DEVELOPMENT OF A FAST COMPENSATION KICKER SYSTEM FOR J-PARC MAIN-RING INJECTION

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Abstract

The injection system of J-PARC Main-ring employs four lumped kickers to deflect the incoming beam. Because the tail field caused by tail and reflection of excitation current exists and increases the closed beam orbit leading to particle loss in high power operation A correction method using a fast kicker system to compensate the remaining error angle is being developed. The kicker magnet is a transmission line type but uses ceramic capacitors instead of parallel metal plates to make the magnet compact and to reduce stray inductance. A Marx generator using semiconductor switches has been developed, which is able to generate arbitrary current waveform to compensate the irregular kicker tail. This magnet system requires wideband above 100MHz A prototype magnet has been fabricated for parameters test. In this paper, we will report the details of the system designs, analyze the measurements results and give future prospects.

INTRODUCTION

The injection kicker magnet for J-PARC Main-ring was installed and has been in operation since Dec. 2011. This injection system employs four lumped kickers to deflect the incoming beam and injects 8 RF bunches in four times [1, 2]. Since the bunch spacing of the J-PARC Main-ring is estimated to be about 300 nsec, the rise time of this magnet system is required to be less than it.

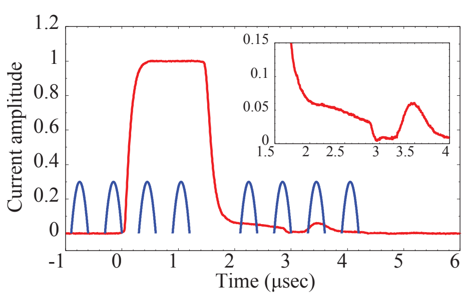

Figure 1: At 4th injection timing, the position relation between the injection kicker's excitation current (red) and beams (blue). Upper right is extended figure of the tail field. The current waveform is normalized by flat top value.

However, as shown in Fig. 1, the total inductance of the kicker magnet is about 1 μH, a mismatching circuit has to be selected to increase rise time, which introduce reflection causing long tail field. Since, the injection process repeats 4 times during the injection period, previous injection beam can "see" the tail field of last 4th injection process, which is illustrated in Fig. 1. Another contribution to the long tail is because of the dispersive of the long transmission cables. So, just improving the injection kickers only can't solve the problem essentially. Thus, new compact kicker magnet for compensation is suggested. This magnet will be located downstream of the main kicker and kicks the beam bunches in an opposite direction to correct the over-kicked angle. An optimal place can minimize the required kicker angle that reduces the difficulty of compensation kicker system design.

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DESIGN OF COMPENSATION KICKER

Design Concept

The goal of this system is to reproduce the magnetic field by tail, thus, an arbitrary waveform shape must be output and excite the magnet while maintaining its original shape. For this purpose, magnet and power supply must be wideband. So, reducing the stray capacitance and inductance in a circuit are very important. The required correction magnetic field integral is estimated to be about 0.06 Tm. The compensation kicker is designed 60 cm long, and the required excitation current should be 500 A. The characteristic impedance of the compensation kicker is designed 10 Ω, and a charging voltage of 10 kV is needed. The aperture size is required to be 200 mm horizontally and 100 mm vertically.

Power Supply

A Marx generator using semiconductor switch devices has been studied. The Marx-type modulator consists of many cells. Charging multi-stage capacitors connected in parallel and discharging them in series, as shown in Fig. 2. In order to generate arbitrary waveform, the timing of each switch can be controlled.

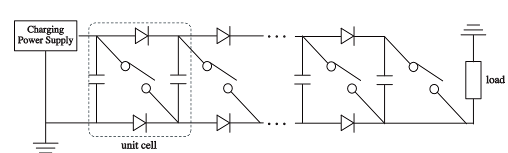

Figure 2: Simplified diagram of a Marx cell.

The MOS FET has been selected as switching device due to its fast time response and low stray capacitance and inductance [3]. Since a switch's absolute maximum rated voltage is about 600V, Marx-cell of approximately 40 or more steps is required. As shown in Fig. 3, the tail current is reproduced in an electrical simulation by controlling the timing each switch.

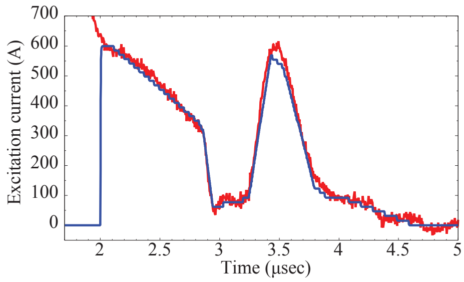

Figure 3: Real tail field (red) and the Waveform reproduced on the simulation (blue).

Magnet

Since fast response speed is needed, a so-called distributed-type structure is employed. It is preferred to configure the structure by smaller inductance and capacitance. A thin core leads to small inductance, but the thickness is limited eventually by the insulating voltages in vacuum. The core thickness per section can be reduced to 10 mm, which corresponds to a coil inductance of 10 nH per cell. Further, ceramic capacitors of 100 pF make the magnet compact. As a result, the bandwidth of the kicker is estimated to be over 100 MHz. The conceptual design of this magnet is shown Fig. 4. The "C" type ferrite core is opposite to each other separated by a eddy current shield, the capacitors connected to each ferrite core are located at the back of the core.

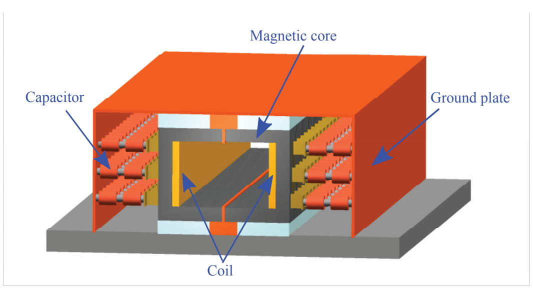

Figure 4: The conceptual design of compensation kicker magnet.

DEVELOPMENT AND MEASUREMENT OF PROTOTYPE

Prototype Description

The prototype of the magnet has been fabricated for parameter tests as shown in Fig. 5. The purpose is to confirm the performance of this new magnet technology. In this prototype measurement, CMD5005 is used as a magnetic core but this seems not to have good frequency characteristic [4]. The ideal performance of the magnet must be evaluated without much stray inductance and capacitance in the space for insulation. Thus, the measurement is performed with only one side and 10 sections at low voltage. The prototype magnet has been fabricated measured pulse response and frequency characteristics. The measurement circuit is

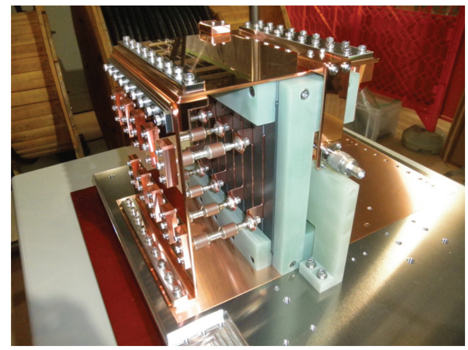

Figure 5: Photograph of the prototype kicker.

shown Fig. 6. The impedance convertor for impedance matching inserts between transmission cable and magnet. This converter is consisted of resistors by T-type connection and work as an attenuator that attenuation rate is about 20 dB. The input and transmission signals are measured by using voltage probes.

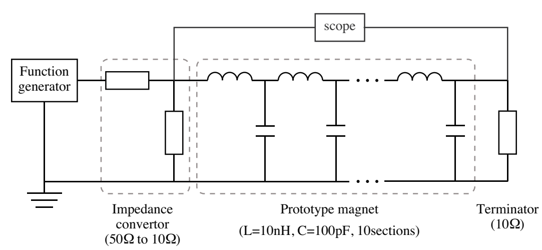

Figure 6: Measurement system.

Result of Pulse Response

At first, the pulse response of this magnet is measured since it is important to determine the magnet rise time. The initial input signal is a square pulse with a fast rise time. The pulse height is 5 V and the pulse length is 1 μsec.

The measured result of the pulse response is shows in the left of Fig. 7. And the right of Fig. 7 shows the result of the simulation. It can be seen that the rise time of the transmitted pulse is longer than the input one. The function generator can output a pulse with a rise time from 5 nsec to 100 nsec. Fig. 8 shows the dependence of the transmission's rise time on the input one. As the rise time of the input pulse exceeds 50 nsec, to follow the rise time of the input signal, the rising edge of the transmission signal becomes slower. This means that the magnet's bandwidth is limited by the frequency, which corresponds to 50 nsec. However, the measured rise time is slower than the calculated one by the electrical circuit simulation. In the same figure, two solid lines show a correlation with the calculated rise time. The difference in these lines is as the follows: 1. in case

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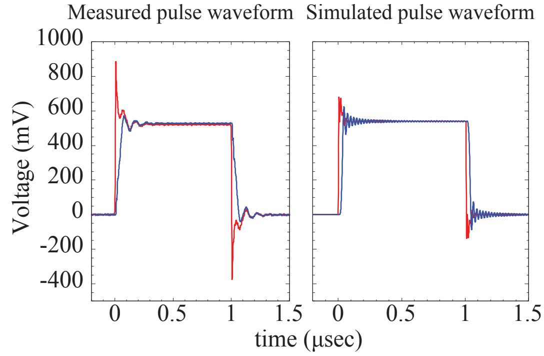

Figure 7: Comparisons with measured (left) and Simulated (right) waveforms. Red line is input and blue line is transmission signal in bath plots.

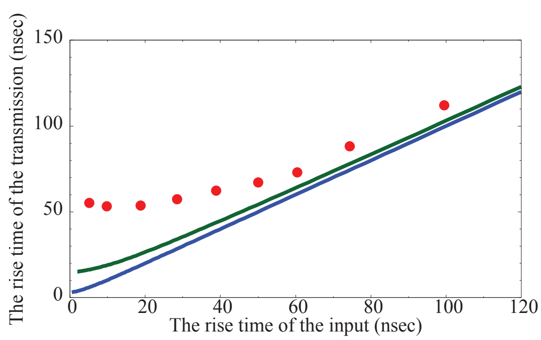

Figure 8: Dependence of transmission rise time for input rise time. Measured data is shown as dots (red), simulated data is shown as line (blue, green).

of an ideal magnet system ; 2. in case of the prototype magnet which includes stray components. The lower limit of the rise time respectively is about 5 nsec and 10 nsec. It seems that the cause of these differences is a low estimation for each parameter. For example, since the magnet length is too short, a coil's inductance may be larger than that we estimated. The coil's inductance and capacitor's capacitance are included in calculations as basic parameters. In addition, the electrode plate's inductance and capacitance, and capacitor's inductance are estimated as stray parameters. However, it appears that it is not enough to include these parameters only. The inductance of the coil might be larger than its predicted value because this magnet's length of about 200 mm is too short compared with it's aperture. Alternatively, the frequency characteristic of the core might affect it, too.

Result of Frequency Characteristic

Next, the frequency characteristics are measured. The initial input signal is a sine wave with variable frequencies from 10 to 50 MHz. The attenuation rate and phase shift are calculated by using their amplitude and phase. The results of AC signal input is shown in Fig. 9. As shown in Fig. 9, the attenuation rate increases rapidly in the region of higher than 20 MHz. As these are compared with simulation result, The tends of characteristics are almost agreement with the results of the pulse response test but absolute value doesn't match.

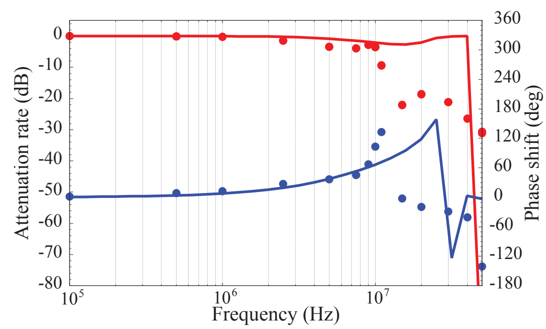

Figure 9: Comparisons with measured (dots) and simulated(solid lines) frequency characteristics. Red is the attenuation rate (right axis) and blue is phase shift (left axis) in both plots.

Prototype Conclusion

At low frequency, the measured results agree well with the simulation results, however, there is much discrepancy between measured and predicted results at high frequency. Several reasons may involve in this phenomena. At the present time, we couldn't decide the reason but the main contribution comes from the ferrite core with limited bandwidth, which leads to significant power losses in ferrite at high frequency. Frequency dependant simulation will be carried out to prove our conclusion, and new ferrite cores with higher frequency characteristics will be implemented for further study.

SUMMARY

We have proposed a new method for the improvement of beam injection into the J-PARC MR. This system is consisted of a distributed magnet and a Marx power supply of wideband. The details of the system design and future prospects are reported. A prototype magnet has been fabricated and measured for some electric characteristics: the pulse response and the frequency response. These results of measurements and analysis are shown in this paper.

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