COUPLING IMPEDANCE STUDY OF THE JINECTION KICKER MAGNETS OF THE JPARC MAIN RING

K. Fan#, T. Toyama, T. Sugimoto, S. Fukuoka, H. Matsmoto, K. Ishii
KEK, Tsukuba, Ibaraki 305-0801, Japan

Abstract

New lumped inductance kicker magnets have been developed for the J-PARC main ring injection system. For high intensity beam operation, the beam coupling impedance of the kickers is required as low as possible, which not only generates significant heating inside the ferrite core impairing the performance of the kickers, but also drives beam instability. Optimization the kicker structure to minimize the coupling impedance is an important part of design tasks. Numerical simulations based on CST studio have been carried out during the design stage. The estimation of coupling impedance has been confirmed by the impedance measurements.

INTRODUCTION

J-PARC is a high intensity proton accelerator complex, which consists of a LINAC, a Rapid Cycle Synchrotron and a Main Ring (MR). The MR aims to accelerate and provide users proton beams with beam power up to 1 MW. With the increasing beam intensity, the interaction between the beam particles and their surroundings become an important issue. The excited wake fields in the critical accelerator components may affect trailing beams significantly. The strength of their interaction is characterized by the coupling impedance of the accelerator components [1]. For JPARC MR, the ferrite based kicker magnets are usually the major contributors to the beam coupling impedance. Careful optimization of the coupling impedance is a prerequisite for achieving desired performance. Therefore, theoretical analysis and computer simulation are crucial tasks in the design of the new injection kicker magnets. Numerical field simulations can provide us a convenient way of obtaining coupling impedance without the need of prototype magnet. Even through electromagnetic field simulation codes have proven to give accurate results, practical impedance measurements are required to ensure the components design and fabrication as expected. An experimental measurement setup base on coaxial wire was used to measure both the longitudinal and transverse impedance.

MAGNET DESIGN

Material Selection

The beam passing through kicker aperture can become a high power current source, which will induce magnetic field inside the ferrite core that not only affects the motion of tail beam but also causes core losses contribute the temperature rise of the kicker. The major core losses are eddy current losses and hysteresis losses, which are determined by the frequency dependant complex permeability of ferrite,

$$\mu_s = \mu_s^{'} - j\mu_s^{''}$$

Where, $\mu_s^{'}$ is the real permeability, and $\mu_s^{''}$ is the imaginary permeability.

Nickel Zinc ferrite materials are popularly used for fast kicker magnet design because of the excellent properties. Fig. 1 compares the complex permeability dispersion of two different ferrite materials CMD5005 and CMD10.

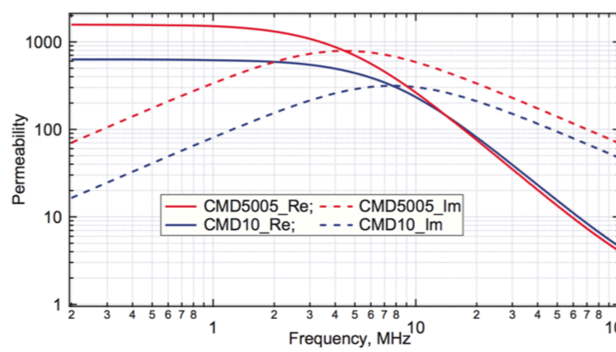

Figure 1: Permeability spectrum comparison

Since the real part of the longitudinal impedance gives rise to power dissipation in ferrite, it is used as a criterion for comparison. Fig. 2 compares the longitudinal impedance of two materials. The CMD10 not only gives lower impedance but also has higher Curie temperature of 250 °C, which is attractive for kicker design.

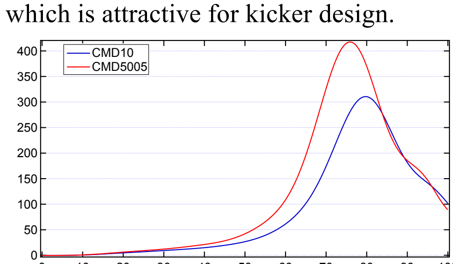

Figure 2: Longitudinal impedance comparison (real).

Geometry Optimization

The kicker is a window-frame magnet, which consists of two "C" type ferrite cores as shown in Fig. 3. A pair of eddy current strips are inserted in the between of the core to stop the induced magnetic flux in the ferrite core due to the eddy current generation, which can reduce the coupling impedance. In view of impedance reduction, thicker stripes are preferable, however, the gap field uniformity will be disturbed [2].

#kj.fan@kek.jp +81-298645272

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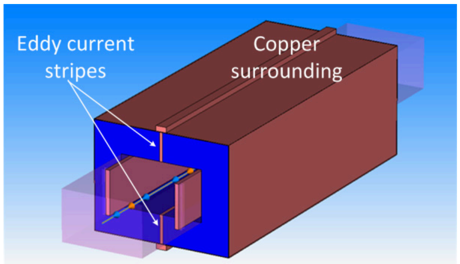


Figure 3: Kicker magnet structure.

Optimization has been carried out between gap field quality and the coupling impedance. Fig. 4 compares the coupling impedance with different strip thickness.

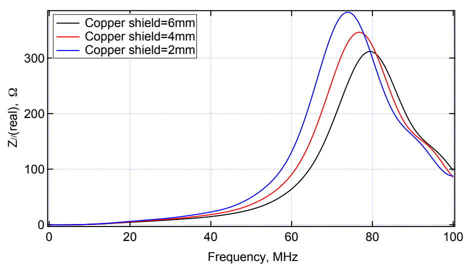
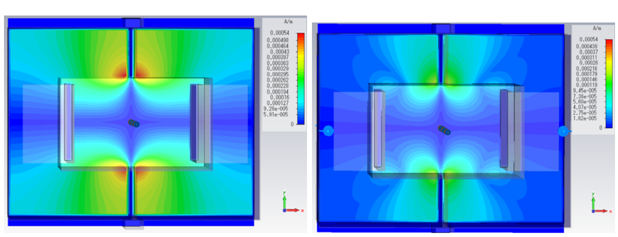


Figure 4: Coupling impedance with strip thickness.

To reduce the coupling impedance further the ferrite core are surrounded by copper plate (see Fig. 3), which can provide a lower impedance path for the induced image current.

External Circuit Effects

The magnet conductor and the matching circuit provide a loop path for the induced current that can generate magnetic flux contact the beam induced flux inside ferrite core. Fig. 5 compares the induced magnetic flux inside ferrite with and without external circuit. As a result, the coupling impedance is reduced greatly as shown in Fig. 6.



a: No external circuit b: with external circuit
Figure 5: Induced magnetic flux in ferrite.

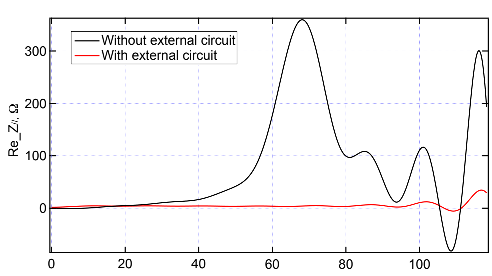


Figure 6: Comparison of coupling impedance with and without external circuit.

However, the circuit also provide a return path for the image current, which will produce heat dissipation in the matching resistors. With the increasing beam intensity, the image current may contribute significant temperature rise in the matching resistors causing injection errors, which has been observed during operation.

Kicker System Coupling Impedance

The four kicker magnets are installed in two vacuum tanks with the total length of 4.2 m. The complex vacuum chamber contributes the coupling impedance also. In order to estimate the coupling impedance precisely, and to compare with the measurements later, the simulation model is very close to the actual device that will be used for the impedance measurements as shown in Fig. 7.

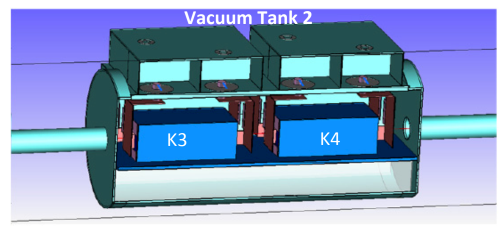


Figure 7: System coupling impedance simulation model

The simulation is based on the wire measurement method, which relay on the fact that the electromagnetic field generated by the ultra-relativistic beam is similar to that of a TEM line. The longitudinal impedance was simulated using signal wire method, which can be obtained by [3],

$$Z_{//} = 2Z_L \ln \frac{S_{21}^{DUT}}{S_{21}^{ref}}$$

Where, Z_L is the line impedance, S_{21} are the transmission parameters of kicker and reference pipe.

The transverse impedance can be deduced from moving wire method, from which the transmission parameter S_{21} of a single wire at different transverse offsets can be simulated, which is shown in Fig. 8.

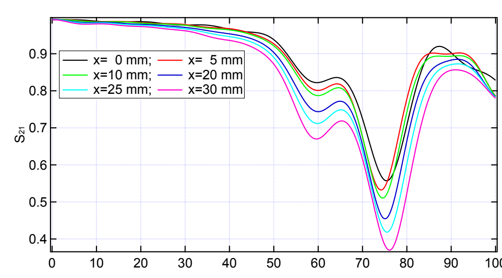


Figure 8: Transmission parameter S_{21} at different offset.

IMPEDANCE MEASUREMENT

Setup

The coupling measurement is based on coaxial wire method [3], which relies on being able to simulate a beam by using a microwave signal travelling on a wire place at the structure electrical center or with offsets from the center [4]. The frequency dependant transmission parameters S_{21} can be obtained with the aid of network analyzer, and from which the impedance of the structure can be deduced.

The measurements were made twice, and every time only two kickers in one vacuum chamber were measured. The measurement setup is shown in Fig. 9, which comprises a network analyzer, two matching sections, a DUT and a reference pipe (not shown). Detailed information can be found in paper [5].

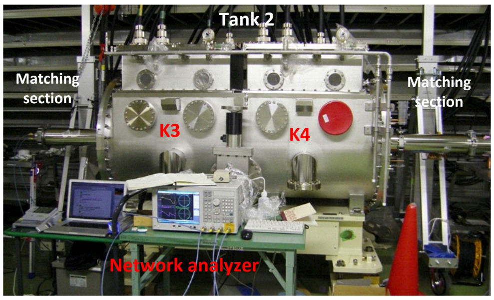


Figure 9: Impedance wire measurement setup (tank2).

Measurement Results

Fig. 10 compares the measured and calculated longitudinal impedance. A good agreement at low frequency is obtained, which is predominated by the kicker magnet. There is a large discrepancy at high frequency because of the simplified vacuum tank structure used in the simulation.

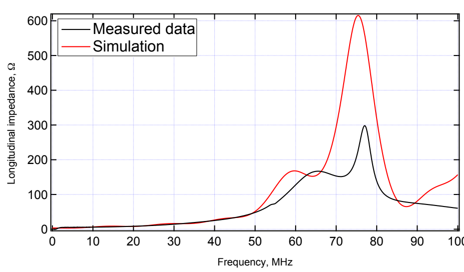


Figure 10: Comparison of simulation and measurement.

Compare with the old transmission line kicker, the longitudinal coupling impedance of the new kickers has been reduced significantly (see Fig. 11).

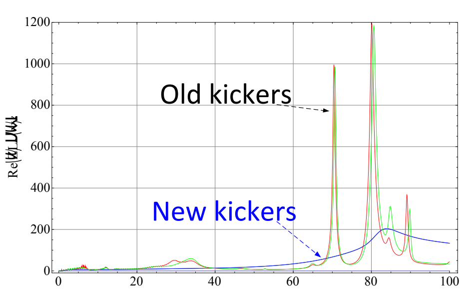


Figure 11: Comparison of impedance between old and new kickers.

Two methods were used to measure the transverse coupling impedances. The first method was using a single wire placed at varying offsets from the electrical center of the kicker system. The second method was twin-wire method. The measurement process and measured results are given in the paper [5].

IMPEDANCE IMPROVEMENT

The quite good agreement with the experimental measurement shows that the numerical modelling of the kicker system is accurate. Based on this model, the coupling impedance of the entire system that includes 4 kickers can be calculated, which can avoid the interference generated by the artificial flange that used for impedance measurement (see Fig. 9).

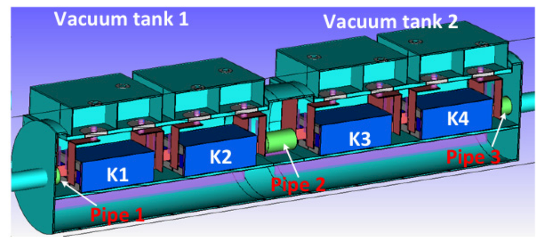


Figure 12: Full kicker system.

There is an abrupt change between the vacuum tank and the kickers. Three copper pipes are installed to smooth the mechanical connection, which is shown in Fig. 12. The pipes also provide image current path that will reduce the coupling impedance. Fig. 13 shows that the coupling impedance can be reduced nearly 10% at low frequency region.

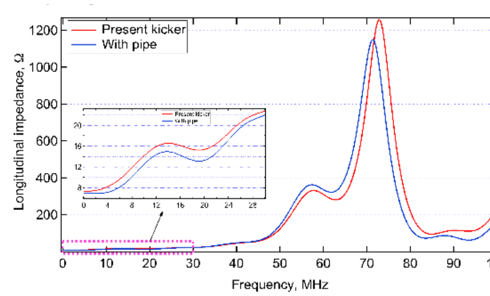


Figure 13: Impedance reduction at low frequency.

SUMMARY

In this paper we have described the optimization of kicker parameters to minimize the coupling impedance. Measurement results have confirmed the accuracy of the simulation. Compared with the old kickers, the coupling impedances of the new kickers have been reduced a lot, which can satisfy the requirement of high intensity beam operation.

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