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.

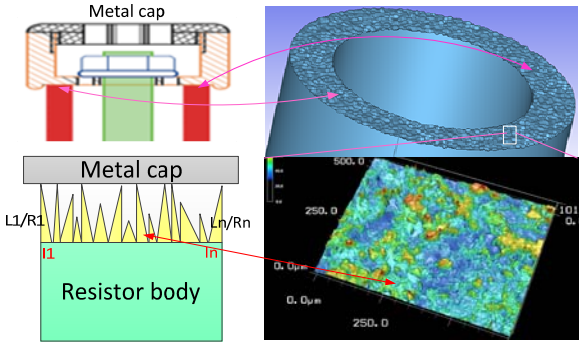


Figure 5: Matching resistor structure

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.

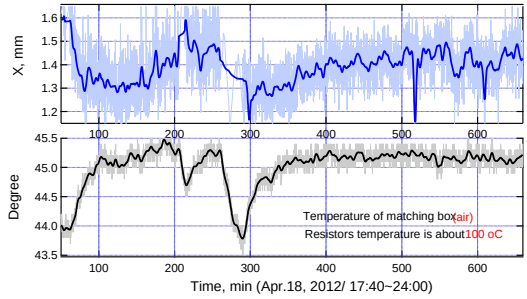


Figure 7: Temperature dependent injection errors

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 2.6×10^{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.

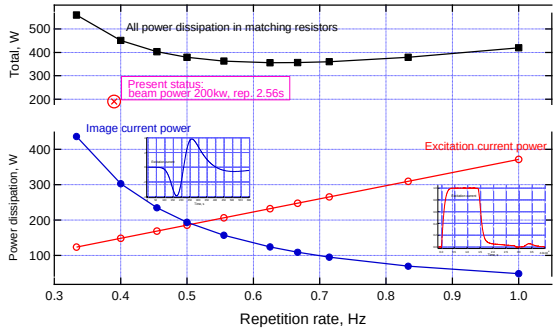


Figure 8: Power dissipation in resistors

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

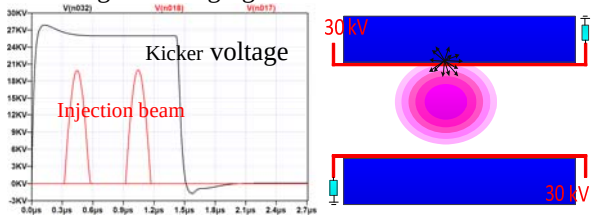


Figure 9: HV discharge inside kicker

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.

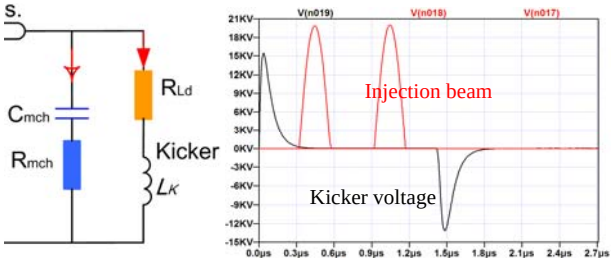


Figure 10: Low potential kicker

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.

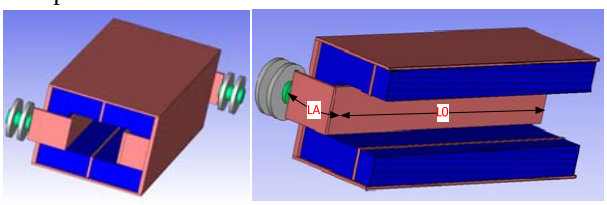
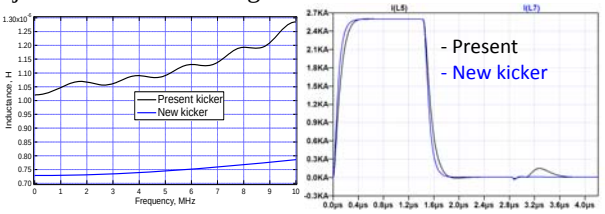


Figure 11: Simple kicker structure.

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.

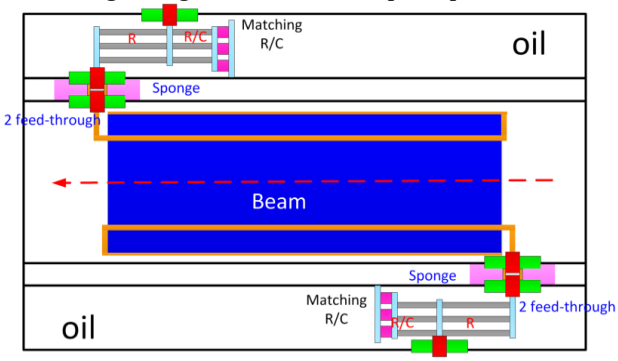


Figure 13: Kicker assembly with cooling fluid.

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.

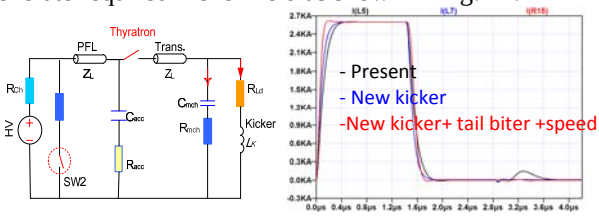


Figure 14: Speed-up and tail biter circuit.

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.

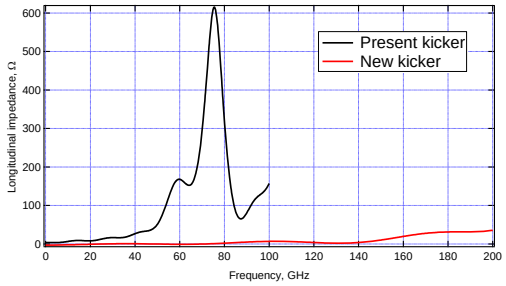


Figure 15: Longitudinal coupling impedance comparison

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.