UPGRADE STUDY OF J-PRAC MAIN RING FAST EXTRACTION SEPTA SYSTEM

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Abstract

The J-PARC main ring (MR) fast extraction (FX) system has two functions: to deliver a high power beam to the neutrino experimental facility and to dump the beam at any time in case of hardware failures. The present FX system consists of five bipolar kickers and eight bipolar septa. In order to raise the beam power to the design limit, both the beam intensity and the repetition rate will increase gradually. The FX system needs to be upgraded to satisfy the new requirements. The upgrade includes FX orbit optimization and new design of devices. Firstly, the conventional multi-turn low-field septa will be replaced by eddy current type septa. Several configurations of the new design have been studied to realize the requirements of thinner septum, higher field quality, lower leakage and higher mechanical stability. To provide sufficient flat top field for the FX beam, superposition of 3rd harmonic pulse will be employed.

INTRODUCTION

The MR lattice takes a 3-fold symmetry, which has three 116.1 m long straight sections. The FX system, located at the third straight section, has two functions: normal beam extraction to the neutrino experimental target, and abort beam extraction to the garbage, when the interlock system is fired. Figure 1 shows the normal FX beam orbit envelope (ε=15 π) and the injection beam (ε=81 π) orbit envelope. The abortion beam orbit is symmetric to the FX beam orbit. The FX system consists of five kicker magnets (K1~5) and eight septa. The septa are divided into two groups, low-field septa (SM11/22) and high-field septa (SM30/31/32/33). In order to realize the two functions of FX and abortion, all the kickers and the septa are designed to be able to generate bipolar magnetic fields.

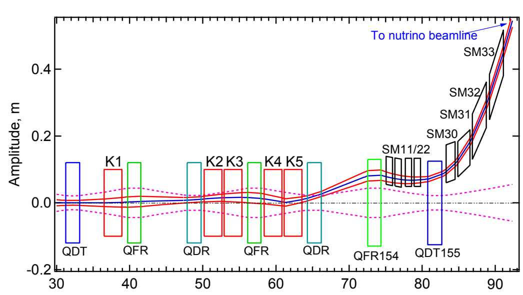

Figure 1: Layout of FX system (Abortion not shown).

The septa work synchronously with the main dipoles so that they can track the beam energy and can abort the beam at arbitrary energy between injection 3 GeV and extraction energy 30 GeV. One resulting problem is the leakage fields of the septa due to the eddy current effects, which impairs the circulating beam particularly at the start of acceleration because of the low energy. Figure 2 shows the beam closed orbit distortion in both the horizontal and vertical direction, changing with respect to the excitation of FX septa. At the start of acceleration, the beam orbit changes quickly, which indicates the eddy current effects are predominant.

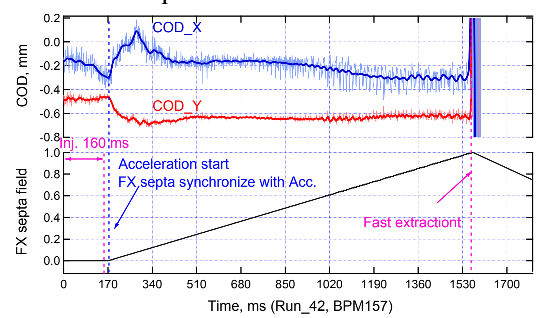

Figure 2: FX septa leakage field effects.

In order to increase the beam power to the design limit, the repetition rate will increase to 1 Hz. The eddy current effects will become severer. In addition, the present FX system cannot work at high repetition rate due to the limitation of its power supply. Therefore, the entire FX system needs to be upgraded for high power operation.

PRESENT SEPTA PROBLEMS

The FX system downstream is shown in Fig. 3. The problems involving FX beam can be classified into 3 different cases: 1) QFR/QDT physical aperture limitation, 2) low-field septa stability, and 3) high field septa leakage field. These problems may become severe in high beam power operation.

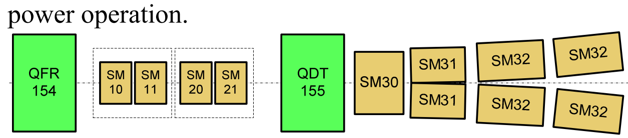

Figure 3: FX system devices downstream.

Q aperture limitation

The original acceptance of Q154 and Q155 was designed for the low intensity and high energy beam of 50 GeV extraction. Figure 4 shows the injection and extraction beam at the Q magnet aperture. The extracted beam orbit is very close to the border of the linear field region of the Q magnet. For low intensity beam with small beam size the physical aperture is enough to accommodate the FX beam without causing beam losses.

However, when the extracted beam energy reduces from 50 GeV to 30 GeV and the beam intensity increases to 4×10^{13} PPP or higher, the extracted beam emittance

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may increase a lot due to the space charge effects, which may exceed the acceptance of the Q magnet.,

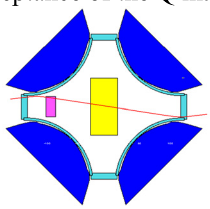

Figure 4: Limitation of Q magnet aperture.

Low field septa

The low-field septum is a four turns conventional design septum with two “c” cores opposite to each other to generate a bipolar dipolar field for both the extraction beam and the abortion beam, respectively. The coils are insulated by a ceramic layer, and are fixed on the shield plate using a stainless steel ribbon (30μm) as shown in Fig. 5. This structure has the defects of low mechanical stability because of the thin ribbon, low field quality and thick septum.

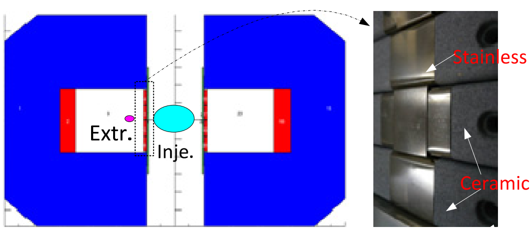

Figure 5: Coil structure of low-field septa.

High field septa

Four high-field septa are congested in a limited space. The 3 different beam pipes of the septa are connected electrically by flanges as shown in Fig. 6. Since the septa are excited by a pulsed current, the electrical connected pipes provide a loop circuit for the induced eddy current, which have bad effects on the field quality.

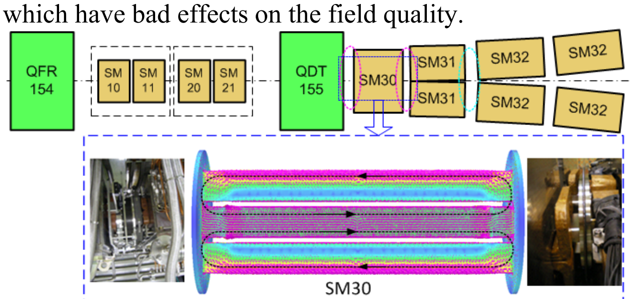

Figure 6: FX septa beam pipe connection.

NEW LOW-FIELD SEPTUM

The upgrade of the FX system involves many elements in the system. Extensive and further studies are needed. First, the low-field septa will be upgraded.

General requirements on low-field septa

The new septa will not only replace the present septa but also have several improvements: 1) capability to provide higher field, 2) higher stability, 3) thinner septum and 4) high field quality. In order to preserve enough space for the upgrade of QFR and QDT in future, the new septa must be shorter than the present ones. Thus the two septa are designed to reduce the total length. Figure 7 shows the arrangement of the new elements and the beam envelope. The new septa enable further studies to optimize the FX beam orbit, which will reduce the requirements on high field septa downstream.

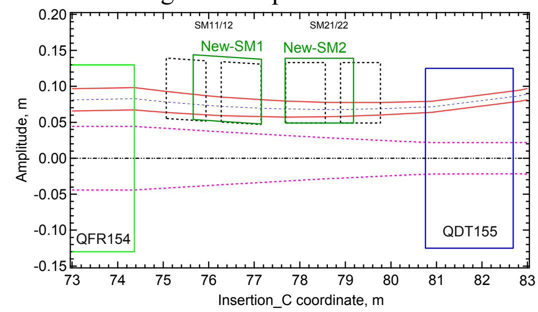

Figure 7: New septa arrangement.

Field quality improvement

Eddy current type septum with fast excitation pulses is selected, which permits thinner passive septum improving the mechanical stability, and reducing the integral leakage field effects. Since the pulse width is about 600 μs, the skin depth of copper is about 2 mm. The septum consists of inner and outer parts to reduce the thickness and to improve the field quality as shown in Fig. 8.

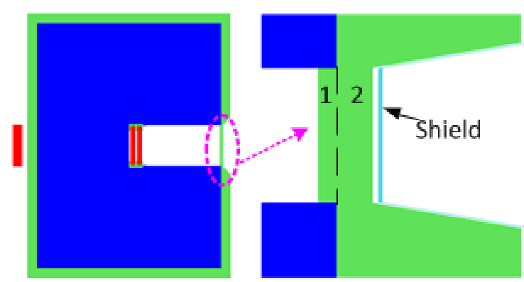

Figure 8: Bipolar eddy current septum.

A comparison of the field quality between the proposed eddy current septum and the present septum SM1 is shown in Fig. 9. 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.

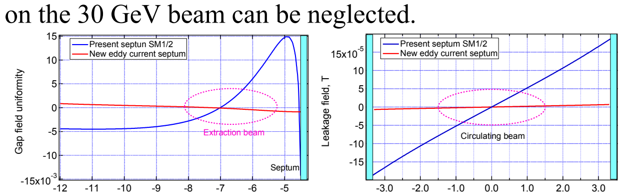

Figure 9: Field comparison between present/new septum.

Fringe leakage field shield

The new septa are designed with a large physical aperture that can accommodate the extracted beam of 70 πmm.mrad. As a consequence one of the detrimental effects is the large end fringe field that will impair the

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circulating beam. The septum copper plate extends beyond the magnet ends to reduce the end fringe field. In addition, an end field clamp (see Fig. 10) is implemented that can reduce the fringe leakage field greatly.

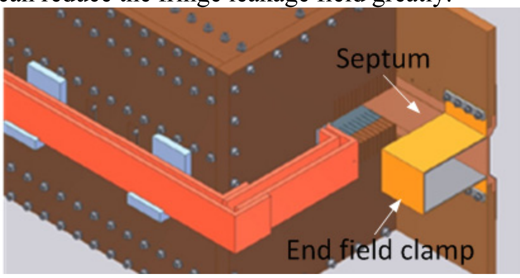

Figure 10: Eddy current with end clamps.

Figure 11 compares the fringe leakage field with and without the end clamps during the acceleration period. Since the leakage field works on the beam of 30 GeV, the effects is negligibly small.

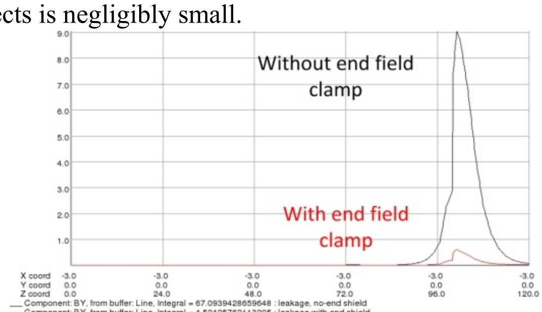

Figure 11: Leakage field comparison.

Flatness of top field

There are 8 bunches spacing by 600 ns in the MR. In order to extract them precisely, the septa must provide a flat top field (>5 μs) with an 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 a thicker septum and worse field uniformity. An alternative way is to superimpose a 3rd harmonic to a fundamental sinusoidal pulse, which can reduce the pulse duration and then reduce the septum thickness [1,2]. Figure 12 shows the principle.

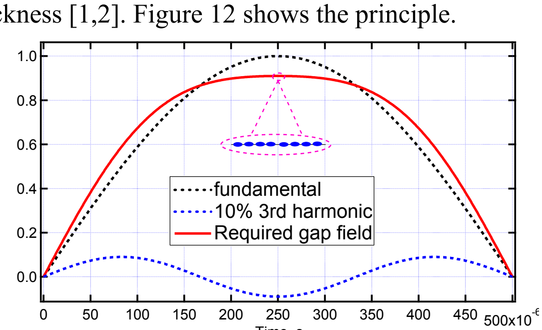

Figure 12: Long flattop field generation.

Circuit design

The basic circuit of the fundamental with a parallel third harmonic L/C resonant circuit is shown in Fig. 13. 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 fundamental inductance L1 and C1. The third harmonic circuit consists of L3 and C3.

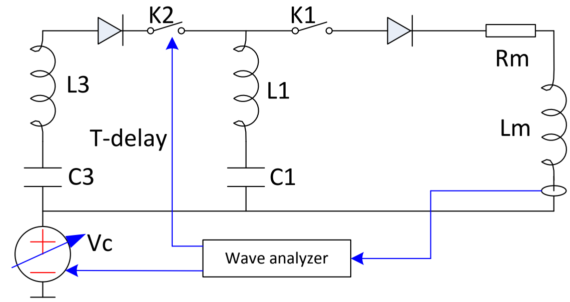

Figure 13: Diagram of 3rd harmonic circuit.

To control the top flatness, the timing of the third harmonic circuit switch K2 is adjusted by the controller. The current reproducibility and the precision of flattop may affected by the variation of circuit parameters, which can be compensated by the time delay of the switch K2 and the charging voltage.

Basic parameters of new septum

The main parameters of the new septum are summarized in Table 1.

Table 1: 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, EPAC 2000.

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

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