UPGRADE STUDY OF J-PARC MAIN RING INJECTION SYSTEM

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Abstract

The J-PARC main ring has the ambitious goal of accelerating proton beam with power of 750 kW. To realize the target, a high performance injection system is crucial. However, several problems due to the imperfect performance of the main elements have been observed in the present injection system, which deteriorate the injection beam orbit and cause beam losses. The problems will become big road blocks to high power operation. Thus, the injection system needs to be upgraded to correct the difficulties. The upgrade includes two new designed septa to reduce the leakage field, an optimized the kicker system to improve the kicker field, and a compensation kicker system to correct the injection errors. Careful 3D electromagnetic field simulations are performed to ensure the accuracy of magnets design. The 3D particle tracks in the entire injection region are studied thoroughly to guarantee the injection beam pass through the injection system without beam loss.

INTRODUCTION

The J-PARC MR injection system consists of two deflecting septum magnets - a high field septum SM1 and a low field septum SM2, four kickers (K1-4) and three bump magnets (BP1~3). The schematic plan view of the injection region is given in Fig. 1.

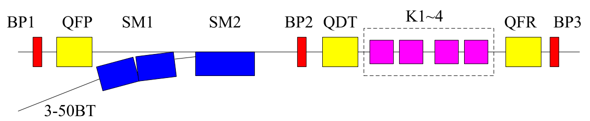

Figure 1: Layout of MR injection system.

The beam to be injected, from the 3-50 BT transport line, passes through two septum magnets with a total deflection angle of 260 mrad, and then the four kicker magnets kick the beam onto the closed orbit with an angle of 8 mrad. A QDT magnet is in the between of the septa and the kicker, which also provide deflection angle to the injection beam and minimize the required strength of the kickers.

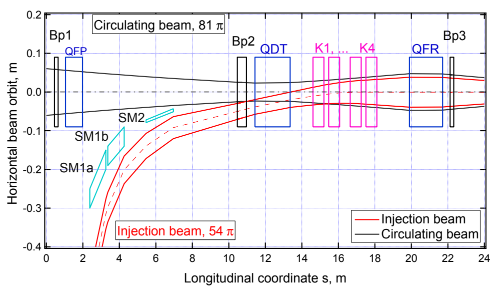

Figure 2: Injection beam orbit.

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From the start of operation many technical problems have been encountered. Some problems have been resolved completely, but some of them are resolved partly [1]. The remaining problems may become worse with the increase of beam intensity and the operation repetition rate, which might become a big roadblock toward the high power operation. Presently, the operation problems involve high field septum, the low field septum and the kicker magnets. The whole system need to be upgraded to realize the high beam power operation.

PROBLEMS NEED TO BE RESOLVED

Injection septum-I

The present injection septum-I has a very large physical aperture, which leads to significant end fringe fields that may interfere the circulating beam. The septum-I consists of two parts SM1a and SM1b as shown in Fig. 3. This configuration makes the situation worse because the downstream part SM1b tilt to the circulating beam line, and its end fringe field can deteriorate the circulating beam significantly.

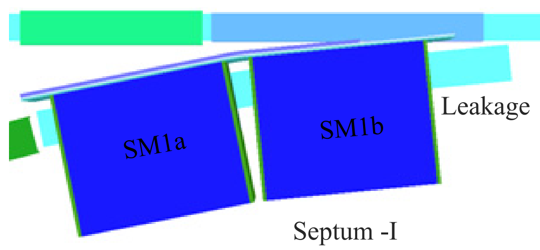

Figure 3: Injection septum-I structure.

Since the septum works in pulse mode, the leakage field is time dependent that modulates the Closed Orbit Distortion (COD) with time as shown in Fig. 4.

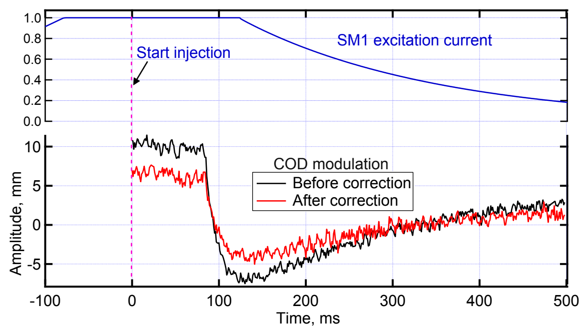

Figure 4: Leakage field effects on COD.

After reinforce the new magnetic shield plates, the leakage field have been reduced to nearly half. It is very difficult to suppress the leakage field effects more because the original design restricts further modification. The leakage field effects on the COD before and after the modification of the septum are compared in Fig. 4. With the increase of repetition rate the leakage field will increase because of the induced eddy current. Therefore its effects on COD become severer and may cause beam loss particularly for high intensity beam with significant beam halo. In addition, the present power supply cannot support the future high repetition operation, which needs to be upgraded also.

Injection septum-II

Due to the narrow beam separation between the injection beam and the circulating beam at the location of the septum-II, an eddy current septum is used. It is powered by a full sine wave current with a period of 600 µs. Two turn coils are selected to reduce the required current of the power supply. Compare the conventional direct drive septum, the septum can be made thinner. The leakage field is reduced greatly by installing a thin magnetic screen in front of the septum as shown in Fig. 5.

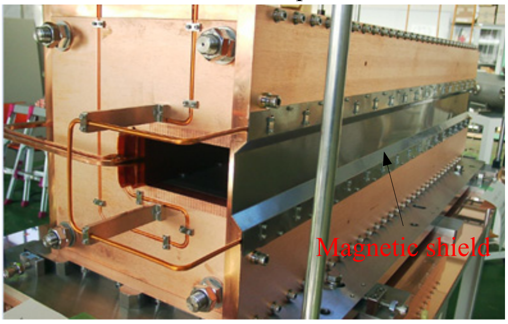

Figure 5: Eddy current septum.

However, the large physical aperture provide considerable end fringe field that can be seen by the circulating beam and causing beam losses. Fig. 6 shows the beam losses recorded by a DCCT monitor during the injection period: the stored beam decrease a little whenever the eddy current septum is fired.

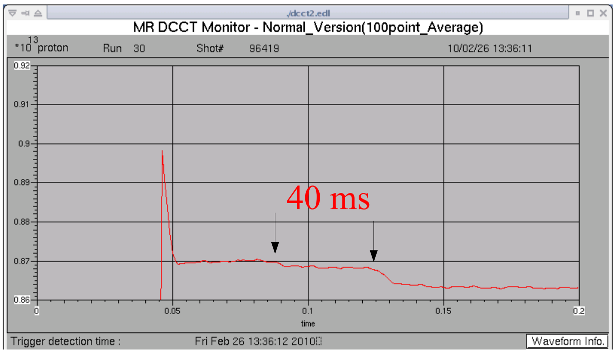

Figure 6: Kicker field waveform.

Kicker system

The MR injection is single-turn injection, which repeats four times to inject 8 bunches to the MR during the injection period. The kicker field must increase from zero to the full during the time interval between the circulating beam and the start of the injection beam, and must be reduced to zero quickly before the subsequent circulating beam come.

The present injection kicker is lumped inductance type, which has simple structure and low cost (Fig. 7). However, the rise time of the field is dependent on the total inductance in the circuit. The total inductance of the present kicker is nearly 1000 nH that might lead to very longer rise time beyond acceptable. Thus, a miss-matching circuit has to be adopted to speed up the rise time to 350 ns, but the reflection field increase. In addition, the present pulsed power supply uses the old big thyratron, which has large conduction impedance at low voltage that enlarge the reflection field about 5%.

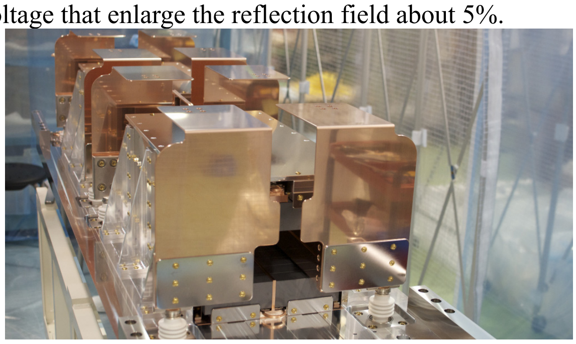

Figure 7: Lumped inductance injection kicker.

The long rise time limits the maximum beam length of the circulating beam 125 ns, which prevent the implementation of the second harmonic cavity to reduce the space charge effects in the high beam power operation. The large tail field can be seen by the previous injection beam and increase that will beam emittance and causing beam losses. Fig. 8 shows the reflection field effects on the circulating beam.

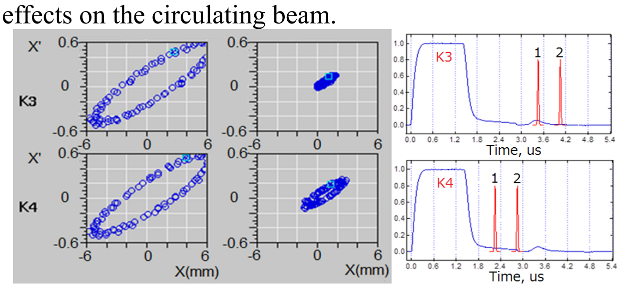

Figure 7: Kicker field waveform.

The matching circuit elements are installed in the air and HV discharge between the end of resistors is a serious problem, which degrades the kicker field waveform and enlarge the deterioration on the beam.

UPGRADE STUDY

In order to increase the beam power to the design limit of 750 kW, both the beam intensity and the repetition rate of the MR must be increased, which calls for the upgrade the injection system. The upgrade includes, design new injection septum magnets, modify the main kicker structure and modify the pulsed power supply. In addition, compensation kickers are being studied in parallel for further improvement the kicker performance.

Injection Septum-I

One of the significant challenges to design a large aperture septum is to reduce the leakage field to avoid affecting the circulating beam. To overcome the problem of the present injection septum, several configuration of the new septum have been studied carefully for optimization. The new septum must parallel to the circulating beam pipe at downstream, which can reduce the penetration of the end fringe field to the circulating beam region. An end fringe field clamp is installed to suppress the leakage field further. Fig. 8 show the structure.

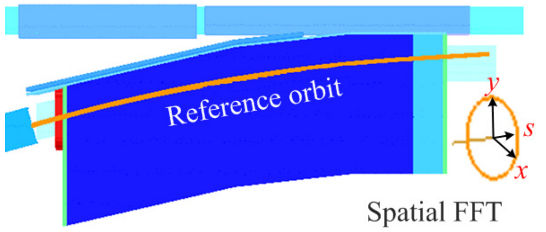

Figure 8: New injection Septum-I Kicker.

Due to the large aperture, the end fringe fields have significant interference on the beam, which can be studied carefully by expending the magnetic field along the reference trajectory to multipoles using spatial Fourier transformation. Fig. 9 shows the multipole field components along the reference injection beam trajectory.

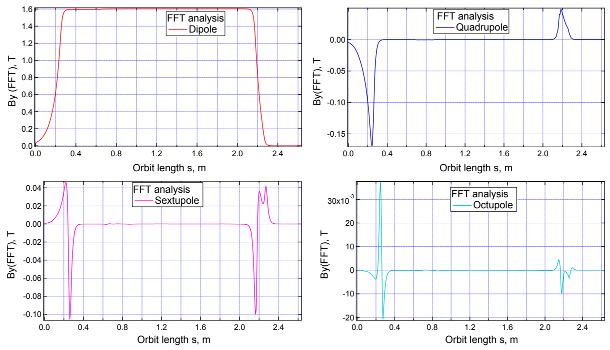

Figure 9: Multi-pole field of septum gap field.

To evaluate the gap field quality, 3D particles can be launched to pass through the septum as shown in Fig. 10. The beam parameters at any location can be obtained by inserting a patch perpendicular to the reference trajectory.

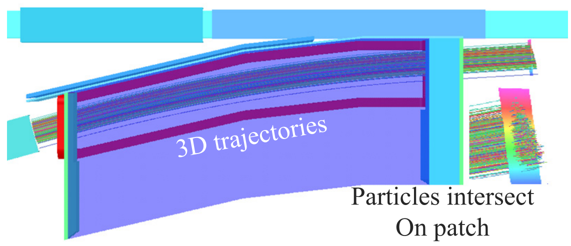

Figure 10: 3D particle trajectories.

Fig. 11 shows the beam parameter at before the entrance of septum and at the exit of the septum.

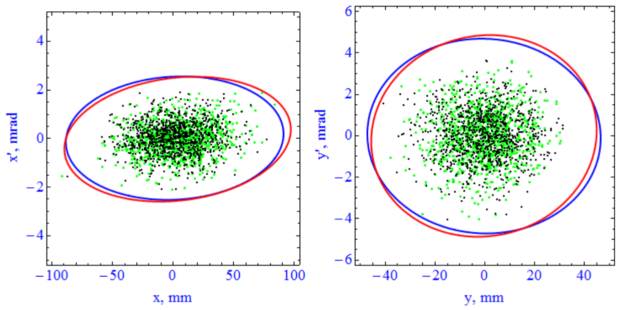

Figure 11: Beam parameters comparison (Blue: entrance, Red: exit).

With the end fringe field clamp, the leakage field can be suppressed to negligible level. Fig. 12 compares the leakage field seen by the circulating beam with and without the end fringe field clamp.

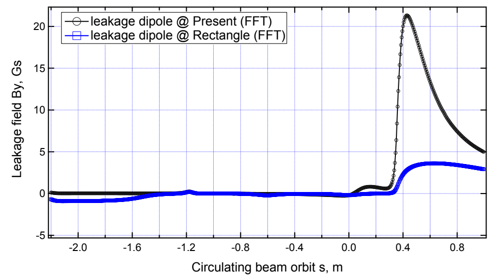

Figure 12: Leakage dipole along circulating beam orbit.

Septum 2

The new eddy current septum has the similar structure as the present one but with several modifications. The excitation pulse width increases from 300 μs to 400 μs to reduce the power supply voltage, and to make it have the ability to generate higher field. The septum consists of 2 parts s shown in Fig. 11 to reduce the effective thickness and to improve the gap field quality.

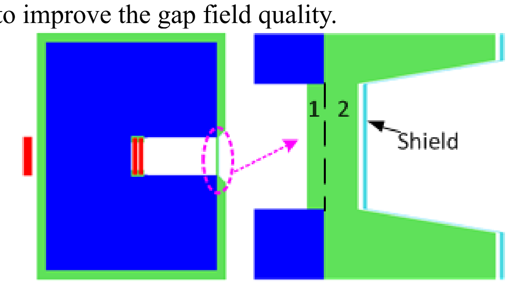

Figure 13: Eddy current septum structure.

Two end fringe clamps can reduce the effects of fringe field on the circulating beam greatly. The circulating beam pipe uses iron to replace the Aluminium pipe can reduce the leakage field further. Fig. 14 shows the end configuration of the new injection septum-II. The two turn coils are insulated using ceramic instead of the present organic materials-kapton so that the radiation resistance increase greatly, which is very important in high beam power operation.

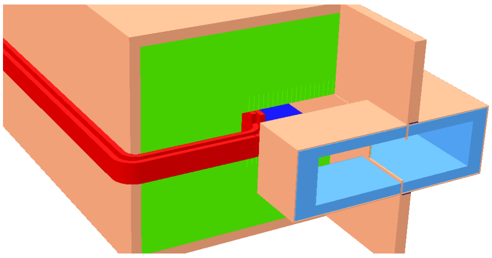

Figure 14: End configuration of new injection septum-II.

The basic parameters of the present septum and the new septum are compared in table. 1

Table 1: Basic parameters of new septa.

Parameters	Present	New
Magnet length, mm	1500	1500
Aperture height, mm	80	80
Septum thickness, mm	10	7
Power voltage, kV	0.6	0.4
Pulse width, µs	300	400
Cir. Beam pipe	Al.	Iron
Insulation	Kapton	Ceramic

Kicker upgrade

The major problems of the kicker system, slow rise speed and large reflection field, are associate with the large self-inductance of the kicker. Serious HV discharge of resistor is because of the ionization of air molecule in the atmosphere. The septum coil structure can be modified so that the matching circuit can be immersed in insulation fluid as shown in Fig. 15. Both the problem of slow rise time and HV discharge can be resolved [2].

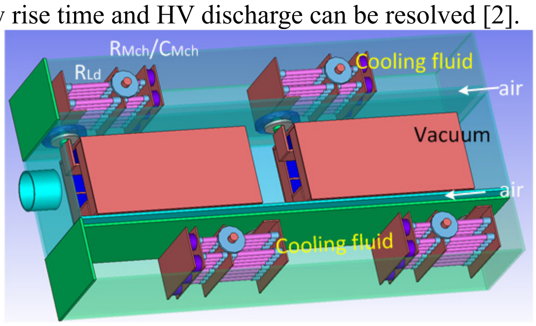

Figure 15: New kicker structure.

The circuit can be modified a little, parallel R_m, to reduce the reflection field as shown in Fig. 16. Experimental result has just been proven to reduce the reflection from 5% to 2%. Further reduction can be realized in principle.

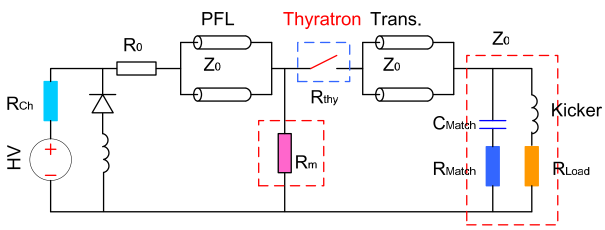

Figure 16: Modification kicker power supply circuit.

Compensation kicker

To improve the kicker performance more, two compensation methods using small compensating kicker are studied. Fig. 17 shows that the exponential slow rise of the kicker excitation current can be speeded up by superimposing a small current pulse, which is generated by a simple LRC circuit in over-damped saturation [3].

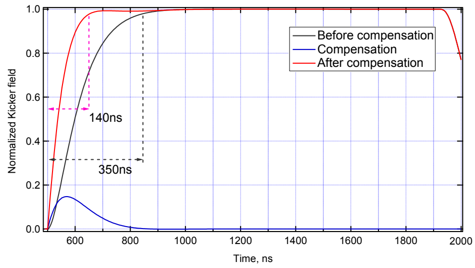

Figure 17: Rise time compensation.

Since the reflection tail field shape is irregular, a fast compensation that can provide an arbitrary waveform is being studied [4]. The kicker is transmission line type using lumped capacitor to make the kicker compact. The structure of the kicker is shown in fig. 18.

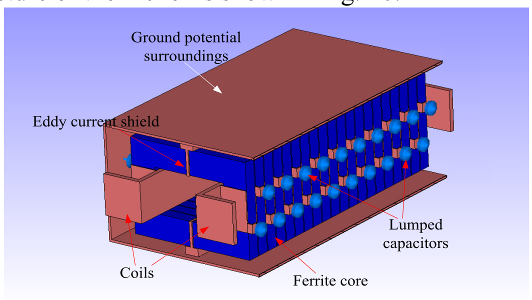

Figure 14: Transmission line compensation kicker.

CLUSION

The upgrade of the whole injection system is being studied. Some of the results have been obtained proving the correct of our prediction. More results will be obtained gradually.

ACKNOWLEDGMENT

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