

# FAST-EXTRACTION KICKER-MAGNET SYSTEM FROM THE KEK-PS MAIN RING

T. Kawakubo, S. Murasugi, E. Nakamura, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan  
S. Tazawa, T.T.S., Ushiku, Tsukuba-shi, 305, Japan

## Abstract

A fast extraction kicker-magnet system from KEK-PS main ring has been developed for a neutrino-oscillation experiment. The kicker system comprises a Blumlein system (which includes a thyatron housing, a HV-DC power supply, two PFN cables (12.5Ω, 130m) and a matching resistor with diodes), a pulse transformer, two transmission cables and a twin-distributed-type kicker magnet. The height and width of the kicker magnet aperture is 55mm and 110mm, respectively. The effective magnet length is 300mm. When the PFN is added with 80kV, the system can produce a magnetic field of 0.14T with a flat top of 1μs and a rise time of 260ns. Although the magnetic strength is sufficient, the rise time is too long to match the desired value of 155ns. The main part of the long rise time comes from the deterioration of the current transmission through PFN cables and current rise time from the thyatron housing with the floating inductance. We are improving them in order to decrease the current rise time.

## 1 KICKER SYSTEM

### 1.1 Outline

We have adopted a Blumlein system, as shown in Fig.1 [1]. After firing the thyatron switch (CX2171: EEV), a negative half PFN-pulsed voltage arises, and goes from the left-end of PFN1 (two parallel of 25Ω co-axial cable) to the right. When the pulse reaches the right-end of PFN1, the total voltage of the right-end of PFN1 is zero, and the voltage difference between the right-end of PFN1 and the left-end of PFN2 (same component as PFN1) is  $V_{\text{PFN}}$ . Therefore, a pulsed current of  $V_{\text{PFN}}/Z$  flows through a primary conductor of a transformer. Secondary currents generated in the transformer pass through the transmission co-axial cables (same component as PFN1), and are connected to a twin distributed kicker magnet. This magnet has a structure such that two distributed kicker magnets (conventional type) face each other. In this case, both magnets have a half core width as the conventional one and their own inner conductors, but share the outer conductor with others. The outer conductor is the earth potential, which is set at the upper and lower core gap (sandwiched between a pair of ferrite core) so as not to interrupt the circulating beam. The pulsed currents which enter into both conductors are  $+V_{\text{PFN}}/(2Z)$  and  $-V_{\text{PFN}}/(2Z)$ , respectively. The current ( $I_m$ ) of the magnet coil is the same as that of the conventional system; however, the

transmission time ( $\tau_m$ ) is half, because of the half-gap width, which is obtained by

$$\tau_m = \frac{2\mu_0 \cdot aw}{h \cdot Z}, \quad (1)$$

where  $a$  is the length of the magnet;  $h$  and  $w$  are the gap height and width, respectively.

In order to double the magnet current, the end of the magnet is shorted. In this case, the transmission time in the magnet becomes double, which is the same value as that of the conventional system.

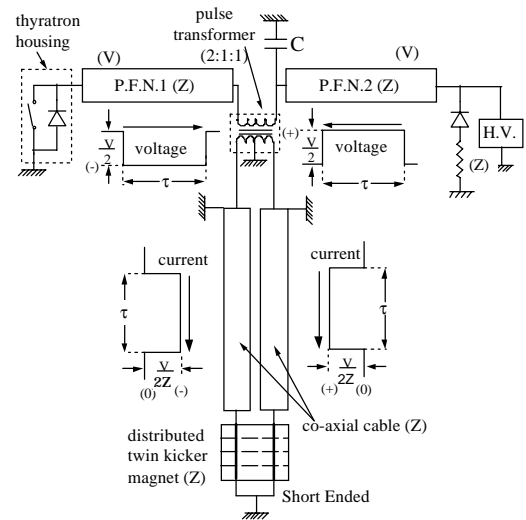


Figure 1: Kicker system for KEK-PS main ring extraction

### 1.2 Merits and Demerits of the New Kicker System

#### 1.2.1 Merits

1) The current height of the new system is double that of the conventional system. Therefore, the kick angle is double with the same characteristic impedance and the same magnet length. In the KEK-PS case, the characteristic impedance of the conventional and new system are 25Ω and 12.5Ω, respectively. Therefore, the kick angle of the new system is four-times larger than that of the conventional system.

2) The absolute potential of the inner conductor is  $V_{\text{PFN}}/2$ . Therefore, the location where a discharge might occur is only the closest point of both conductors, where the potential difference is  $V_{\text{PFN}}$ .

### 1.2.2 Demerits

1) A reflection current is generated at the ends of the magnet. These currents return to both PFNs, reflect at the ends of the PFN, and return again to the magnet. Therefore, many reflection currents appear successively in the magnet. (see Figs.3a and 3a')

2) When there is a stray inductance ( $L_s$ ) at the thyatron switch, the current rise time coming into magnet is  $L_s/Z$ , while that in the conventional system is  $L_s/(2Z)$ . In this case, the characteristic impedance of the conventional and new system (Blumlein) is  $25\Omega$  and  $12.5\Omega$ , respectively. Therefore, the rise time of the new system is four-times larger than that of the conventional system.

### 1.3 Improvement

In order to overcome the above mentioned demerits, we have made the following improvements:

#### 1) Diode set parallel to a Thyatron

The anode of a thyatron is added by the negative potential generated by reflection from the short ended magnet. This causes severe damage to the thyatron. Fig.2a shows the anode voltage of a thyatron, which is measured at a model circuit with  $V_{PFN}=1kV$ . In order to remove this problem, a diode is set parallel to the thyatron, as shown in Fig.1. Fig.2b shows that the negative voltage is perfectly cut by the diode.

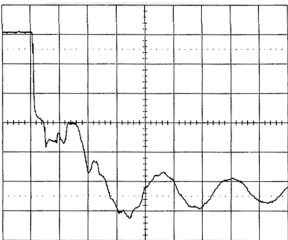


Figure 2a: Anode voltage without a diode

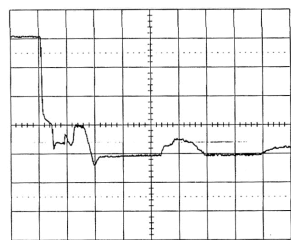


Figure 2b: Anode voltage with a diode

(Note) The zero voltage line is one division below the vertical center line (X:  $1\mu s/div$ , Y:  $250V/div$ ).

#### 2) Matched Resistor with a Diode

Figs.3a and 3a' show the magnetic field in the core gap measured by a long search coil at  $V_{PFN}=30kV$ . In this case, there is no matching resistor, and many reflections occur while being decayed by a stray resistance. These reflections can be partly suppressed (as shown in Fig.3b) by connecting a matched resistor (at the right end of PFN2 in Fig.1). The reason why the suppression is not perfect is that we cannot attach another matched resistor with a diode to the left end of the PFN1 because of the sign of the reflected current pulse.

#### 3) Speed up Capacitance

In order to speed up the rise time of the magnetic field, a capacitance is attached to the left-end of PFN2, as shown in Fig.1. We use eight parallel  $25\Omega$  co-axial cables with

a 7m length as a substitute for the capacitance. The rising speed is much shorter (Fig.4b) than that in the case with no capacitance (see Fig.4a).

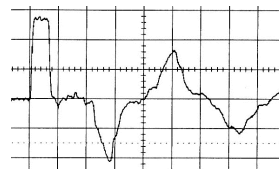


Figure 3a: Magnetic field without a matching resistor (X:  $2\mu s/div$ , Y:  $500mV/div$ )

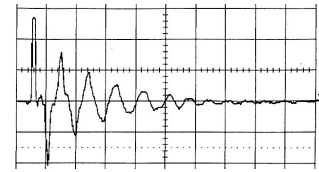


Figure 3a': Magnetic field without a matching resistor (X:  $10\mu s/div$ , Y:  $500mV/div$ )

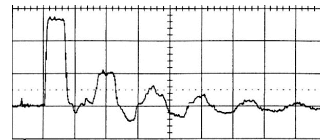


Figure 3b: Magnetic field with a matching resistor (X:  $2\mu s/div$ , Y:  $500mV/div$ )

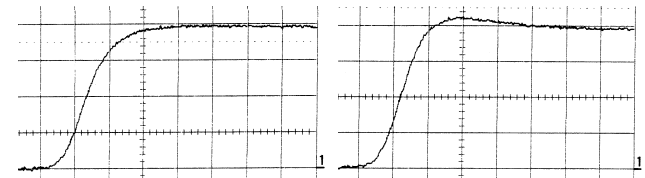


Figure4: Magnetic field by long search coil  
4a: without capacitance      4b: with capacitance  
(X:  $100ns/div$ , Y:  $1V/div$ ; at  $V_{PFN}=80kV$ )

### 1.4 Observed Magnetic Field

Fig.5 shows the magnetic field in the core gap at 80kV with a speed-up capacitance, as mentioned above. The rising time from 5% to 95% is 148ns, and the droop of the flat top is 8%. The dependence of the peak magnetic field of the core gap on the voltage of the power supply is shown in Fig.6. The measurement is in good agreement with the calculation (solid line). We can generate a magnetic field larger than the desired value of 0.11T.

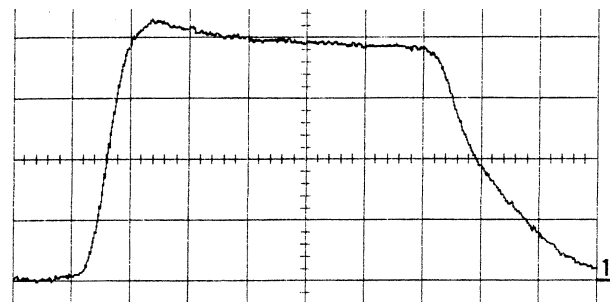


Figure 5: Magnetic field measured using a long search coil. ( $V_{PFN}=80kV$ ) (X:  $200ns/div$ , Y:  $1V/div$ )

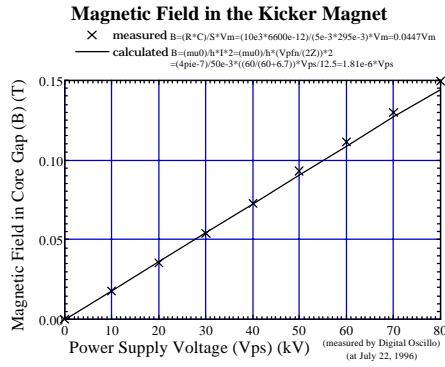


Figure 6: Dependence of the peak magnetic field of the core gap on the power supply voltage

Even if the magnetic field of the kicker magnet is ideal, the extraction efficiency to the beam-channel line is 98%, as shown in Fig.7 [2]. From this figure, the averaged efficiency caused by the error field from  $-6\%$  to  $+2\%$  is about 97%. Therefore, when this system is used for extraction in which the bunch spacing is 155ns, the beam loss would be 1% less than that of the ideal kicker field.

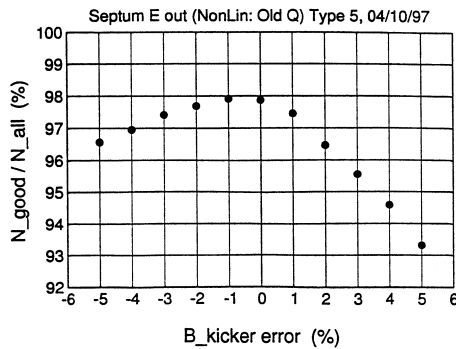


Figure 7: Dependence of the beam extraction-efficiency on the kicker magnetic field error.

## 2.5 Further improvement

### 1) Decreasing the floating inductance and capacitance of the thyatron housing

At first, we thought that the main reason for the slow current rise time is due to the floating inductance and capacitance of the thyatron housing. We therefore tried to decrease the diameter of the outer conductor (earth potential) surrounding the thyatron tube and to remove the insulating oil ( $\epsilon=2$ ) from the housing. By these changes, the floating inductance decreased to half that of the original with almost the same floating capacitance. However, the current rise time was not changed at all. The main part of the slow current rise time might come from a deterioration of the current transmission through the PFN cables, which is due to the inner and outer conductors of the cable covered by a semi-conductor layer against electric discharge.

### 2) Spark Gap

The rise time can be decreased by spark gaps set at the center of the co-axial cable between the transformer and the magnet (see Fig.1), as shown in Fig.8a [3]. However, since the time jitter of the spark gap is about 100ns, as shown in Fig.8b, it cannot be used for normal operation.

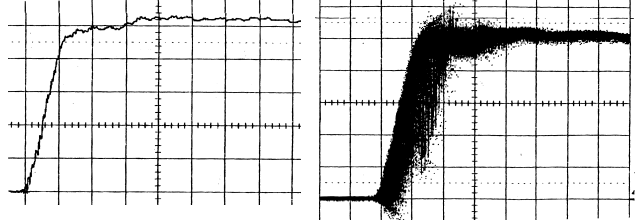


Figure 8a: Single shot (improved by spark gaps) Figure 8b: Multi shots (much time jitter happens)  
Magnetic field in the gap measured by long search coil

(100ns/div) ( $V_{PFN} = 80$  kV)

### 3) New system

The rise time of the current caused by stray inductance in the thyatron housing of the single line system (conventional type) is  $L_s/(2Z)$ , while that of the Blumlein system is  $L_s/Z$ . Therefore, we will test the new system of a twin kicker magnet with two single (conventional type) line power supplies, as shown in Fig.9. In this system, every kicker magnet has its own single line system, and the reflection current will be perfectly absorbed.

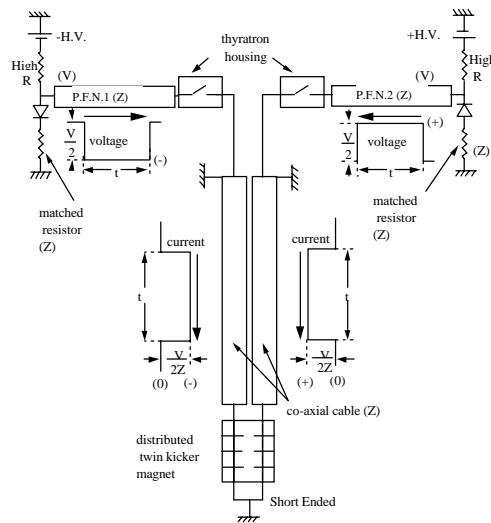


Figure 9: Improved kicker system with two single lines.

## 2 REFERENCES

- [1] T. Kawakubo et al, EPAC96, Spain, June, 1996
- [2] N. Tokuda, KEK-PS, private communication, April, 1997
- [3] T. Kawakubo et al, XVI RCNP, Osaka, Japan, March, 1997