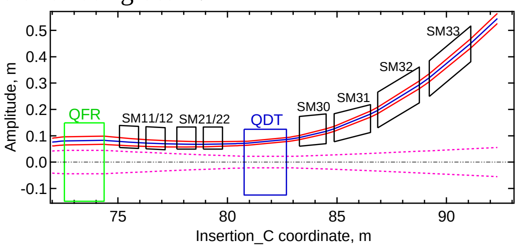

Figure 2: FX orbit in septa region

The system has been operated successfully since 2008. However, several problems involved in the septa of the FX system have been encountered. One of the big problems of the septa is the large leakage. The septa work in pulsed mode having the same excitation pattern as the main dipole. The resulting error fields due to the eddy current impair the circulating beam particularly at the start of acceleration because of the low energy. Fig. 3 shows the beam closed orbit distortion in the both horizontal and vertical direction changes with the excitation of FX septa. At the start of acceleration, the beam orbit changes quickly, which indicates the eddy current effects are predominant.

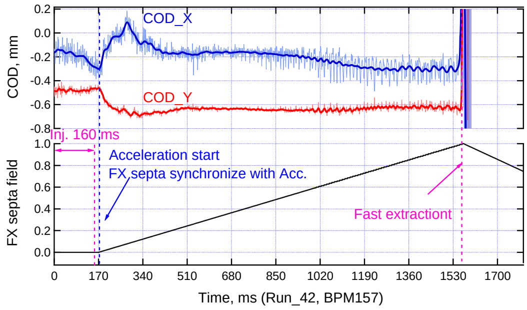

Figure 3: FX septa leakage effects on COD

Some of the FX septa problems have been corrected but some are still remained. To realize high power operation, it is extremely important to keep beam loss within the collimator capacity that is determined by the radio-activation control scenario. However, the remaining problems may lead to severe beam loss becoming road blocks toward high power operation. In addition, several potential problems may arise because of the high repetition rate operation and high beam intensity. Therefore, the entire FX system needs to be upgraded for high power operation. Since the upgrade of FX system involves many elements in the system extensive and further studies are needed. This paper focuses on the low-field septa upgrade only.

LOW-FIELD SEPTA PROBLEMS

The four low-field septa are installed inside two vacuum chambers as shown in Fig. 4. The basic parameters of the septa are summarized in table 1.

Table 1: Basic parameters of low-field septa

	Turns number	Length, m	Current, A	Gap field, T
value	4	0.875	3250	0.23

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Figure 4: Low-field septa in vacuum chambers

The low-field septum is a four turns conventional design septum with two "c" cores opposite each other to generate bipolar dipolar field for both the extraction beam and the abortion beam, respectively.

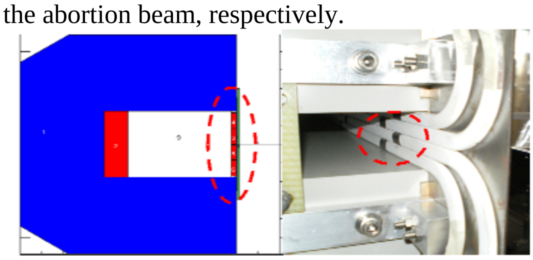


Figure 5: Coil structure of low-field septa (Left half side)

The coils are insulated by a ceramic layer, which is deposited using a plasma deposition. In the original design, the coils were fixed on the iron shield plate by skews insulated by ceramic washers. However, the washers were broken due to the strong electromagnetic force on the coils. An alternative method is fixing the coils on the shield plate using stainless steel ribbon (30μm) as shown in Fig. 5. The thin ribbon restricts the maximum gap field and the highest operational repetition rate because of the weak strength.

NEW LOW-FIELD SEPTUM

General requirements on low-field septa

The new septa will not only replace the present septa but also have capability to provide higher field for orbit optimization. In order to preserve enough space for the upgrade of QFR and QDT in future, the new septa must shorter than the present septa. Due to the narrow beam separation, thinner septum is also required. Fig. 6 shows the arrangement of the new elements and the beam orbit. The new septa enable further studies to optimize the FX beam orbit so that the requirements on high field septa at downstream can be reduced.

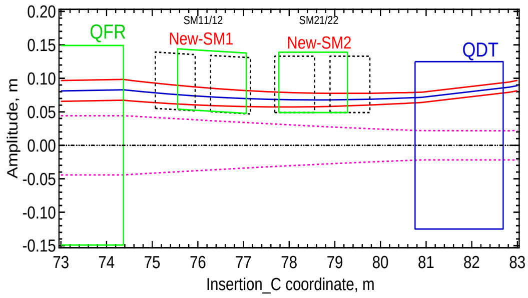


Figure 6: New septa arrangement

Field quality improvement

To satisfy the above requirements, two long eddy current type septum magnets are proposed to replace the present four short septa. The cross section of the eddy current septum magnet is shown in Fig. 7. Compared with the present low-field septum, an eddy current septum has several merits, such as thinner septum thickness, stable mechanical structure, low leakage field and high gap field uniformity. Since the coils are wound at the back-leg region where there is no restrict space limitation, multi-turn coils can be used so that the magnet has the capability to provide higher field.

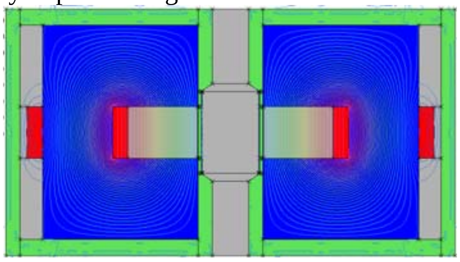


Figure 7: Bipolar eddy current septum

A comparison of the field quality between the proposed eddy current septum and the present septum SM1 is shown in Fig. 8. Eddy current septum can produce much better field uniformity and much lower leakage field. In addition, the eddy current septum is excited at beam extraction energy only, the influence of the leakage field on the 30 GeV beam can be neglected.

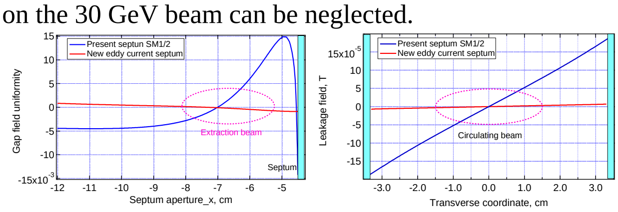


Figure 8 Fields comparison between present/new septum

Flatness of top field

In order to extract 8 bunches from the MR precisely, the septa must provide flat top field (>6 μs) with accuracy of nearly 10^{-4}. If the eddy current septum is excited by a fundmental sinusoidal pulse only, the pulse duration must be longer than 1 ms, which results in thicker septum and worse field uniformity. An alternative way is superimpose a 3rd harmonic to a fundamental sinusoidal pulse, which can reduce the pulse duration and then reduce the septum thickness [1,2]. Fig. 9 shows the principle.

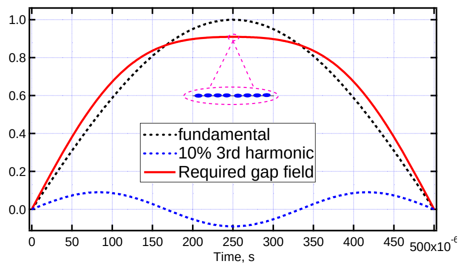
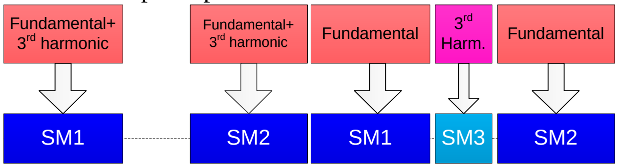


Figure 9: Long flattop field generation

Two methods can be applied to realize the super position of a 3rd harmonic on a fundamental harmonic. One way is super position in pulse generator circuit, and other way is super position in magnetic field. Fig. 10 illustrate the principle.



A: super position in circuit B: super position in field

Figure 10: Realization of superimpose of 3rd harmonic

Super position in magnetic field is easier, but it requires at least three magnets and power supplies in this case. Three magnets not only occupy more space that may required for Q magnet upgrade but also consume more cost. Super position in the pulse generator circuit creates difficulties in the circuit design and waveform adjustment. But it has the advantage of cost effective and can leave more space for Q magnet upgrade in future. So, the study will focus on the second method.

Circuit design

In order to obtain a long flat top, a third harmonic circuit can be added in series or in parallel on the fundamental harmonic circuit. The basic circuit with a parallel L/C resonant circuit is shown in Fig. 11. In the ideal lossless case, the current flowing in the septum (Lm) is given by,

$$i_{sep}(t) = k_1 \sin \omega t + k_2 \sin 3\omega t$$

Where, ω is determined by the inductance L1 and C1. To optimize the third harmonic, it is necessary to adjust the parameters of the inductor L1.

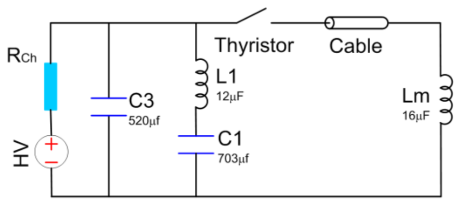


Figure 11: basic circuit.

The excitation current must be stable during the period the extracted beams pass through the septa. To achieve the very high stability and reproducibility, a digital control loop must be applied

Fringe leakage field shield

The new septa are designed with large physical aperture that can accommodate the extracted with 70 πmm.mrad. As a consequence one of the detrimental effects is the large end fringe field that will impair the circulating beam. The septum copper plate extends beyond the magnet ends to help to reduce the end fringe field. In addition, four end field clamps (see Fig. 12)are installed that can reduce the fringe leakage field greatly.

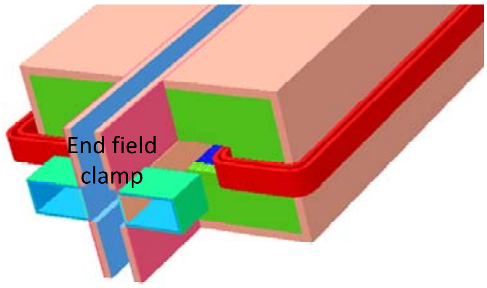


Figure 12: Eddy current with end clamps

Fig. 13 compares the fringe leakage field with and without the end clamps during the acceleration period (t=0.2s), which is predicted by OPERA [3]. Since the leakage field works on the beam with 30 GeV, the effects is negligible small.

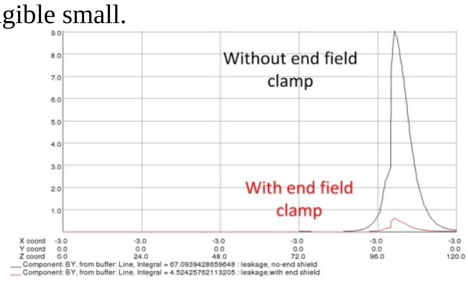


Figure 13: Field comparison

Basic parameters of new septum

The main parameters of the new septum are summarized in table 2.

Table 2: Basic parameters of new septa

Parameters	value	unit
Magnet length	1500	mm
Aperture height	80	mm
Aperture width	120	mm
Septum thickness	7	mm
Maximum field	0.6	T
Maximum charging V	300	V
Pulse duration	500	μs
Flat-top duration	10	μs

SUMMARY

In order to provide high beam power for the neutrino experimental station, high beam intensity injection and high repetition operation are necessary. However, the existing and anticipated problems of the FX system may have significant effects on the high power beam. Upgrade of the FX septa is necessary. The new eddy current septa can not only resolve the present problems but also can deal with the anticipated problems.

REFERENCES

[1] G.H. Schroeder, et al., A novel eddy current septum magnet for sps extraction towards LHC and CNGS.

[2] J.P. Royer, et al., High current with high precision flat-top capacitor discharge power converters for pulsed septum magnets.

[3] Opera user manual, Cobham Ltd.