DESIGN AND TEST OF INJECTION KICKERS FOR JPARC MAIN RING

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Abstract

The old injection kicker system of the J-PARC main ring consists of three transmission-line type kicker magnets. In order to overcome the operational problems, four lumped kickers have been developed because of the structure simplicity and operation reliability. The tight demands on the fast rise and fall time of the field create the difficulties for the kickers design. Low coupling impedance is also required for the high intensity proton beam operation. This paper presents the design, construction and measurements of the kickers.

INTRODUCTION

The J-PARC main ring (MR) aims to accelerate proton beam with beam power up to 1 MW. The original MR injection system comprises two septa (Sep-I/II), three kickers (K1~3) and three bump magnets (BP1~3), which is shown in Fig. 1. The three injection kickers were transmission line kicker magnets. Two kickers are terminated with matched 10 Ω resistors, and one is short ended to double the kick strength. They provided an 8.6 mrad deflection to the injected to fill 8 RF buckets spaced at 300 ns interval, which requires the kicker field must be increased from zero to maximum within 300 ns in order not interfering the circulating beam.
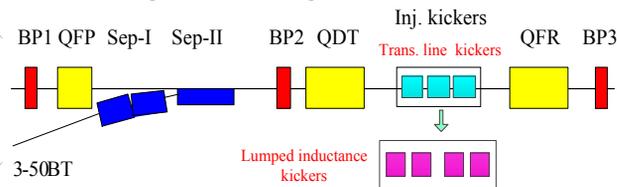

Figure 1: Layout of MR injection system.

The performance of the old kickers system has been degraded after several years operation. Four new lump inductance kickers were designed, constructed, tested and installed during the nine months shutdown due to the big earthquake. The new kickers have identical specifications and are expected to produce identical magnetic field pulse shape. Thus, they are designed with the same mechanical and magnetic specifications.

DESIGN CONSIDERATION

In order to produce magnetic field with very fast rise and fall time transmission line kicker magnet is preferable, which can perform much faster than lumped inductance magnet. However, the design, construction and maintenance are more complicated. In our case the

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spacing between trains of bunches is about 300 ns making it possible to use lumped inductance kicker. Thus four identical lumped inductance kickers are designed.

Lumped inductance kicker has the advantages of structure simplicity and high reliability. However, the rate of rise and fall of the field is limited by the total inductance in the circuit and the impedance of the pulse generator. The magnetic field rise time is exponential with a time constant τ_{lump},

$$\tau_{lump} = \frac{L_m + L_s}{Z},\qquad(1)$$

where L_m and L_s are the kicker inductance and the stray inductance respectively.

Magnet Geometry

The magnets are of a ferrite (CMD10) window frame design as shown in Fig. 2. Eddy current strips are inserted in the middle of the magnet, which plays a role of flux barrier to increase the reluctance of the magnetic path induced by the circulating beam, and thus decrease the flux that couples the circulating beam. However, the presence of copper stripes will impair the gap field quality and thus must be optimized to satisfy both the requirements of the gap field and the coupling impedance.
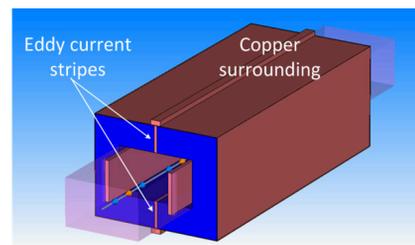

Figure 2: Structure of kicker magnet.

Field Quality Optimization

The presence of the eddy current strips will worsen the gap field distribution in the aperture center. In view of gap field uniformity, thinner eddy current strips are preferable. However, the lower coupling impedance requires thicker copper strips to stop the magnetic flux induced by the circulating beam. Fig. 3 shows the gap field integral spatial distribution of the kickers with 6 mm thick copper strips. It shows clearly that the field integral near the copper strips decreases significantly. The main beam will pass through the aperture center of kicker except a small part of beam edge will experience the "weak" field, which receives less kicker angle and might cause beam losses.
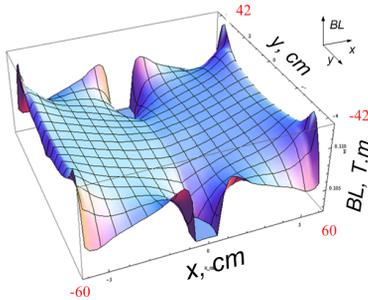
Figure 3: Copper strip effects on field integral spatial distribution.

Magnet Length Optimization

To meet the stringent requirement of field rise time less than 300 ns, the total inductance in the circuit must be strictly controlled, which sets an upper limit of the kicker length. However, a shorter kicker magnet needs higher charging voltage to provide enough kick angle, which will increase the operation risk of HV discharge. Therefore, one of the important design tasks is to optimize the total inductance of the kicker. The kicker magnet length is designed as 600 mm, and the coil inductance is about 600 nH. Fig. 4 shows the self-inductance contributed by individual ferrite cell.
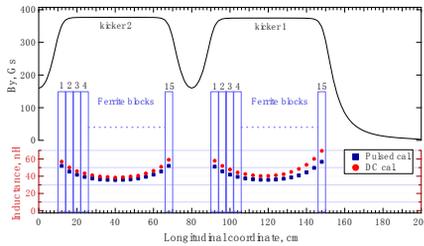

Figure 4: Individual cell self-inductance (2 kickers).

Coupling Impedance Optimization

Beam coupling impedance is an important issue for a high intensity particle accelerator. The real part of the longitudinal impedance can give rise to power dissipation in the ferrite core, which may cause significant heating that leads to the temperature increase over Curie point and impair the kicker functionality. High temperature can cause mechanical damage also. Besides the eddy current strips, the entire kicker is surrounded by copper plates, which provides a low impedance circuit for the image currents, thus further reduce the coupling impedance (see Fig. 1). Fig. 5 compares the longitudinal coupling impedance with and without copper surroundings [2].
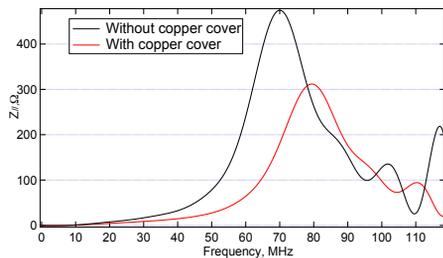

Figure 5: Comparison of coupling impedance with and without copper surroundings.

Magnetic Field Pulse Shape

For injection kicker magnet one important issue is to eliminate the reflection field in order not affecting the circulating beam. Thus a perfect matching load is needed, which can be realized by a very simple circuit as shown in Fig. 6. The terminator impedance is (Laplace transform)

$$Z_L = \frac{(Z + sL_K)(Z + 1/sC_m)}{2Z + sL_K + 1/sC_m}, \quad (2)$$

where C_m is the matching capacitance, Z is the terminating resistor. The circuit is perfectly matched if matching capacitance C_m is
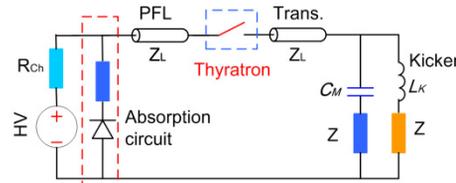
$$C_m = \frac{L_K}{Z^2} \quad (3)$$

Figure 6: Main circuit diagram of injection kicker.

However, the connection conductor between the transmission cable and the coil contributes significant inductance. Using CST Microwave Studio, the total inductance of the kicker is estimated about 1 μH. in this case, a perfect matching with capacitance C_m of 10 nF will lead to long rise time. In order to satisfy the requirement of fast rise speed small capacitance has to be used, which cause mismatch and generate small reflection.

Image Current Effects

The magnet coil and the matching resistors provide a closed path for the image current. The generation of image current depends on the bunch intensity and the bunch length. Fig. 7 compares the image current generated by 2 different beams, which have the same intensity of 1.2×10^{13} PPP but with different bunch length.
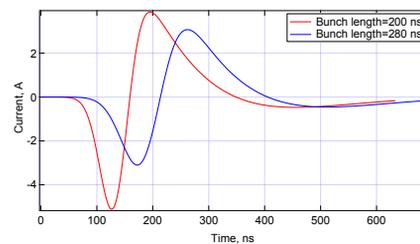

Figure 7: Image current comparison.

With the increasing of beam intensity, the power dissipation in the matching resistor (Z in Fig. 6) due to induced image current may overtake that due to the excitation current. The temperature dependant resistance in the circuit will change both the main excitation current and the reflection current, which will create injection errors. High efficiency cooling system is needed to keep the temperature of the matching resistors constant during the operation.

Main Parameters

The main parameters of the new kicker magnets are listed in Table 2.

Table 2: Main Parameters

Item	Value	Unit
Aperture	130×98	mm
Magnet length	600	mm
Rise time	350 (1~99%)	ns
Charging voltage	51	kV
Deflection angle	7	mrad
Field top duration	1.4	μs

KICKER MEASUREMENT

Magnetic Field Measurement

The magnetic field measurement was performed in the tunnel due to availability of power supply. A measurement setup was used to measure the time-response of field integral and the distribution of $By \cdot L$ in the transverse planes. The integral measurements were made with a long search coil positioned in x and y direction by 2×2 linear motors as shown in Fig. 8. In addition to the integral measurements, "point" measurements were also made with short search coils to study field distribution near the magnet ends. Since the fields were measured in air, the applied voltage was limited within 25 kV.
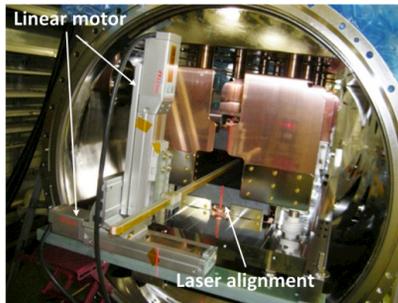

Figure 8: Setup of field integral measurement

Coupling Impedance Measurement

Four lumped inductance kickers are installed in two jointed vacuum chambers with total length of 4.2 m. Conventional coaxial wire methods were used to measure the coupling impedance of the kicker system. Since the entire kicker system together with two measurement matching pipes will exceeds 5 m long, it is difficult to make such a measurement system. The measurements were made twice, and each time measured 2 kickers in one chamber. The setup is shown in Fig. 9.
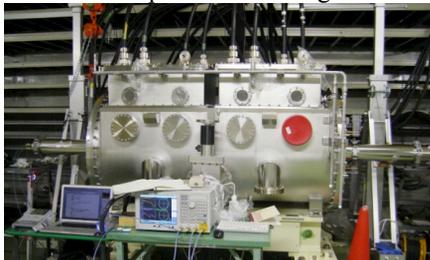

Figure 9: Setup of the impedance measurement.

The longitudinal coupling impedance was measured using a single wire method. The transverse impedance measurement was made by the shifting wire method and the twin wires method. The effects of the external circuits including the transmission cable on the coupling impedance were also taken into consideration. Detailed information can be found in these proceedings [3]. Measurements showed that the new kicker impedance is much lower than that of the old kickers, see Fig. 10.
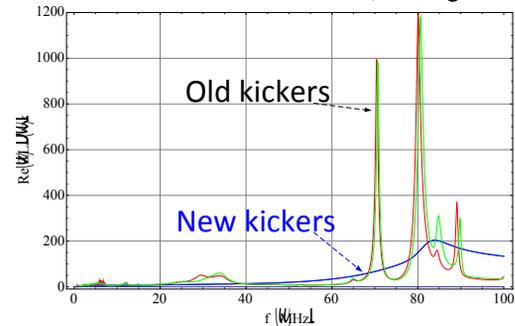

Figure 10: Comparison of longitudinal impedance.

Waveform Adjustment

The magnetic field waveform adjustment was compromised between the rise time requirement and the reflection field requirement. Currently the matching capacitance is set 7400 pF. The kicker excitation current waveform (measured at kicker) is shown in Fig. 11. Compared to the old kicker, the waveform improves a lot.
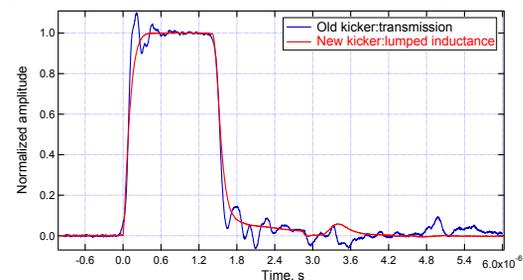

Figure 11: Comparison of excitation current.

FUTURE IMPROVEMENT

In order to reduce the rise time and the reflection field, upgrade studies have been carried, which include reducing the coil inductance by using strip line structure, and reducing the reflection field by using compensation circuits.

REFERENCES

[1] KEK report 2002-13.
[2] K. Fan, T. Toyama et al., "Impedance Study of the New Injection Kicker Magnets of JPARC Main Ring", these proceedings
[3] T. Toyama, K. Fan et al., "Coupling Impedance Measurement of the Lumped-Circuit Kicker Magnets for the MR Injection, Using the Stretched-wire Method", these proceedings.