

# PERFORMANCE OF A FAST KICKER MAGNET FOR RARE-RI RING

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## Abstract

To inject rare isotopes individually into the storage ring, Rare-RI Ring, recently constructed at RIBF, a fast kicker magnet was developed. The developed kicker magnet is distributed constant twin type. The shape of magnetic field is essential for the individual injection, and the timing property is given by the inductance and capacitance components of the kicker. Based on detailed simulations of the equivalent electronic circuit of the kicker, we optimized the electrodes and ferrite cores of the kicker. In June 2015, we carried out the first commissioning of Rare-RI Ring using  $^{78}\text{Kr}^{36+}$  beam with an energy of 168 MeV/nucleon. We succeeded in injection and ejection particle-by-particle by using the developed kicker system.

## INTRODUCTION

The Rare-RI Ring is an isochronous storage ring developed to measure the masses of rare isotopes with a precision in the order of  $10^{-6}$  [1]. The rare isotopes are randomly produced as secondary beams by in-flight fission or fragmentation of an intense DC beam from the RIBF accelerator complex, and their yields are as small as 1 events/day. Therefore, we apply the individual injection method to perform mass measurements of rare RI efficiently.

The individual injection method consists of fast kicker magnet with the RI beam self-trigger system [2]. The trigger pulse for the kicker is generated by a particle detector installed upstream of the beam line at F3, and is sent to the kicker system by a fast coaxial cable (see Fig. 1). The most important is that magnetic field is quickly excited before rare RI of interest arrives at the ring. The kicker should have a fast rising time and also a fast falling time for injected rare RI to be stored in the central orbit of the ring.

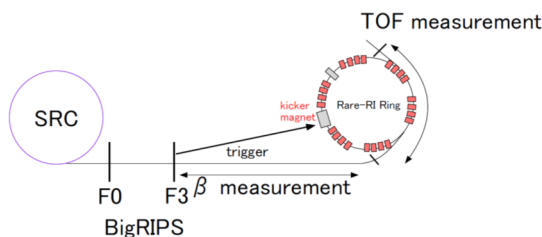


Figure 1: Schematic of the beam line of the Rare-RI ring facility.

## DEVELOPMENT OF KICKER MAGNET

The developed kicker magnet is distributed constant twin type. The kicker magnet is equivalent to an electronic circuit that is  $\pi$  type LC circuit. To achieve the impedance  $Z = 12.5 \Omega$ , the parameters of inductance  $L = 70 \text{ nH}$  and capacitance  $C = 230 \text{ pF}$  were designed. The inductance is given by the shape of ferrite cores, and the capacitance is given by the distance between high-voltage and ground electrode of the kicker. Figure 2 shows a photograph of the prototype kicker magnet.

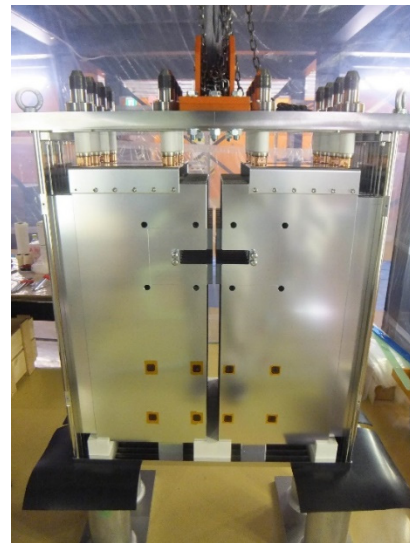


Figure 2: Prototype kicker magnet.

First, we optimized the parameter for one side of the kicker magnet (left or right electrode shown in Fig. 2). As the result, the parameter are  $L = 120 \text{ nH}$  and  $C = 280 \text{ pF}$ . Figure 3 shows a comparison of the simulation result and experimental data. The agreement is satisfactory.

However, the current pulse shape of the both side kicker magnet (full system) was different from that of one side kicker magnet, because of mutual inductance between both ferrite, as shown in Fig. 4. Based on the result of one side kicker magnet and the simulations, the mutual inductance was estimated to be  $M = 30 \text{ nH}$ . The result was well reproduced by the simulation, as shown in Fig. 4. However, a tail component around 800 ns in the pulse shape still remains as shown in Fig. 4. The tail component of magnetic field disturbs the trajectory of particle stored in the ring.

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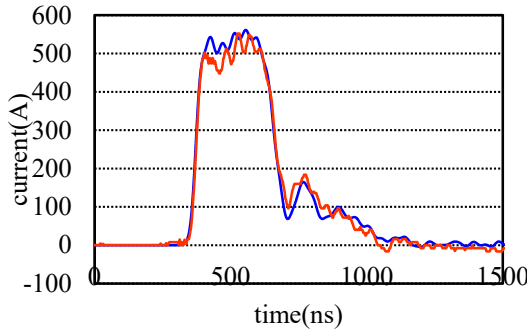


Figure 3: Typical current pulse shape (one side kicker) as a function of time. Blue and red lines are simulation and experiment data, respectively.

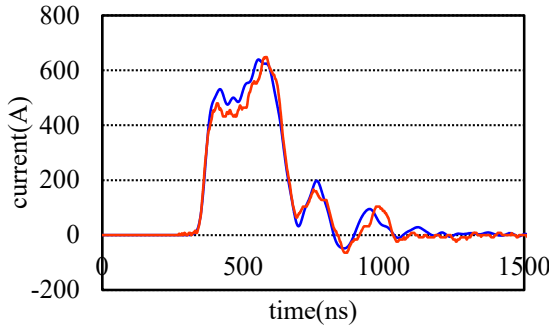


Figure 4: Typical current pulse shape (full kicker system) as a function of time. Blue and red lines are simulation and experiment data, respectively.

We use these simulation results to develop a new kicker magnet. The new kicker magnet parameters are designed to be  $L = 100$  nH and  $C = 350$  pF to improve impedance matching. Therefore, additional capacitance of 2600 pF was attached to the entrance of kicker magnet to prevent reflection. The current pulse shape of improved kicker magnet is shown in Fig. 5.

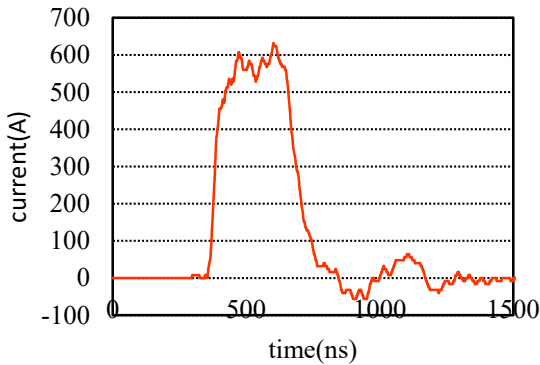


Figure 5: Typical current pulse shape of a new kicker magnet.

We apply the search coil method to measure magnetic field. The magnetic field (magnetic flux  $\phi$ ) is determined from raw voltage signals  $V$  of the search coil (turn number  $N$ ) using the equation,

$$\phi = -\frac{1}{N} \int V dt \quad (1)$$

The result of magnetic field of the new kicker magnet is shown in Fig. 6, where the magnetic field has a flat top with a width of about 100 ns.

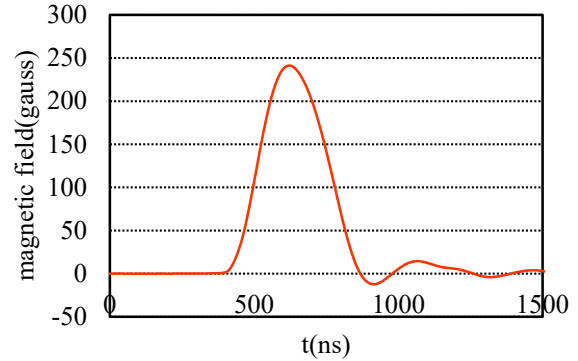


Figure 6: Typical magnetic field of a new kicker magnet.

## RESULT OF COMMISSIONING

In June 2015, we carried out the first commissioning of Rare-RI Ring using  $^{78}\text{Kr}^{36+}$  beam with an energy of 168 MeV/nucleon. The kick angle of 11.4 mrad is required to inject into the Rare-RI Ring. The relation between the kick angle  $\theta$  and necessary magnetic field is described as

$$B = \frac{B\rho}{L} \theta, \quad (2)$$

where  $L$  is the kicker magnet length (369 mm) and  $B\rho$  is magnetic rigidity, 4.21 Tm. For the present beam condition, a magnetic field of 434 G is required. Thus, kicker power supply should be charged up to 26.6 kV.

### Result of Injection

We tested individual injection method using the new kicker magnet. To confirm injection of the beam, a plastic scintillation counter was placed in the central orbit after one sector. When the beam is kicked correctly, it is counted by the plastic scintillation counter. We measured the number of counts by changing injection timing and charging voltage, as shown in Fig. 7. The change of the number of counts by the plastic scintillator is consistent with the shape of magnetic field. Also, the charging voltage giving the maximum is consistent with the estimated value. The present results show that the individual injection method was successfully performed.

### Result of Ejection

We tested the ejection of stored beam using the same kicker magnet after 700  $\mu\text{s}$  storage. A plastic scintillation counter was placed at the exit of the ring. We measured the number of events counted by the plastic scintillator by changing the ejection timing. The result is shown in Fig. 8. The maximum number of events was observed around 350 ns, which is consistent with the revolution period in the ring. The stored beam was successfully ejected from the ring.

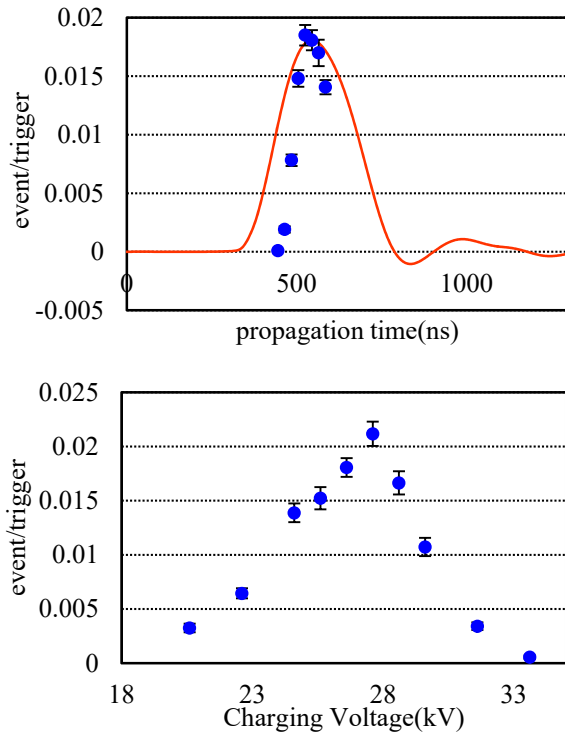


Figure 7: Up: The number of events counted by the plastic scintillation detector as a function of kicker timing. Down: The same as a function of the charging voltage of kicker magnet. Blue points are experimental data and the red line is the magnetic field for comparison.

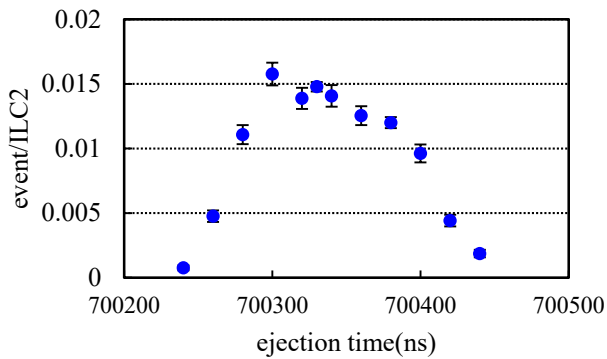


Figure 8: The number of events counted by the plastic scintillation detector at the exit of the storage ring as a function of ejection delay timing.

## CONCLUSION

Rare-RI Ring is a storage ring developed to measure the masses of unstable nuclei with a precision in the order of  $10^{-6}$ . To inject rare isotopes individually into the ring, we developed the fast kicker magnet with a fast rising and falling time. Based on the offline test of the kicker magnet and detailed simulations of equivalent kicker circuit, we improved the kicker magnet with better impedance matching. The resultant magnetic field shape is satisfactory for the individual injection. In June 2015, we carried out the commissioning of Rare-RI Ring using  $^{78}\text{Kr}^{36+}$  beam with an energy of 168 MeV/nucleon. We succeeded in

injecting and ejecting Kr ions particle-by-particle by using the present kicker system.

## REFERENCES

- [1] A. Ozawa et al., Prog. Theor. Exp. Phys. 2012 (2012) 03C009.
- [2] I. Meshkov et al., Proceedings of EPAC 2004, Lucerne, Switzerland.