# UPGRADE DESIGN OF INJECTION KICKERS FOR JPARC MAIN RING

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*Abstract*

The JPARC main ring injection kicker system consists of four identical lumped inductance kicker magnets. The system can inject 8 bunches into the ring to fill 9 buckets with spacing of 300 ns. It requires the kickers to produce fast field pulse with rise time less than 300 ns and no reflection. However, the total inductance in the circuit restricts the rise speed of the kicker field. A matching circuit installed in the air is used to reduce the reflection, but it creates a serious problem of high voltage discharge. In order to resolve the existing problem a new structure of kicker magnets has been studied. The new kickers have small self-inductance that can make the kicker field faster and reduce the reflection. To keep the temperature of the matching resistors constant, the new structure enables the matching circuit be installed in a container filled with insulation oil, which not only cools the resistors efficiently but also reduces the risks of HV discharge.

## INTRODUCTION

The J-PARC main ring (MR) injection system comprises two septa (SM1/2), four kickers (K1-4) and three bump magnets (BP1~3), which is shown in Fig. 1. The four lumped inductance type kicker magnets were developed during the period of big earthquake shutdown [1,2]. Lumped inductance kicker has the merits of structure simple and operation stable. But the kicker field waveform is heavily depends on the total inductance in the circuit, particularly the coil self-inductance.

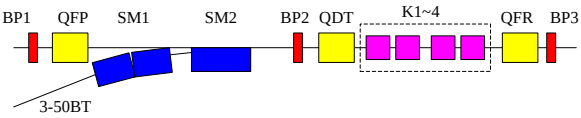


Figure 1: Layout of MR injection system

One big problem of the kicker is that the coil self-inductance is very large, which is about 1100 nH. Large coil inductance results in long rise time of the kicker field. A matching circuit is needed to reduce the reflection caused by the mismatch between the kicker and the transmission cable. However, the matching circuit elements are installed in a matching box filled with air only. This configuration creates another big problem of high voltage discharge in the matching resistors. Potential problems due to high beam intensity and high operation repetition rate in future may arise also.

The injection kickers need to be upgraded to realize high power operation. The upgrade will not only resolve the existing problems but also can deal with the anticipated problems.

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## PROBLEMS NEEDS TO BE RESOLVED

### *Kicker large self-inductance*

The basic circuit is shown in Fig. 2, in which the kicker is represented as an inductor. The kicker current response is heavily dependent on the kicker coil self-inductance. In order to eliminate the reflection due to the mismatch between the kicker coil and the transmission cable, a matching circuit is used which compose of $C_{mch}$, $R_{mch}$ and $R_{ld}$. The actual coil inductance consists of 3 parts LA, L0 and LB as shown in Fig. 3. In view of kicker field generation, LA and LB should be reduced as much as possible.

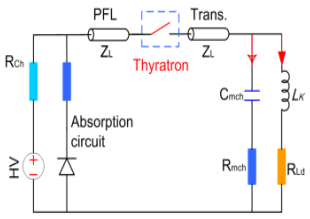



Figure 2: Basic circuit

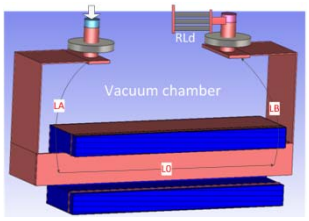



Figure 3: Kicker structure

A perfect matching circuit can be constructed to eliminate the reflection in the kicker field. However, due to the large self-inductance the rise time becomes too long to be acceptable. Currently, the actual inductance is relatively large (1100 nH) and a mismatched circuit had to be adopted. The resulting kicker field waveform (see Fig. 4) has 3 defects (A, B and C) that will cause injection errors.

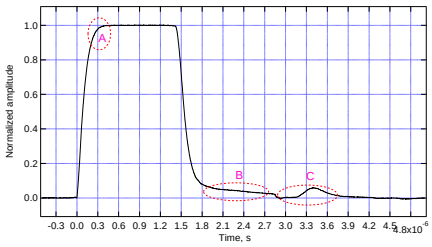



Figure 4: Kicker field waveform

### *High voltage discharge of matching resistor*

The kickers are installed inside the vacuum chamber while the matching resistors are installed in a matching box, which is separated from the vacuum chamber by feed-throughes. In order to protect the vacuum system from contamination in the case of a broken feed through, the matching box is filled with air only.

The voltage across the resistors is about 25 kV, and the total current is about 2.5 A. Fifteen resistors are installed

in parallel to decrease the current density. However, the pipe structure and the rough contact surface of the resistor reduce the effective contact area greatly, which leads to very high "local" current density and high "local" electric field between the resistor and the metal cap. A large number of micro-discharge occurs easily and may damage resistors [3]. Fig. 5 shows the pipe structure of resistors.

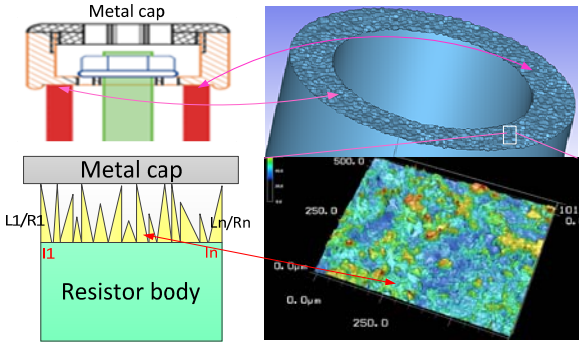



Figure 5: Matching resistor structure

## *High temperature of matching resistors*

The excitation current and the image current will generate significant joule heat in the terminator resistors. Because cooling water can only be installed at earth potential as shown in Fig. 6, the cooling efficiency is relatively low.


Figure 6: Cooling of matching resistor

For long term stable operation the temperature of the matching resistors must keep constant. In practice, however, the operation may stop occasionally and then restart that might change the temperature of the resistor. The resistors' temperature variation will change the circuit parameters, which lead to different kicker angle of subsequent injection beam as shown in Fig. 7.

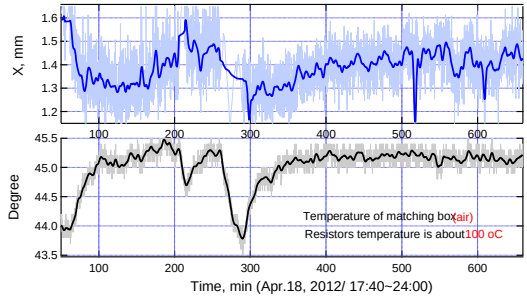



Figure 7: Temperature dependent injection errors

## *Potential high temperature in resistors*

To realize the beam power of 1MW, both operation repetition rate and beam intensity will increase a lot. The heat generated by excitation current increases linearly with the repetition rate, while the image current heat generation depends on beam intensity as shown in Fig. 8. Suppose repetition rate is 1 Hz and beam intensity is $2.6\times10^{13}$ PPP, the resulting heat generation in the resistors is about 420 W and the temperature is expected higher than 200 $^{o}$C, which might break the resistors.

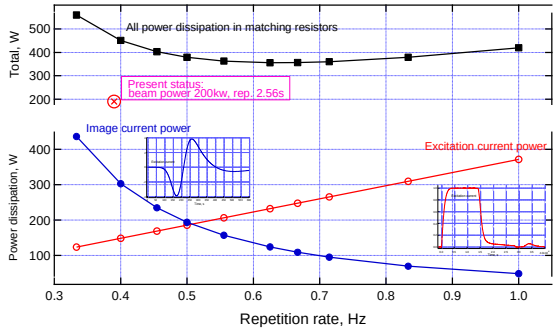



Figure 8: Power dissipation in resistors

## *Potential HV discharge inside kicker*

The present circuit makes the kicker coil maintain high voltage during the beam injection as shown in Fig. 9. For high intensity beam injection beam halo can be large enough to strike the ferrite generating secondary particles. These particles can, in turn, ignite discharge inside the kicker magnet damaging the ferrite core

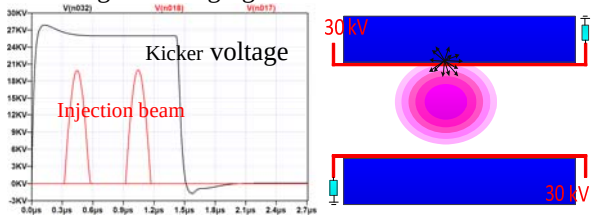



Figure 9: HV discharge inside kicker

# UPGRADE DESIGN

## *Circuit optimization*

If change the kicker and the resistor position, the kicker coil potential becomes high only at the start and at the end of excitation. The kicker can keep earth potential during moment when the injection beam pass though the kicker , which is illustrated in Fig. 10. Therefore, even if high intensity injection beam strikes the ferrite and generate a large number of secondary particles, discharge cannot occur, which protects the kicker.

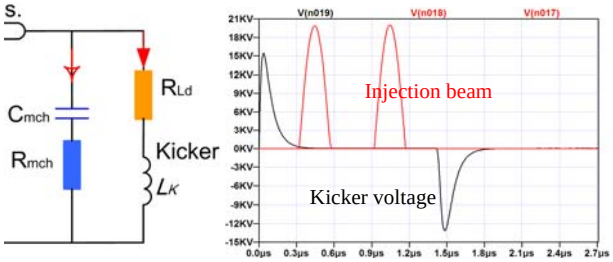



Figure 10: Low potential kicker

### *Structure optimization*

The new circuit enables the coil to connect to ground directly so that the kicker configuration can be optimized to reduce the total inductance. Fig. 11 illustrates the principle.

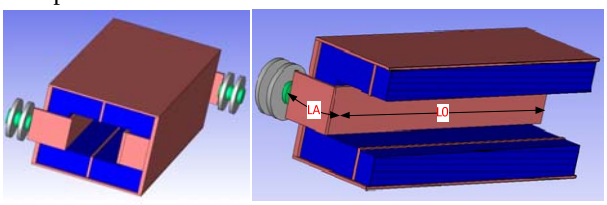
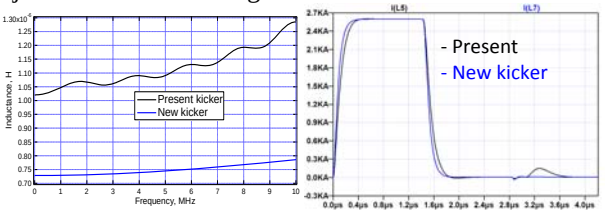



Figure 11: Simple kicker structure.

The total inductance of present kicker can be reduced from 1100 nH to 710 nH. In this case, a perfect matching circuit can be realized to eliminate the reflection while the rise time can also satisfy the requirement of beam injection as shown in Fig. 12.




A: Inductance comparison B: Field wave comparison

Figure 12: Small inductance and resulting kicker field.

### *Cooling efficiency and insulation improvement*

For high beam power operation in the future, the high power dissipation in the matching resistor may increase the temperature in excess of 200 $^{o}$C. So it is necessary to immerse the resistors in the cooling oil. To prevent vacuum system contamination from a break in the feed-through, the kicker magnet system must be modified. The oil container is separated from the vacuum chamber by 2 feed-throughs. Fig. 13 illustrates the principle.

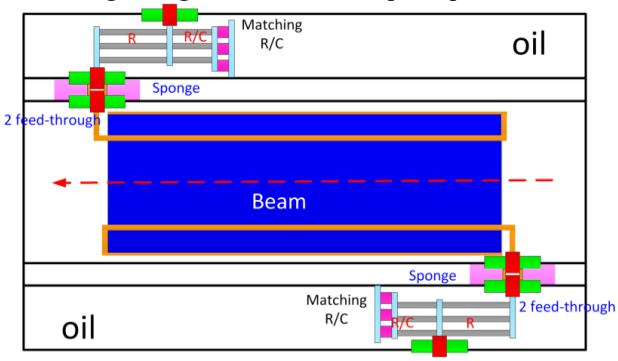



Figure 13: Kicker assembly with cooling fluid.

The insulation cooling fluid (silicone oil, flourinert) not only improves the cooling ability but also helps to reduce the HV discharge of the resistor.

### *Tail biter and speed-up*

To mitigate the strong space charge effects of a high intensity beam, second harmonic cavities are used to flatten and lengthen the beam to reduce the space between bunches. Narrow bunch spacing requires even faster kicker field beyond what the present kicker can provid

We cannot improve the rise time by reducing the kicker inductance further because of the restriction of the kicker power supply. One solution is using a speed-up circuit ($C_{acc}$/$R_{acc}$) and a tail bite circuit (Sw2)which, together, can generate required kicker field as shown in Fig. 14.

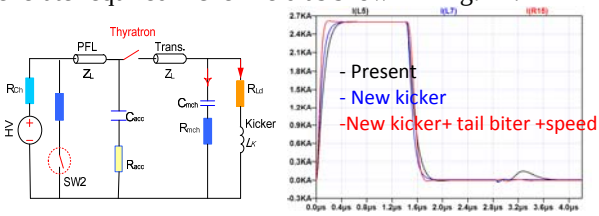



Figure 14: Speed-up and tail biter circuit.

### *Coupling impedance reduction*

For future high-intensity beam operation, beam-coupling impedance of the kicker is an important parameter. The new simple kicker structure reduces the coupling impedance significantly. Fig. 15 compares the longitudinal coupling impedance.

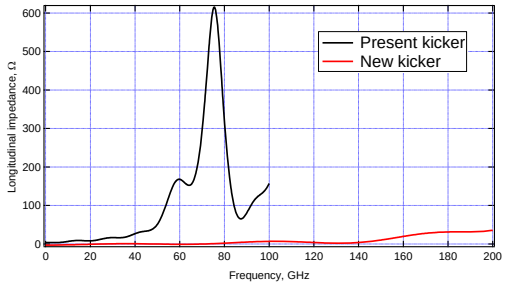



Figure 15: Longitudinal coupling impedance comparison

### *Kicker pulse generator upgrade*

The stray inductance in the pulse generator needs to be minimized also. New thyratron and its housing structure will be redesigned. The absorber circuit will be modified also to reduce the stray inductance.

## SUMMARY

The biggest problem in the present injection system is the kicker magnets that might be a big road block to high power operation. To realize full power operation of the J-PARC main ring the injection system needs to be upgrade. In addition to the corrective actions on the existing problems, we need to develop new technologies to deal with the potential problems of high power operation.

## REFERENCES

[1] K. Fan, et al., “Design study of lumped injection kickers for JPARC main ring,” PASJ 11.

[2] K. Fan, et al., “Design and test of injection kickers for JPARC main ring,” IPAC12.

[3] T. Sugimoto, et al., “Performance of the Injection Kicker Magnet for the J-PARC Main Ring,” This proceedings.