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KICKER MAGNET GENERATING HIGH MAGNETIC FIELD WITH LOW IMPEDANCE

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ABSTRACT

A PFN type kicker magnet with low impedance which can generate a high magnetic field with rapid rise time is introduced. The characteristics of this magnet were measured and are in good agreement with the design values.

INTRODUCTION

The field strength of kicker magnets used in most proton synchrotrons is about 0.4 kG[1,2] , which is very small compared with the saturating field in ferrite of 3 kG. The reason is that a short rise time is preferred to saving longitudinal space for the magnet.

For future synchrotrons, however, keeping the longitudinal space small will also become important. Therefore, we wanted to make a kicker magnet which can generate a high magnetic field of 3 kG with 150 ns rise time. In order to keep the charging voltage of the PFN to within the practical range, the characteristic impedance of this magnet should be small. In the following sections, basic formulas to design the kicker magnet are introduced and the technique of how to make the characteristic impedance low is explained. Measurements of the dispersion relation and Q-value are in good agreement with an equivalent electric circuit calculation. The voltage of the coil plate at every cell and the magnetic field in the core gap were also measured.

DESIGN

When a kicker magnet kicks a charged particle θ, the magnet length (l_m) is required as

$$l_m = \frac{(B\rho)\,\theta}{B_g} \tag{1}$$

where, $(B\rho) = p/e$ is the magnetic rigidity of the particle, B_g the magnetic field in the gap and we use the maximum saturated value in ferrite of 3 kG as the field. In order to generate B_g in the gap with a height h, the needed current is

$$I = \frac{B_g\,h}{\mu_0} \tag{2}$$

The ideal PFN type kicker magnet is the equivalent electric circuit as shown in Fig. 1.

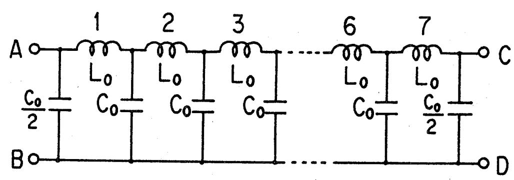

Fig. 1

The equivalent circuit of the ideal PFN type kicker magnet.

The characteristic impedance (Z) is related to the inductance (L_0) and capacitance (C_0) of the unit cell by

$$Z = \sqrt{\frac{L_0}{C_0}} \tag{3}$$

where,

$$L_0 = \frac{\mu_0\,l_0\,w}{h} \tag{4}$$

with w and l_0 are the gap width and the thickness of a unit core, respectively. And the Z is also related to I and the charging voltage (V_{PFN}) by

$$Z = \frac{V_{PFN}}{2I} \tag{5}$$

Therefore, To increase the current (I) with keeping V_{PFN} in a rage of practical use, Z should be decreased. However, As the capacitance of the conventional kicker magnet is made by metal plates facing each other attached to each coil at every cell, it is difficult to have a large magnet capacitance, and the impedance calculated by (3) is too large to satisfy (5)

We increase the capacitance by connecting capacitors between the plates. The plan of this magnet is shown in Fig. 2.

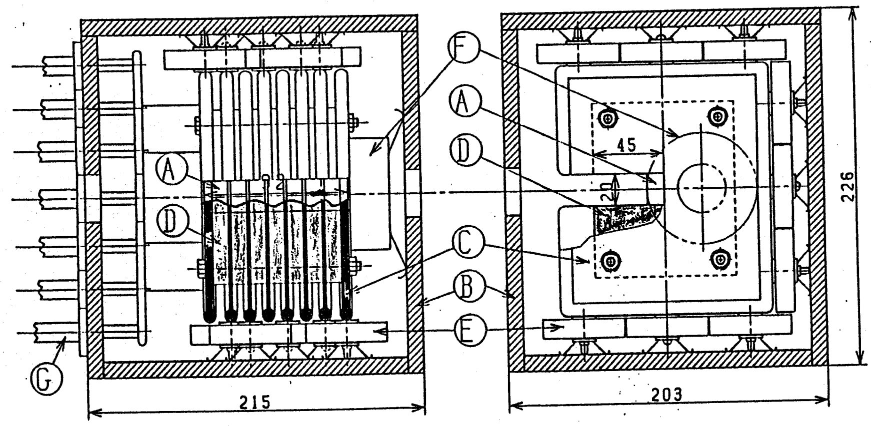

Fig. 2 The plan of the PFN type kicker magnet generating a high magnetic field with impedance, where (A) coil with high potential, (B) coil with earth potential, (C) m plate connecting coil to a condenser, (D) ferrite core, (E) condenser, (F) matc resistor and (G) 50 Ω Coaxial cables in 27 parallel.

The rise time of the total magnetic field is calculated by

$$\tau = N\sqrt{L_0 C_0} \qquad (6)$$

where N is the cell number. The relation between Z and τ is obtained by (3) and (6) as

$$\tau = \frac{N L_0}{Z} \qquad (7)$$

Therefore, decreasing the impedance causes an increase of the rise time. If the rise time calculated by (6) is larger than the design value required from the beam extraction time, the magnet should be separated to two magnets which are attached by their own power supplies.

In order to generate a magnetic field of 3 kG in a core gap of 20 mm, an electric system was constructed as shown in Fig. 3.

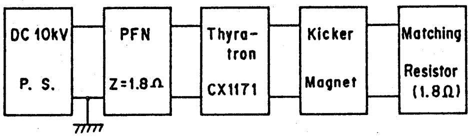

Fig. 3. The block diagram of the kicker magnet system.

The design parameters are listed in Table 1.

ITEM	SYMBOL	DESIGN VALUE
Gap height (mm)	h	20
Gap width (mm)	w	45
Total core length (mm)	ℓ_m	89
Cell number	N	7
Inductance of a unit cell (nH)	L_0	36
Capacitance of a unit cell (nF)	C_0	11
Characteristic impedance (Ω)	Z	1.8
Gap field (kG)	Bg	3
Coil current (kA)	I	4.8
PFN voltage (kV)	V_{PFN}	17.4
Field rise time (ns)	τ	138

Table 1. The design parameters of the kicker magnet.

MEASUREMENT

From the measurement by an impedance meter at the first cell ((A) and (B) at Fig. 1) by short and open of the coil plates at the end cell ((C) and (D) in the above fig.), the dispersion relation and the dependence of the Q-value on the frequency were obtained as shown in Fig. 4 and Fig. 5, respectively.

The calculated results by using the equivalent circuits shown in the top figures of Fig. 4 and Fig. 5 are also plotted in the same figures with dotted curves, where $C_0 = 10nF, L_0 = 49.5nH$,

$c_1 = 1.33 \times (C_0/2)$

and $r = 7.22 \left(\frac{f}{f_c}\right)^{3.49}$ (Ω) ($f_c = 14.3\,MHz$)

It can be said that the measurement and calculation are in good agreement with each other.

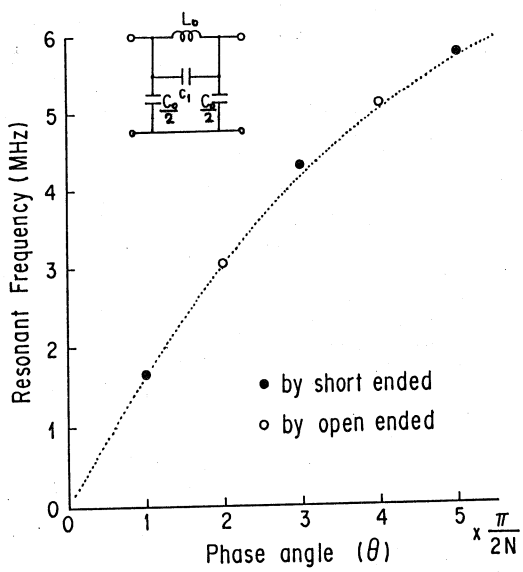

Fig. 4 The dispersion relation of the kicker magnet.

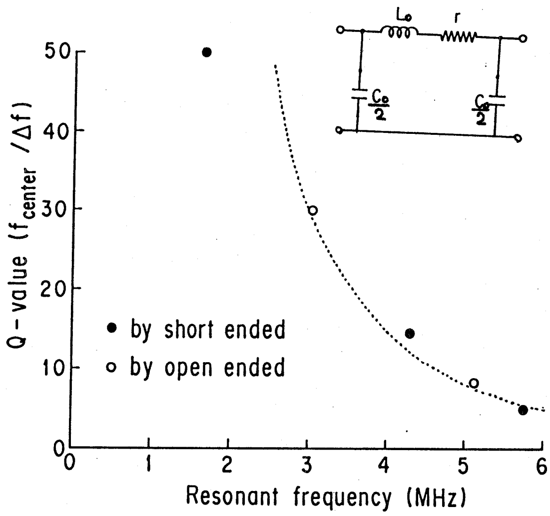

Fig. 5

The dependence of the Q-value of the kicker magnet on the frequency.

The voltage pulse at the electrode of the first and the last cell ((A) and (C) in Fig. 1) are shown in Fig. 6.

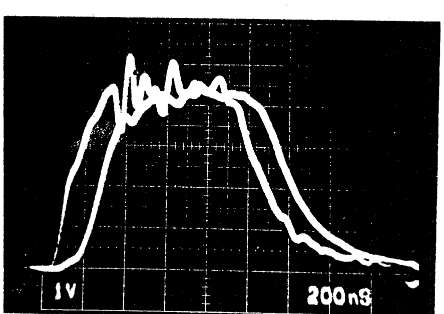

Fig. 6

Voltage of the electrode of the first and last cell, where the scale is 200 ns/div and 1 kV/div.

The magnetic field was measured by a search coil with a width of 10 mm and a length of 300 mm through the measuring system shown in Fig. 7.

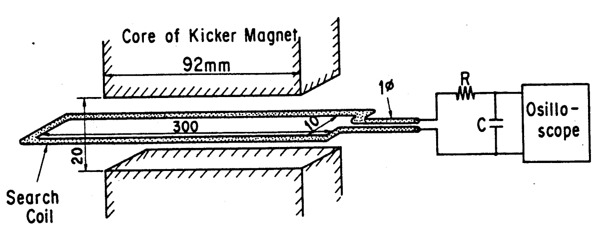

Fig. 7

The measuring system of the the kicker magnet field, where R=100 kΩ and C=1.4 nF.

As the length of the search coil is longer than the magnet, the output signal of the magnetic field shown in Fig. 8 is the average of two figures in Fig. 6.

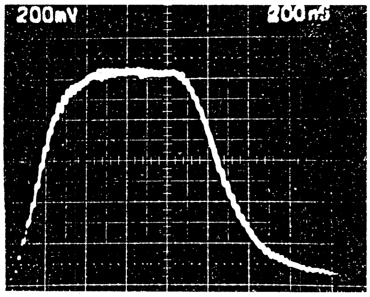

Fig. 8

The magnetic field in the gap of the kicker magnet, where the scale is 200 ns/div and 200 mV/div.

The measurment shows that our kicker magnet generates a magnetic field of 1.6 kG with a rise time of 400 ns. The reason why the magnetic field is smaller and the rise time is longer than the design values is that the maximum output of our DC Power Supply (10 kV) for charging the PFN is about half the design value and the turn-on time of the Thyratron is long because its standard operating voltage is 120 kV and is too high for our present operation.

CONCLUSION

By connecting condensers to the coil plates of the kicker magnet, the magnet has low characteristic impedance of 1.8Ω and generates a gap field of 1.6 kG with a rise time of 400 ns. Those values do not reach the designed ones because of the low output of our DC power supply and of the much larger standard operating voltage of the Thyratron than the operated value. Therefore, we are intending to increase the DC output voltage and change the Thyratron to a suitable one. By the measurement of the dispersion relation and Q-value, the equivalent circuit of this magnet was obtained.

ACKNOWLEDGEMENTS

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