Pulsed Septum Magnet with a Wide Flat-top

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Abstract

At the cyclic particle accelerators, we usually use the septum magnets when the beam is injected and extracted.

When the magnetize current is an impulse wave but not a D.C. wave we need level the highest point of the pulse.

At the KEK PS accelerators, till today duration of the flat-top has been 100 μsec(4-msec base and 8000 A peak).

Because we made the new power supply which is expected to 350 μsec (At the same base and peak current). we want to report the circuit and principle, and conclusion.

1 Introduction

In KEK, proton accelerator consists of many sections, pre-injector, linac, booster, and main-ring. (Fig-1)

When the beam is extracted from the booster, the frequency of acceleration is 6.027-MHz, and when the beam is injected to the main ring, it is 6.017-MHz.

Because there is difference of 10-kHz between the two frequencies, the perfect transport timing comes every 100 μsec.

So we have needed the pulsed septum magnet, where the duration of the flat-top is 100 μsec, but recently, we need the longer flat top time, to answer to the sift of the center of the shaking time, and the difference of the frequency. Structure of the circuit is shown in Fig-2(a). Resonance circuit consists of the condenser-(C_0) and the reactive load-(L_0).

Fig-2(b) is sinusoidal current and the voltage of the load.

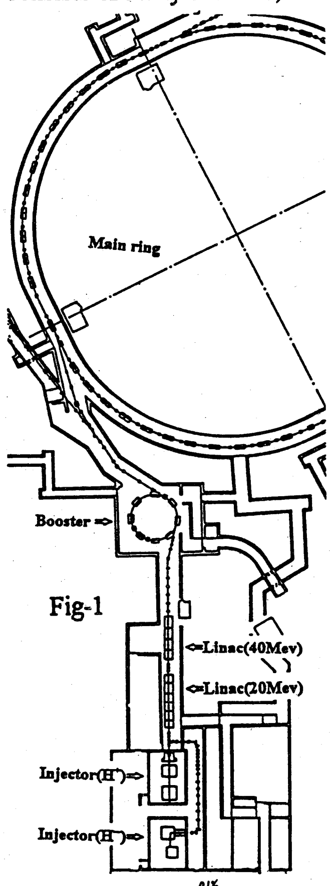


Fig-1

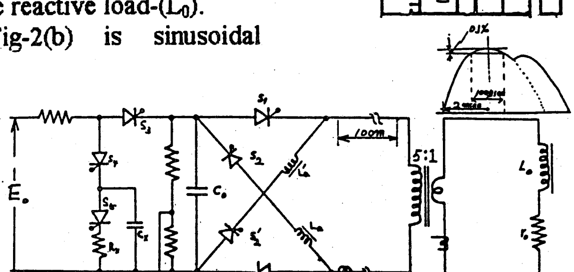


Fig-2 (a)

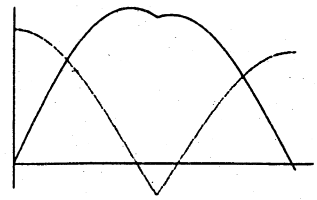


Fig-2 (b)

But, when a center of the shaking time moves we must adjust every time. Also when the difference of the frequency is less than 10-kHz the beam is injected a way from the closed orbit occasionally.

Therefore, we have to increase the flat top time of the pulse, twice or more.

2 Requirement of the Pulse Format at a Rating of the Load

There are several methods to increase duration of the flat-top of the pulse. But we must use the existing load and transformer.

The specifications on the load magnet are in the following:

1) Peak current must be about 8000-A.
   (Output of the power supply is 1600-A.)

2) Peak of the voltage (maximum of L_0*dI/dt) is less than 200-V.
   (Output of the power supply is 1000-V.)

3) Product I*t of the load is less than 270-Asec/pulse.
   (Output of the power supply is 55-Asec/pulse.)

These requirements are derived from view point of heat, voltage, magnetic saturation of the core of the transformer and droop in the secondary current.

In order to the requirements (1)~(3), the form of the pulse must be like the trapezoid only: neither sinusoidal current with wider base nor P.F.N. can be used.

3 Construction and Calculation of the New Type Power-supply

3.1 Principle

Fig-3 shows principle of the construction of our circuit. In the circuit, the current of the coil (L_0) satisfies the next differential equation.

$$\frac{d^4 I}{dt^4}+\left(\frac{1}{C_0 L_1}+\frac{1}{C_1 L_0}+\frac{1}{C_1 L_1}\right)\frac{d^2 I}{dt^2}+\frac{I}{C_0 C_1 L_0 L_1}=0 \qquad \cdots\cdots(1)$$

The general solution $I_0(t)$ of this equation appears

$$I_0(t)=A\cos\omega_1 t+B\sin\omega_1 t+C\cos\omega_2 t+D\sin\omega_2 t \qquad \cdots\cdots\cdots(2)$$

[A,B,C,D are integral constants and ω_1^2, ω_2^2 are roots of the equation $x^2-\left(\frac{1}{C_0L_1}+\frac{1}{C_1L_0}+\frac{1}{C_1L_1}\right)x+\frac{1}{C_0C_1L_0L_1}=0$]

Now, as the initial conditions,

$$\begin{pmatrix} E_{C_0}(0)=E_{C1}(0)=E_0 \\ I_{L_0}(0)=I_{L1}(0)=0 \end{pmatrix} \Rightarrow \begin{pmatrix} I_0(0)=\ddot{I}_0(0)=0 \\ \dot{I}_0(0)=E_0/L_0 \\ \dddot{I}_0(0)=-E_0/C_1L_0^2 \end{pmatrix} \quad \cdots\cdots(3)$$

Equation(2) is then changed as

$$\begin{pmatrix} I_0(t) = A_1\sin\omega_1 t + A_2\sin\omega_2 t \\ \omega_1 A_1 + \omega_2 A_2 = E_0/L_0 \\ \omega_1^3 A_1 + \omega_2^3 A_2 = E_0/C_1L_0^2 \end{pmatrix} \quad \cdots\cdots\cdots(4)$$

Further we take the values of C_0, C_1, L_0, L_1

$$\frac{C_1}{C_0} = \frac{L_1}{L_0} = \frac{n}{(n-1)^2}\left(=\frac{1}{p}\right)$$

We obtain $\frac{\omega_2}{\omega_1} = n \quad \left(= \frac{p-2\pm\sqrt{p(p-4)}}{2}\right)$

and equation (4) is

$$I_0(t) = \frac{n^2}{(n^2-1)\omega_0 L_0}E_0 \sin\frac{n-1}{n}\omega_0 t + \frac{1}{(n^2-1)\omega_0 L_0}E_0\sin(n-1)\omega_0 t \quad \cdots\cdots (5)$$

$$\left[\omega_2 > \omega_1 > 0, \quad and \quad \omega_0 = 1/\sqrt{C_0L_0}\right]$$

When we choose n to 4m-1 (m is integer), equation (5) appears on Fig-4 (a) , (b) , (c) and (d) for m=1,2,3 and 4, respectively.

For n (=4m-1), most desirable one is 3, but we adopt 11 because of too high inductance(L_1), longer base-line and ringing. ($C_1/C_0 = L_1/L_0 = 0.11$).

It can be confirmed easily that if a capacity and initial voltage of the condenser-(Co) are same at the circuit of the Fig-2. The peak current and maximum voltage of the load-(Lo) are same also but a skirt of the pulse is expanding a little(n/(n-1)time).

This is one of the reason which we could not adapt 3 or 7 for n.

3.2 Construction

For the circuit of the new power supply is shown in Fig-5. The equation of this circuit is given like the equation(1). (For d/dt=>D)

$$\{(C_0D+g_0)(C_1D+g_1)(L_0D+r_0)(L_1D+r_1) + (C_0D+g)(L_1D+r_1)+(C_0D+g_0)(L_0D+r_0) + (C_1D+g_1)(L_0D+r_0)+1\}I_0=0 \cdots\cdots\cdots(6)$$

Where $L_1=L_{11}+L_{12}+2M+L_2$, g_0,g_1,r_0 and r_1 are conductance and resistance of C_0,C_1,L_0 and L_1, respectively.

Since it is very difficult to solve this equation, and also we don't find out the correct value of L_0 and r_0, we have provided many corrective condensers in order to fine-adjust the C_1-value, and varied M by changing the distance between the two coils.

4 Adjusting C_0,C_1 and L_1

4.1 C_0

We adjust the C_0 under the suitable C_1,L_1 ($C_1 \fallingdotseq C_0/10$, $L_1 \fallingdotseq L_0/10$).

Consequently we obtain C_0 = 2700 μF, but this value is larger than old one (C_0=2200 μF).

4.2 C_1

By changing the C_1, we adjusted a flat-top to lie on a straight line; not-curving on the top.

The width of flat-top, having 0.1% flatness, is slightly increased by making a concave shape at the top ; this is done by using smaller C_1 value.

4.3 L_1

By changing the L_1, we leveled the highest point (straight line). Firstly, we adjust roughly for exchanging taps and bring the straight line to near the top. Secondly, we adjust the details for changing M (moving the coil L_{11})

A pulse motor is mounted to adjust L_1 from the remote central control room, too.

5 Driving the Power-supply with Load

We take 210 μF and 175 μF for C_1, and 2700 μF for C_0.

The current wave form by the current transformer (CT) is shown in Fig-6; (a) is the case for an old power supply , (b) is new one. And expanded top shapes of these curves are shown in fig-7; (a) is for conventional resonant network, (b) and (c) for C_1=210 μF and 175 μF, respectively.

It can be seen that time of flat top is expanding from 2.5 to3.5 times rather than that of the old one.

6 Test by the Beam

Then we studied magnetic field wave of load magnet by passing 500MeV proton beam through it. Kicked angle of beam was studied using profile monitor. Result of the test is shown in Fig-8.

It appears that (a) : real positions at a profile monitor and (b) : variation of a kick angle by the septum magnet which is calculated from(a). (○:C_1=200 μF, ●:C_1=175 μF)

7 Conclusion

Because there is no large difference between Fig-7 and Fig-8, it is adequate to adjust using C_1 and L_1,which have the parameter near the calculated value, only by seeing the current wave form from the CT.

Acknowledgment

The authors thank Mr.Y.Arakida who helped taking data and exchanging condenser and tap of coil, and Mr.T. Tanigaki (I. D.X.) who made the power supply accepting our difficult orders.

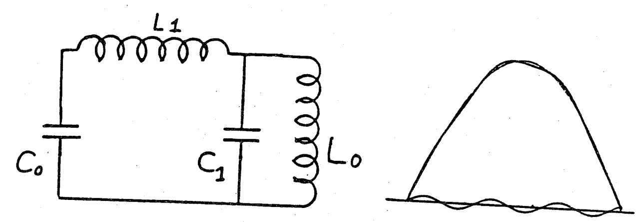


Fig-3

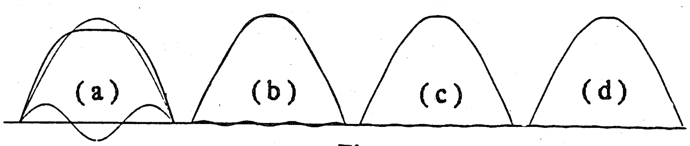


Fig-4

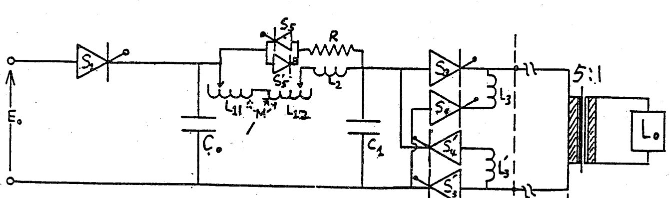
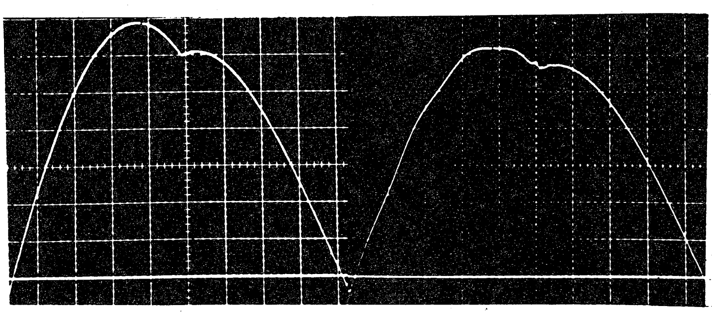
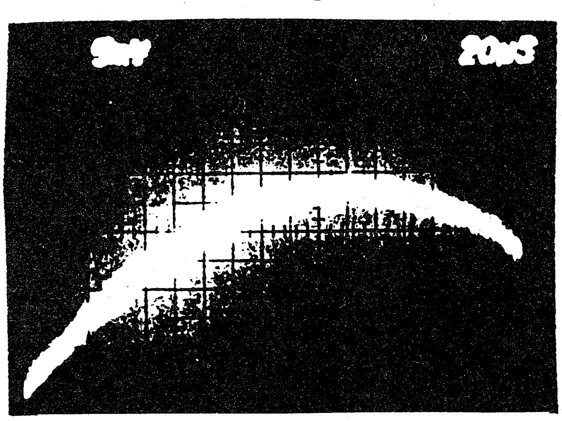


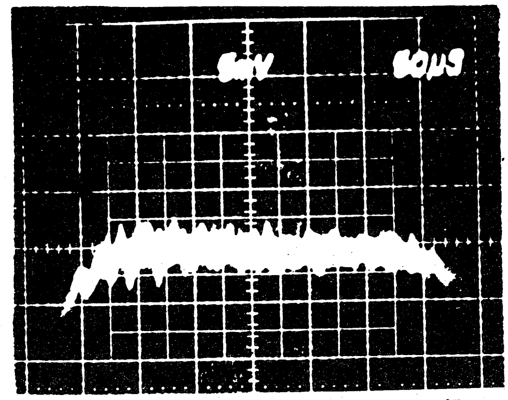
Fig-5



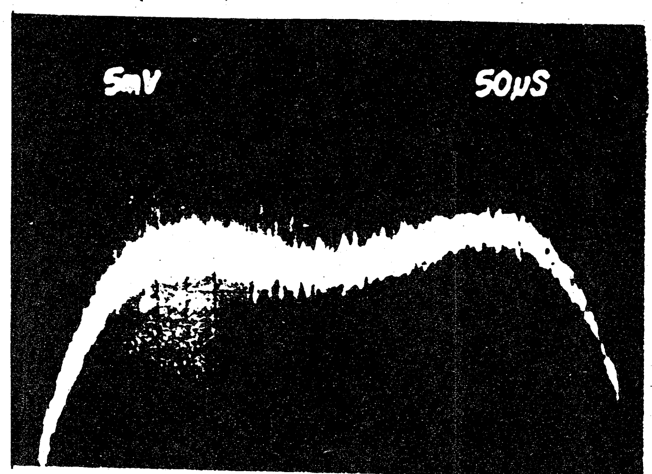
(a) 1000A/D , 500μsec/D (b)
Fig-6



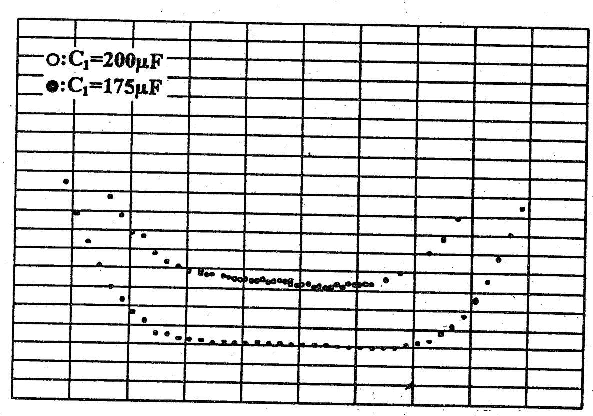
10A(~0.15%)/D Fig-7(a) 20μsec/D



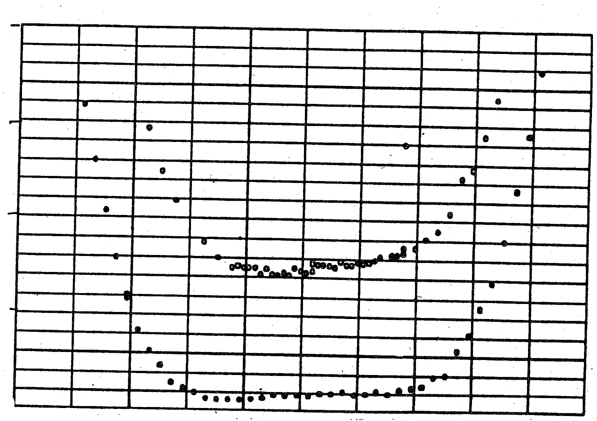
10A(~0.15%)/D Fig-7(b) 50μsec/D



10A(~0.15%)/D Fig-7(c) 50μsec/D



2.5mm/D Fig-8(a) 100μsec/D



0.2 %/D Fig-8(b) 100μsec/D