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# NEW DESIGN OF J-PARC MAIN RING INJECTION SYSTEM FOR HIGH BEAM POWER OPERATION

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*Abstract*

The present J-PARC main ring (MR) injection system has worked for 6 years since 2008, and the performance has been improved a lot by correcting the original design faults. But there are still problems in the existing injection system that affects the daily operation. In order to realize the MR beam power to the design limit, a high performance injection system is crucial. The remaining problems may have severe effects on high intensity beam, and become a big block to the realization of high beam power operation. Thus, upgrade the present injection system to satisfy the demands of high beam power operation is extremely important. The upgrade will redesign injection septa to obtain high performance, which will reduce the leakage field greatly. The kicker rise time will be reduced greatly by optimizing the configuration and using speed-up circuit. A compensation kicker magnet is being studied for reflection tail field cancelation. Careful 3D electromagnetic field simulations and 3D particle tracking are performed to ensure the accuracy of magnets design.

## INTRODUCTION

The J-PARC is a high intensity proton accelerator jointly collaborated by KEK and JAEA. The MR injection system is integrated into one of three long straight sections as shown in Fig. 1. The injection device consists of the 2 magnetic septa (SM1, SM2), four kickers (K1~4) and three bump magnets (BP1-3). A defocusing quadrupole magnet (QDT) is located between the septa and the kickers. The injection beam from the 3 GeV RCS (Rapid Cycling Synchrotron) is deflected by two injection septa with a total deflection angle of 260 mrad at first, and then kicked by the four kicker magnets with an angle of 8 mrad onto the closed orbit.

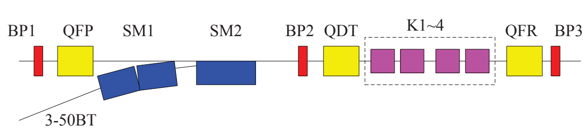


Figure 1: Layout of MR injection system.

In the case of high intensity beam injection, the beam clearance between the circulating beam and the injection beam at the low-field septum SM2 becomes narrow because of large beam envelope due to the strong space charge effects. Thus, a slow dynamic injection bump in the opposite direction is created by the three bump magnets so that the beam clearance can be increased to avoid beam loss. The bump orbit can increase the turn separation from 23 mm to 27 mm at SM2. After injection the bump orbit is turned off. Fig. 2 shows the beam envelope in the injection area without injection bump. The injected beam envelopes is 81 $\pi$mm·mrad and the circulating beam is collimated to 54 $\pi$mm·mrad.

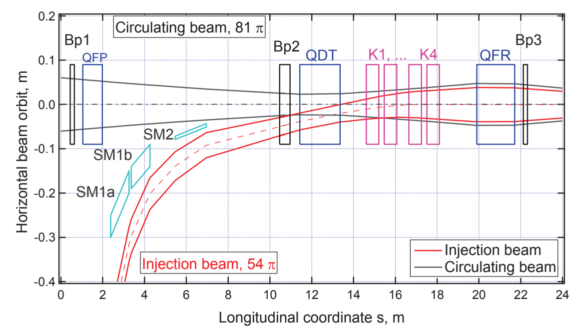


Figure 2: Injection beam orbit.

To improve the injection efficiency and minimize beam losses, the performance of injection devices is critical for obtaining good injection and a good equilibrium orbit of the circulating proton beam. However, many technical problems have been encountered since its start of operation, which relate both septa and kicker magnets. A lot of efforts have been made to improve the performance of the injection system. But there are still some problems have not resolved completely due to the restriction of original design. The remaining problems may become worse in the high beam power operation that might become a big roadblock toward the high power operation.

## NEW DESIGN OF INJECTION SYSTEM

In order to meet the high demands from neutrino experiments, the J-PARC is being upgraded to improve its beam power. The injection beam intensity will increase gradually, and thus the space charge effects become severer. Since the MR needs 0.12 s to accept 8 beam bunches, the beam emittance may grow up quickly during the injection that leads to significant beam losses [1]. To mitigate the space charge effects, one alternative method is to increase the repetition rate of the MR. Consequently, the injection system need to be upgraded to meet the new requirements. One critical issue is to reduce the beam loss to an acceptable limit to prevent the activation of components. Thus, much effort is taken in the upgrade design of injection devices. The upgrade includes: 1) a new designed high-field septum, 2) a new designed low field eddy current septum, and 3) improvement of the existing kicker and new design a compensation kicker.

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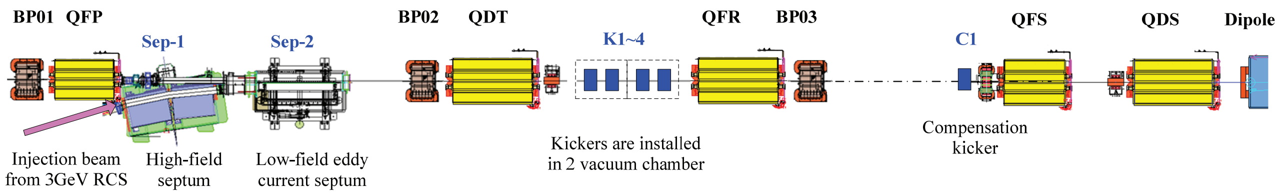


Figure 3: Upgrade of injection system (new design Sep-1, Sep-2 and correction kicker C1; improvement of K1~4 )

## High-Field Injection Septum

The new injection system will accept high intensity beam with significant beam halo due to space charge effects. Thus, new high-field septum must have large physical aperture to accommodate injection beam without beam loss. However, one challenge to design such a large aperture septum is how to reduce the leakage field. To deal with this difficult, several magnet configurations have been studied carefully for optimization. The "sector" type septum is selected as shown in Fig. 4, which consists of 4 parts.

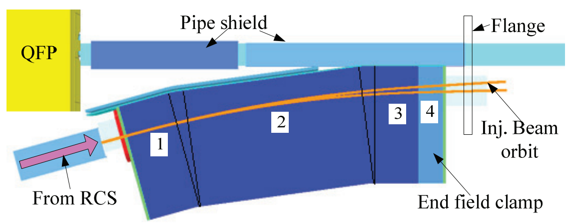


Figure 4: configuration of high-field septum.

Several measures have been taken to suppress the leakage field. At downstream the magnet core parallels to the circulating beam to minimize the penetration of the fringe field to the circulating beam region. An end field clamp is installed to reduce the leakage field further, which is shown in Fig. 5. Compared with the present high-field septum, the new design can suppress the leakage field to negligible level.

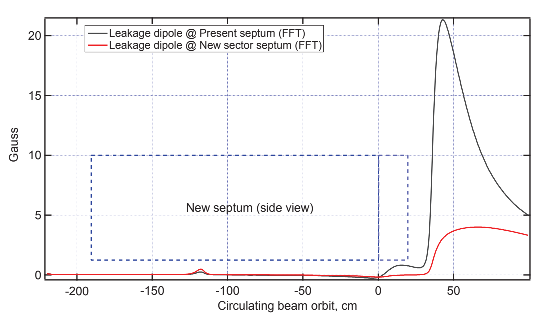


Figure 5: Leakage field comparison.

Due to the large physical aperture, significant nonlinear fields exist in the fringe field. The multipole field components along the reference trajectory can be analyzed using spatial Fourier transformation. To evaluate the effects of the multi-pole field components, 3D particles tracking is studied. Fig. 6 compares the beam parameters before and after passes through different the septum.

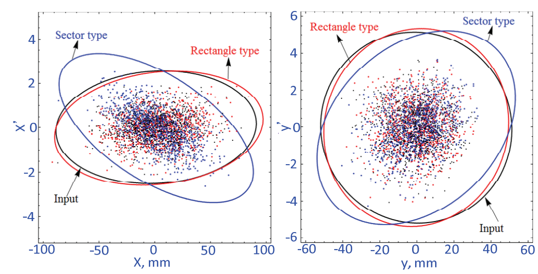


Figure 6: Beam parameters comparison.

## Low-Field Eddy Current Septum

The new injection eddy current septum has the same structure as the existing one, but with several improvements as shown in Fig. 7. The excitation pulse width increases from 300 μs to 400 μs to reduce the power supply voltage. The septum is divided into inner and out parts that can reduce the septum thickness from 10 mm to 7 mm.

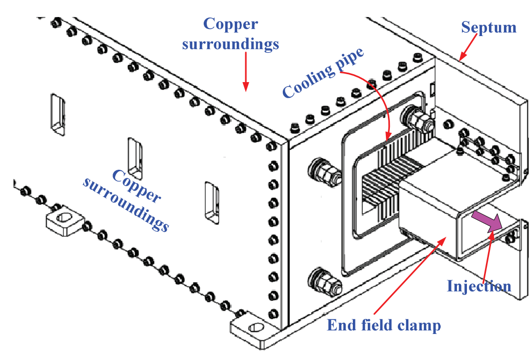


Figure 7: Eddy current injection septum.

Two end fringe clamps are installed to reduce the leakage. The circulating beam pipe uses iron to reduce the leakage field further. The two turn coils are insulated using ceramic so that the radiation resistance increase greatly, which is very important in high beam power operation.

## Main Injection Kickers Speed Up

The original injection kickers were traveling wave type kickers, which had the major problems of significant ringing of kicker field. After the big earthquake, four identical lumped inductance kicker magnets have been designed to replace the old traveling kicker. The ringing of kicker field has been suppressed greatly. However, new problems arise from the new kickers, which includes 1) reflection field at tail due to the mismatching in the circuit, 2) slow rise time due to large total inductance, and

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3) HV discharge in the matching resistors. Since the operation of the new kicker system, the MR has been suffering beam emittance growth and beam losses. A lot of efforts [2,3] have been made to improve the performance, such as development of new resistors to eliminate HV discharge, design new thyratron housing to reduce internal inductance, install a resistor to improve matching in the circuit. After exhausting all of the operational means, the kicker performance improves a lot. But several problems still remain, such as the insufficient thermal capability of the matching resistors and slow rise time, which will limit the ramp-up of the MR beam power to its design goal.

One critical problem is the slow rise speed that will limits the operation in 2nd RF harmonic mode, which is required for high intensity beam injection. A speed-up circuit is implemented to increase the rise speed. The basic circuit is shown in Fig. 8.

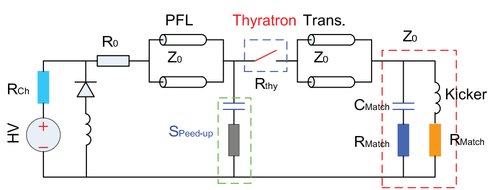

Figure 8: Speed -up circuit.

By optimizing the circuit parameters, the rise time can be reduced from 350 ns to 200 ns. However, the trade-off is the reflection tail field increase as shown in Fig. 9 (Upper part). Two reflection peaks can blow up the beam emittance quickly during the injection period, which must be corrected.

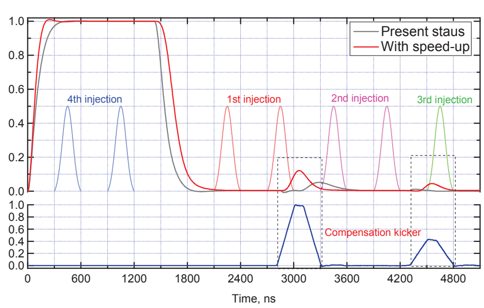

Figure 9: Kicker field and compensation field.

## *Compensation Kicker*

The available space for the compensation kicker magnet is near the end of the long straight section as shown in Fig. 3, which is just after the collimators. The anticipated radiation level will be very high in high beam power operation. Considering worker safety and device survivability, the pulse generator will be located outside the tunnel to reduce worker exposure to radiation and to allow application of solid state devices. Ideally an arbitrary waveform generator is the best choice. However, this option is high cost and effort intensive. Collaboration with BNL, a much simpler circuit (Fig. 10 ) was proposed, which that can generate a trapezoidal waveform to correct the reflection tail field as shown in Fig. 9.

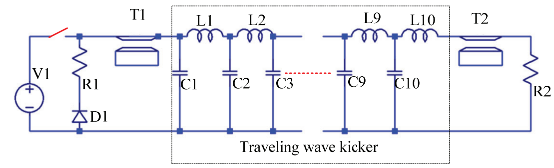

Figure 10: Layout of compensation kicker.

The "C" type kicker with ceramic pipe is selected as the compensation kicker (Fig. 11). The ceramic pipe will separate the vacuum requirements from the high voltage requirements, which is an extremely useful feature that makes further modification and improvement easier.

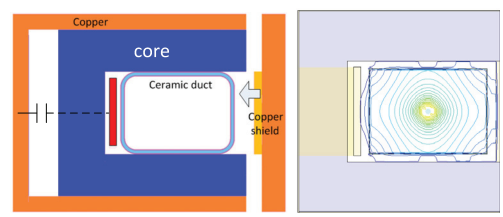

Figure 11: Compensation kicker and beam induced field.

Metal coating is needed to reduce the coupling impedance. Since the compensation kicker field is very fast, the coating thickness is limited to 100 nm. The coupling impedance can be reduced greatly as shown in Fig. 12.

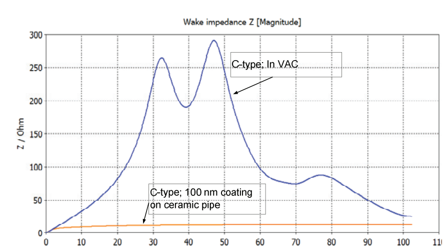

Figure 12: Coupling impedance reduction by coating .

## CONCLUSION

The new injection system not only corrects the existing problems but also has the capability to deal with anticipated difficulties. The new devices are being constructed and will be tested soon.

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