MAGNETIC FIELD MEASUREMENTS OF THE KICKER MAGNET FOR MUSES

T. Ohkawa†, Y. Chiba, M. Wakasugi, RIKEN, Wako, Saitama, Japan
T. Katayama, CNS, Univ. Tokyo, Tokyo, Japan

Abstract

In the MUSES project, kicker magnets are used for ion-beam injection and fast extraction. The injection kicker field must fall from approximately 99 % to 10 % of full strength and extraction kicker field must rise from approximately 10 % to 99 % of full strength during the time interval between bunches. The high performance of the kicker magnet is important for the efficiency of beam injection and extraction. In this paper, the magnetic field measurements of the kicker magnet for MUSES are presented.

1 DESIGN

1.1 Magnet

We have adopted the traveling wave type of kicker magnet which is often used to generate a high magnetic field with a rapid rise and fall time. An elementary cell of the kicker magnet consists of C-shaped ferrite core and electrodes. The thickness of the ferrite core and electrode are 19 mm and 5 mm, respectively. The ferrite cores and high-voltage electrodes are stacked alternately. Earth electrodes are interleaved at the middle position between high-voltage electrodes. Inductance per cell is determined by the aperture of the ferrite core (TDK Corp. L6H material), whose effective permeability is 150 at 20 MHz. Capacitance per cell is provided by high-voltage and earth electrodes, attached independently to the high-voltage and earth conductors.

In order to generate a magnetic field of the design value in a core gap, PFN voltages is required up to 100kV. When the PFN is charged with 100 kV, the kicker magnet is expected to produce a magnetic field of 0.084 T with a flat top of 1 μs and a rise time of 95 ns. The design parameters are listed in Table 1 and a photograph of the kicker magnet is shown in Fig.1.

Table 1: The parameters of the kicker magnet

ITEM	DESIGN VALUE
Gap height	30mm
Gap width	130mm
Total core length	225mm
Cell number	9
Inductance of unit cell	0.136μH
Capacitance of unit cell	108.9pF
Characteristic impedance	25Ω
Gap field	0.084T
Coil current	2000A
PFN voltage	100kV
Field rise time	95ns

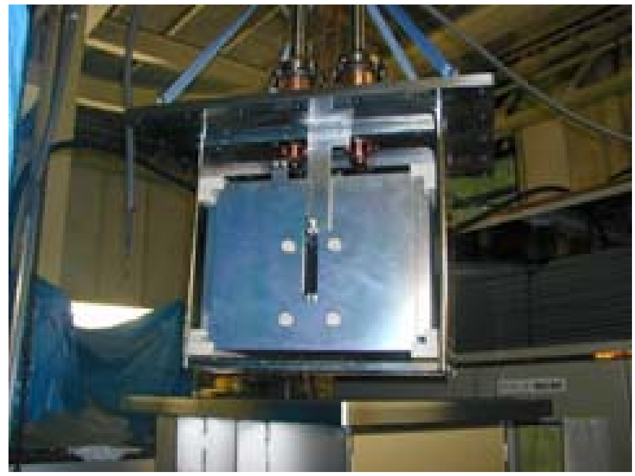

Figure 1: Photograph of the kicker magnet.

1.2 Power Supply

The power supply of kicker magnet consists of two pulsed resonant power supplies, a PFN, a thyratron, and a terminator. Table 2 shows the parameters of the power supply.

Table 2: The parameters of the power supply

ITEM	DESIGN VALUE
Charging voltage	100 kV
Current	2000 A
Pulse width	1125 ns
Pulse interval	more than 0.3 s
Repetition	1 Hz
Jitter	±5 ns
Thyratron type	CX1171(EEV)
Termination resistance	24±2 Ω (changeable)

2 MEASUREMENT

2.1 Magnetic Field

A long search coil is used for the measurement of the magnetic field. The long search coil is an one-turn coil with 2 mm wide and 470 mm long. The diameter of the wire is 0.5 mm. Output voltages are measured with attenuators and digital oscilloscope. The attenuators have coaxial structure whose characteristic impedance is 50 Ω. The waveform of the magnetic field is obtained by integrating the induced voltage at the ends of the search coil. Here the effective length of the magnet is assumed to be 240 mm for the calculation. The results of the measurement are shown in Fig.2 - 4. In order to prevent discharge the measurements are carried out in a vacuum. Figure 2 shows the waveforms of induced voltage and magnetic field at 100 kV, Figure 3 shows the waveform of magnetic field at the flat-top and Figure 4 shows two outputs measured by switching the polarity of the search coil and each output is averaged 64 times. In Fig.4 'plus waveform' means that the output is positive at the rise time and the other output ('minus waveform') is measured by switching the polarity of the search coil.

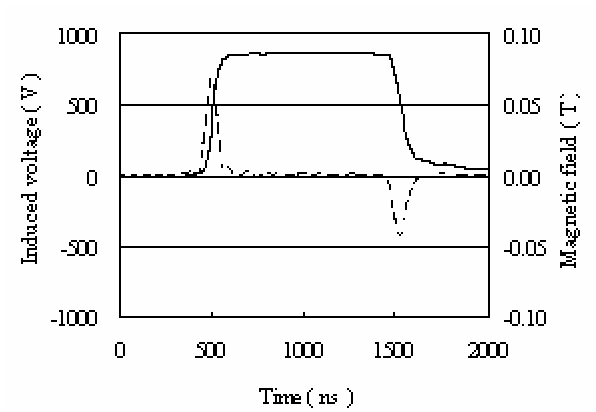

Figure 2: Magnetic field and induced voltage.

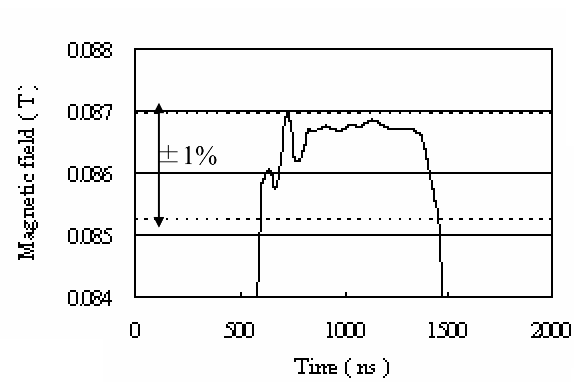

Figure 3: Magnetic field at the flat-top.

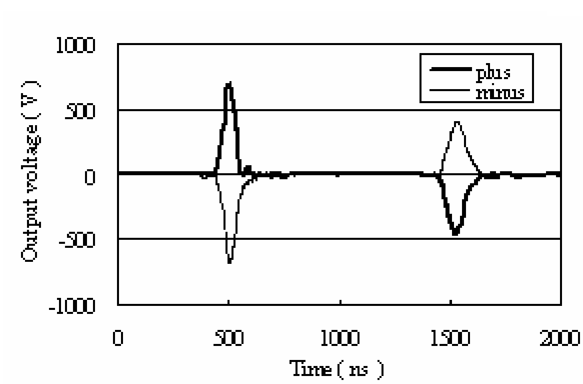

Figure 4: Outputs measured by switching the polarity of the search coil

In order to improve the signal to noise ratio of the measured voltage, the induced voltage in Fig.2 is obtained by averaging two outputs in Fig.4 upon changing the sign. The rise (from 10% to 99% of full strength) time of the waveform is approximately 129 ns, the flat-top (field stability is ±1%) time is 854 ns. The rise time of field is longer than the design value (95 ns).

2.2 Field Stability

As shown in Fig.3, the rise time of field is longer than the design value (95 ns). This is due to the mismatch of impedance between the kicker magnet and feedthrough. Therefore, matching capacitors were inserted between the kicker magnet and feedthrough to improve matching. By using a capacitor inserted in the inlet of the kicker magnet, a first dip is removed. The capacitor inserted in the outlet of the kicker magnet is used to shorten field rise time and improve a second dip. Figures 5 and 6 show the improved waveforms at 100 kV. The optimum values of the capacitance are 122 pF at the inlet and 295 pF at the outlet of the kicker magnet. The rise time of waveform is approximately 83 ns, and the flat-top time is 888 ns. These results satisfy the design value.

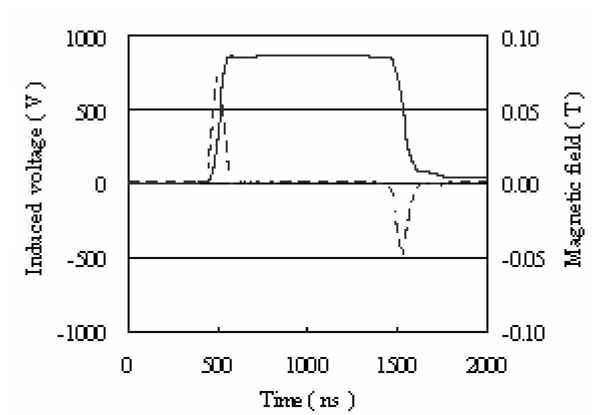

Figure 5: Magnetic field and induced voltage with the capacitors.

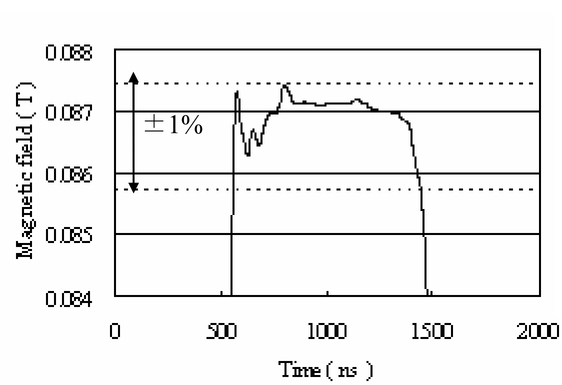

Figure 6: Magnetic field at the flat-top with the capacitors.

2.3 Field Distribution

We measured the horizontal distribution of the magnetic field with a long search coil. The measurement is carried out in the atmosphere to move the position of the long search coil along the medium plane. A schematic drawing of the core gap is shown in Fig.7. An electric discharge happens when the PFN voltage is charged with more than 30 kV. To avoid electric discharge of the kicker magnet, we measured the magnetic field at 20 kV. The horizontal distribution of the average magnetic field at the flat-top is shown in Fig.8.

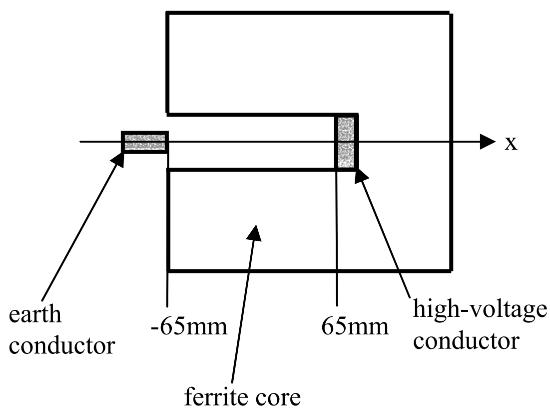

Figure 7: Schematic drawing of the core gap

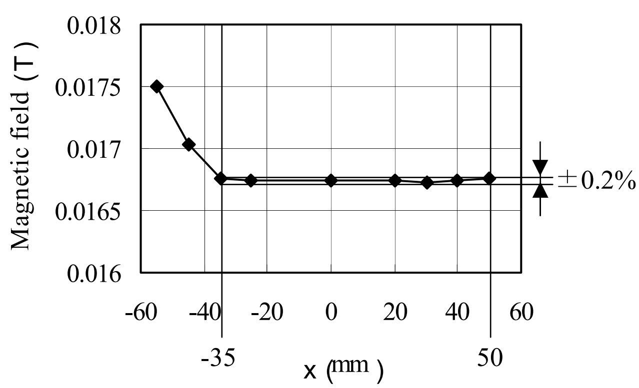

Figure 8: Horizontal distribution of the average magnetic field at the flat-top.

The result of the measurement shows that field uniformity is less than ±0.2% in the range of 85 mm (from –35 mm to 50 mm). Figure 8 shows that the magnetic field near the earth conductor is a little higher than that of near the high-voltage conductor. Here, it is important to calculate the effect of eddy currents on the magnetic field because the excitation pulse contains high frequency components. So, we carried out the dynamic analysis of the magnetic field using a finite element code "Maxwell". The dependence of the horizontal distribution of the magnetic field by changing pulse frequency is shown in Fig.9. Figure 9 shows that the magnetic field near the earth conductor is a little higher than that of near the high-voltage conductor at the frequency above 100 Hz. Because the excitation pulse width of the kicker magnet is 1125 ns, the excitation pulse contains high frequency components more than 100 Hz. Therefore, it is certain that the magnetic field at the earth conductor is a little higher than that of at the high-voltage conductor due to the effect of eddy currents.

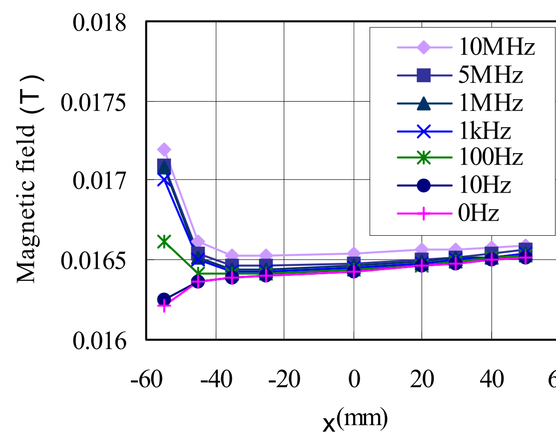

Figure 9: Dependence of the horizontal distribution of the magnetic field on pulse frequency

3 CONCLUSION

We designed and fabricated the kicker magnet. And we measured the magnetic field stability and distribution with a long search coil. To measure the field stability accurately, we used the coaxial type attenuators. In order to improve the signal to noise ratio, two signals are measured by switching the polarity of the search coil and averaged upon the changing the sign. The following results were obtained by the magnetic field measurement. The optimum values of the matching capacitance are 122 pF at the inlet and 295 pF at the outlet of the kicker magnet. The rise time of waveform is approximately 83 ns, and the flat-top time is 888 ns. The uniformity of the magnetic field is less than ±0.2% in the range of 85 mm. These results satisfy the design value.

4 REFERENCES

[1] T. Ohkawa et al, "Development of the kicker magnet for BSR," EPAC2000, Vienna, June 2000.