THE KICKER MAGNET SYSTEM USED TO GENERATE A HIGH MAGNETIC FIELD WITH A FAST RISE AND A LONG FLAT TOP

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Abstract

The KEK-PS has used the slow extraction system from the main ring. A neutrino oscillation experiment has been proposed,[1] which requires a fast extraction system, which should be constructed in the near future. In order to extract nine bunches of the 12-GeV beam successively, the magnetic field of the kicker magnet should have a rise time less than 30ns, the flat top should be more than 1.1µs and the strength should be higher than 0.11T. The desired rise time is so short that one of nine bunches is not injected, which means that the space for the rise time is 155ns. In order to double the magnetic field and eliminate any discharge in the kicker magnet, we use a Blumlein system with a “distributed twin kicker magnet”.

1 REQUESTED KICKER FIELD

1. Bunch spacing (τ_s): The space between a bunch and the following bunch is about 30ns at the extraction of the main ring. Although the magnetic field in the kicker should rise within this space, it is too short for the present technique. Thus, one of the nine bunches is not injected in order to ensure the rise time of the kicker magnet (Fig.1). Therefore, the bunch spacing (τ_s) is 155ns.

2. Flat top (τ_f): Eight bunches are extracted successively. Since the time distance between the bunch peak and the following one is 125ns at extraction, the required flat top used to extract the successive eight bunches is (see Fig.1) (τ_f) is 970ns.

3. Magnetic field (B): The magnetic field is

$$B = \frac{(B\rho)_{12GeV}}{a_T} \cdot \theta_T , \qquad (1)$$

where a_T is the total longitudinal magnet length, $(B\rho)_{12GeV}$ the rigidity at 12GeV and θ_T the total kick. By inserting the concrete values ($(B\rho)_{12GeV}$ =43.04[Tm], a_T =2[m], θ_T =5*10^{-3}[r]) into eq.(1), B=0.11[T] is obtained.

2 HOW TO GENERATE A FIELD

In order to generate a magnetic field, we check the merits and demerits in various kicker systems using following formula concerning the distributed kicker magnet:

1. Kick angle: $\theta = \frac{1}{(B\rho)} \cdot \frac{V_{ef} \cdot \tau_m}{w}$, (2)

where θ is the angle by one kicker magnet, V_{ef} the added kicker voltage to the kicker and τ_m the transmission time through the core gap of a kicker magnet, obtained using

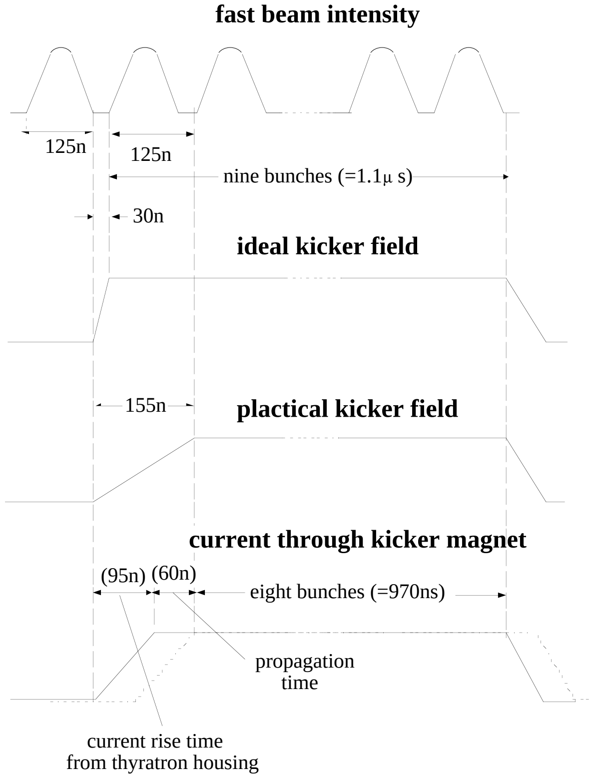

Figure:1 Bunch spacing and kicker rise time.

$$\tau_m = \tau_s - \tau_r , \qquad (3)$$

where τ_r is the rise time of the current coming to the kicker magnet.

2. Magnet length: $a = \frac{1}{\mu_0} \cdot \frac{h}{w} \cdot \tau_m \cdot Z$, (4)

where a is the longitudinal length of one kicker magnet, Z is the characteristic impedance and h and w are the height and width of the core gap, respectively.

3. Number of kicker magnets: $N_k = \theta_T / \theta$, (5)
where N_k sets of kicker magnets are needed to kick the beam with an angle of θ_T.

4. Total longitudinal space (a_T): $a_T = N_k * a_1$, (6)
where a_1 is the longitudinal space to set one kicker magnet, including an additional space (a_s) for an inlet conductor of the magnet ($a_1 = a + a_s$).

5. Typical value:
- ∗ PFN (two parallel of 25Ω co-axial cables) voltage (V_{PFN}): 70∗10^3[V].
- ∗ Characteristic impedance (Z): 12.5[Ω].
- ∗ Additional space (a_s): 50∗10^{-3}[m].
- ∗ Aperture of the magnet core gap: height (h)=50∗10^{-3}[m], width (w)=110∗10^{-3}[m].

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[1] K. Nishikawa et al., KEK Preprint 93-55/INS Report 297-93-9.

* Transmission time (τ_m): inserting τ_s=155*10^{-9} [s] and τ_r=95*10^{-9}[s][2] into eq.(3), τ_m=60*10^{-9} [s].

2.1 Conventional System of KEK-PS

The conventional system of the KEK-PS kicker magnets, which are used for extraction from the booster ring and injection into the main ring, is shown as Fig.2. Since the half voltage of the PFN (V_{PFN}) is added to the kicker magnet, the kick angle deduced by eq.(2) is

$$\theta = \frac{1}{(B\rho)} \cdot \frac{V_{PFN} \cdot \tau_m}{2w} \quad . \qquad (2')$$

Upon inserting the values given in section 2 into the above equation, θ=0.44*10^{-3}[r], and into eqs.(5) and (4), we obtain $N_k \geq 12$ and a=271*10^{-3}[m], respectively. Therefore, a_1=321*10^{-3}[m], a_T=3.85[m]. This length is almost double the allowed space for setting the kicker magnets. This system has another demerit that the thyratron cathode is a floating potential. Since the power supply for the heater and the reservoir of the thyratron should be isolated from the earth potential by transformers, the floating capacitance between the cathode and the earth increases and the switching on time is increased[3].

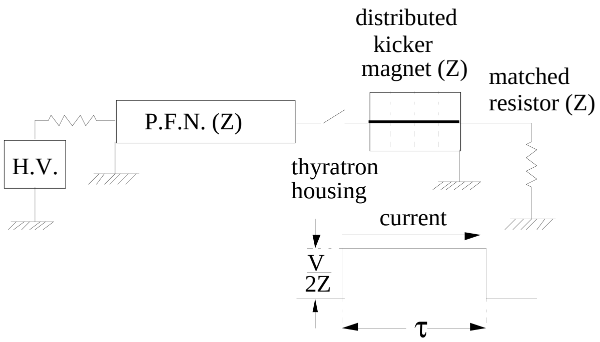

Figure:2 KEK-PS conventional kicker system.

2.2 Blumlein System

In this system (see Fig.3), the full voltage of the PFN is added to the kicker magnet. Thus, the kick angle is double the case in the conventional system,

$$\theta = \frac{1}{(B\rho)} \cdot \frac{V_{PFN} \cdot \tau_m}{w} \quad . \qquad (2'')$$

However, the magnet tends to discharge because a full PFN voltage is added to it. There are also other demerits. Since the outer conductor of the transmission cable is connected to the inner conductor of a PFN 1 cable, its potential changes to -V_{PFN}/2 after turning on the thyratron switch, and the floating capacitance between the outer conductor and the earth is big.

[2] Since the PFN cable length is as long as 130m, the rise time of the current from the thyratron housing is greatly increased. If we can decrease it by some technique, such as "Shock Line" (private communication by R. Cassel at SLAC), we can use a longer τ_m.

[3] T. Kawakubo et al., N.I.M.A306 (1991) p426

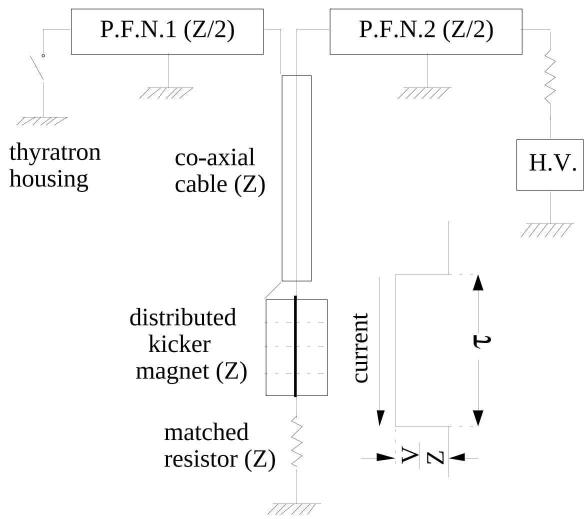

Figure:3 Blumlein system.

2.3 Blumlein system with a pulse transformer and a matched twin kicker magnet

The "distributed twin kicker magnet" has a structure such that two kickers face each other, as shown in Fig. 4. Since each magnet is connected to a secondary coil of the transformer via a transmission coaxial cable, as shown in Fig.5, they are added by the pulsed potential of $\pm V_{PFN}/2$, respectively. Compared to the conventional distributed kicker magnet, the transmission speed is double, because of the half-core width (w) (i.e., half inductance). Since the magnetic field inside the core is the same as the conventional one, the total kick angle is double with the same transmission time (see eq.(2')), however in this case, the magnet length is twice the conventional one (see eq.(4)). In this system, a discharge of the magnet hardly occurs because the absolute potential values added to inner coils are half the PFN voltage.

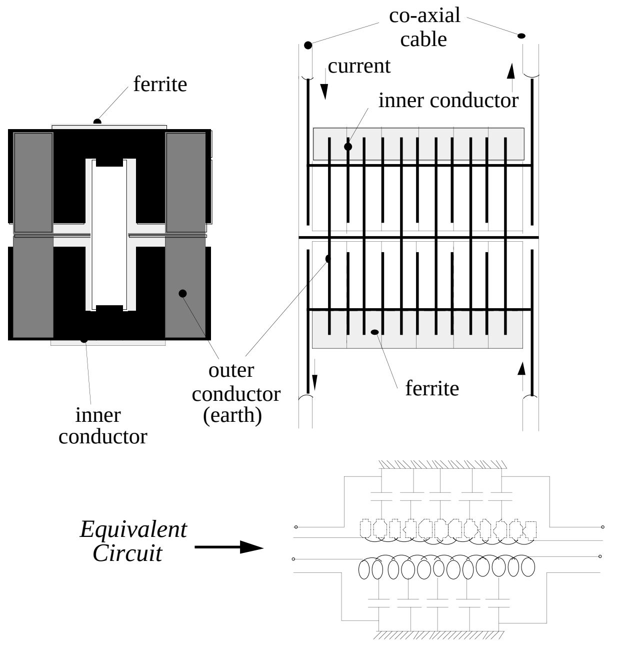

Figure: 4 Structure of the distributed twin kicker magnet.

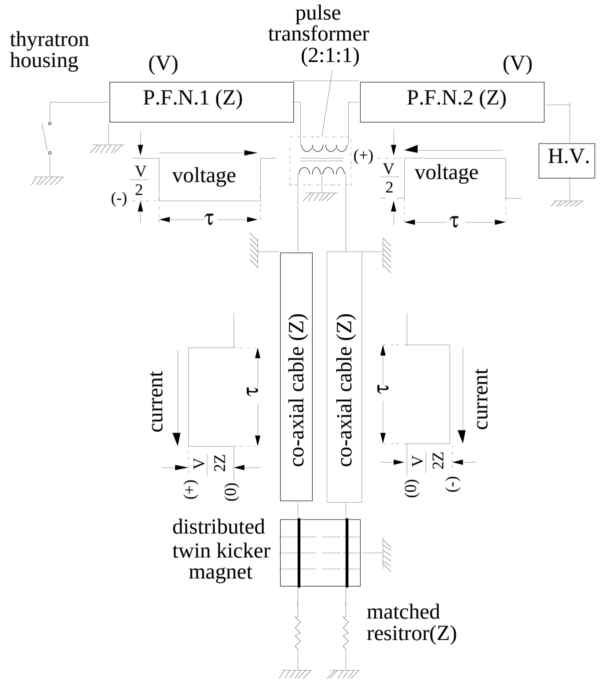

Figure: 5 Blumlein system with a matched twin kicker.

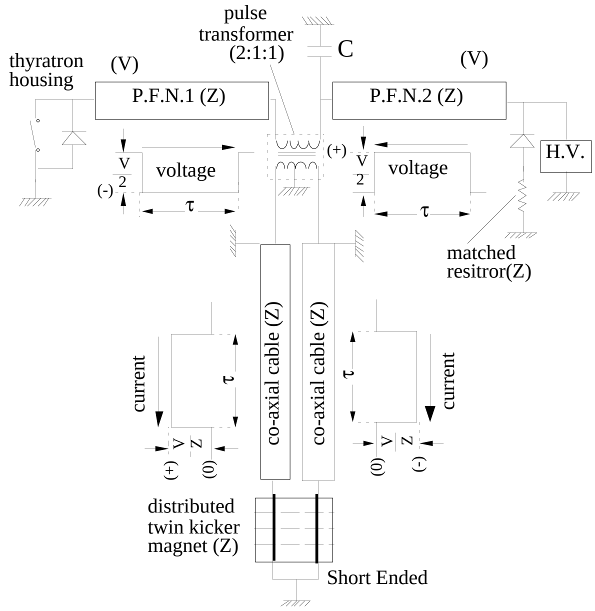

Figure: 6 Blumlein system with a short-ended twin kicker.

2.4 Blumlein system with a pulse transformer and a short-ended twin kicker magnet

In order to cut the magnet length in half while maintaining the same kick angle, the following system (see Fig.6) has been introduced. Since the magnet ends are shorted instead of connecting with matched resistors, the current through the magnet becomes double. The transmission time (τ_m), however, becomes double because of the current returning time from the end to the entrance of the magnet. By decreasing the magnet length half, we can make a magnet having the same transmission time and kick angle as that of the former system. Therefore, the length is

$$a = \frac{1}{2} \cdot \frac{1}{\mu_0} \cdot \frac{h}{w} \cdot \tau_m \cdot Z \ . \qquad (4')$$

The reflected currents at the ends of the magnet go to the transformer and spread to the thyratron and DC power supply via PFN cables. These cause a negative potential to the anode of the thyratron, and deteriorates the tube. Fortunately, since our kicker is for beam extraction, the circulating beam does not remain when the reflected current comes to the kicker magnet again. In order to eliminate the negative potential added to the thyratron anode and to decrease the reflected current, a diode is set parallel to the thyratron, and another with matching resistance is set at the end of the PFN 2 cable. A special capacitance is added to the entrance of the PFN2 in order to decrease the rise time of the current. Upon inserting w=110/2*10^{-3}[m] into (2'), the kick angle becomes θ=0.89*10^{-3}[r]; using eqs.(5) and (4'), we obtain $N_k \geq 6$ and a=271*10^{-3}[m], respectively. Thus, a_1=321*10^{-3}[m], a_T=1.93[m] . This length is less than the allowed space for setting the kicker magnets.

3 MEASURED RESULTS

The system shown in Fig.6 was constructed and the magnetic field was measured, as shown in Fig.7. Since the kicker magnet is a primitive model having weak insulation with a gap height (h) of 50mm, a width (2w) of 174mm and a length (a) of 295mm, the added PFN voltage is only 18kV. According to the measured flat-top magnetic field of 3.5*10^{-2}T, it will be 0.14T at a PFN voltage of 70kV, which is larger than the desired value. The rise time is, however, about 200ns[4], which is slightly longer than the desired value. The flat top is 1.4μs, which is much longer than the desired value.

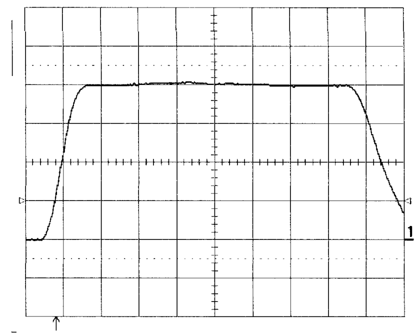

Figure: 7 Magnetic field in the core gap of a short-ended kicker magnet. (X:200ns/div, Y:8.8*10^{-3}T/div)

[4] In order to decrease the rise time, two sets of 25Ω co-axial cables with 10m length are connected for the capacitance (C) in Fig.6. The causes of the long rise time comes from the large transmission time (τ_m: calculated to be 103ns by eq.(4')) and the long rise time of the current from the thyratron housing (τ_r=120ns). There is a plan to decrease the latter value, as mentioned in Footnote 2.