SLAC-TN-14-003
Replaces: SLAC CN-256

# Beam-dump Kicker Magnets

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# MAJOR COMPONENTS:

1. Thyratron – English Electric Type CX1574C deuterium-filled ceramic thyratron.
   35 KV, 15 KA peak, 6 Adc.
   Fil. 6.3 V @ 40A, Res. 5V @ 10A.
2. Diode – EG&G Type HR-3 hydrogen-filled ceramic diode.
   25 KV, 2 KA peak, 2 Adc.
   Fil. 6.3 V @ 15A, Res. 6.3V @ 6A.
3. Charging Diode – Unitrode Type UDA-15 rectifier stack, 15 KV P.I.V., 0.67 Adc, 30 A surge. (3 required, series connected)
4. Storage Capacitor – High voltage ceramic disc, 0.0027 μF, 30 KV, TDK Type UHV-6 or ERIE Type DHS60 N4700 272M-30. (15 required, parallel connected).
5. Load Resistor – Carborundum Type 889SP ceramic power resistor, 12 Ω, 275 W, 10 KV, 12" x 1" dia. (7 required, parallel connected).
6. Charging Choke – 25 H, special order to specifications.

So far, only the current rise time ($t_m$) has been specified and used in calculations. The entire pulse length ($t_o$) will now be determined, where $t_o$ is the time required for the magnitude to decay to <u>0.67%</u> of $I_o$

$$t_o = t_m \left[ 1 + \frac{2V_R}{\pi} \left( \frac{K \ln \frac{K+1}{K-1}}{f(K)} \right) + \frac{10 f(K)}{\pi V_R} \right]$$

Using the previous values of $V_R = 0.2$, $K = 3$ and $f(K) = 0.75$,

$$t_o = 400 \left[ 1 + \frac{2 \times 0.2}{\pi} \left( \frac{3 \ln 2}{0.75} \right) + \frac{10 \times 0.75}{\pi \times 0.2} \right]$$

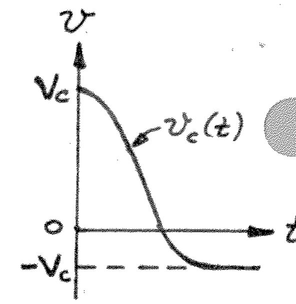
$$= 400 \left( 1 + 0.35 + 11.9 \right) = 400 + 140 + 4760$$

$$= 5300 \text{ ns} = \underline{5.3 \ \mu S} \text{ for } i_L(t) = 0.0067 \ I_o$$

The three terms in the expression for "$t_o$" represent the three time frames depicted in Fig. 3. The "10" in the third term represents "twice" the number of time constants, hence the 0.67% for 5 time constants. This number of time constants can be changed to any desired value.

$$R = \frac{V_R}{f(K)}\sqrt{\frac{L}{C}} \qquad \text{where } V_R = \frac{|-V_c|}{V_c}$$

$$K = \frac{\sigma}{\sqrt{\sigma^2 - \omega_0^2}}, \quad \sigma = \frac{1}{2RC}, \quad \omega_0 = \frac{1}{\sqrt{LC}}$$




$$f(K) = K\left[\exp\left(-\frac{K-1}{2}\ln\frac{K+1}{K-1}\right) - \exp\left(-\frac{K+1}{2}\ln\frac{K+1}{K-1}\right)\right]$$

The required initial charge on the storage capacitor is calculated for the lossless case, which is essentially what this circuit is during the rise time.

$$V_c = I_0\sqrt{\frac{L}{C}} = 2426\sqrt{\frac{1.6\times10^{-6}}{0.04\times10^{-6}}} = \underline{15.34\ \text{KV}}$$

which agrees, as it should, with the previously calculated $e_L = L(di/dt) = 15.33$ KV.

$$V_R = \frac{3\ \text{KV}}{15.34\ \text{KV}} \approx 0.2$$

Choosing <u>K=3</u> gives a value of <u>0.75 for f(K)</u>. Selecting a value for "K" is a trade-off between the size of the resistor, the peak current thru the resistor/diode and the total time of the magnet current pulse.

$$e_L = L\frac{di}{dt} = 1.6\times10^{-6}\frac{d}{dt}(2426 \sin 3.95\times10^{6}t)$$

$$= 1.6\times10^{-6}\times 2426\times 3.95\times10^{6} = \underline{15.33\ KV}$$

To determine the approximate power dissipated in the magnet:

d (skin depth) for copper at 20°c $= 6.62(f_{Hz})^{-1/2}$ cm.

A (area) = d × P (P = perimeter of conductor)

$R = \rho\frac{\ell}{A}$ ($\rho$ for copper $= 1.724\times10^{-6}$ Ω-cm)

Using the frequency associated with the rise time $(0 - t_m)$ of the magnet current:

$$f = \frac{1}{4\times400\times10^{-9}} = 625\times10^{3}\ Hz.$$

$$d\ (\text{skin depth}) = \frac{6.62}{\sqrt{625\times10^{3}}} = 8.37\times10^{-3}\ cm.$$

$P = 2\frac{1}{4}'' = 5.715$ cm.

$A = d\times P = 8.37\times10^{-3}\times 5.715 = 4.78\times10^{-2}\ cm^2.$

$\ell = 2 + 2 = 4\ m = 400$ cm.

## MAGNET DESIGN :

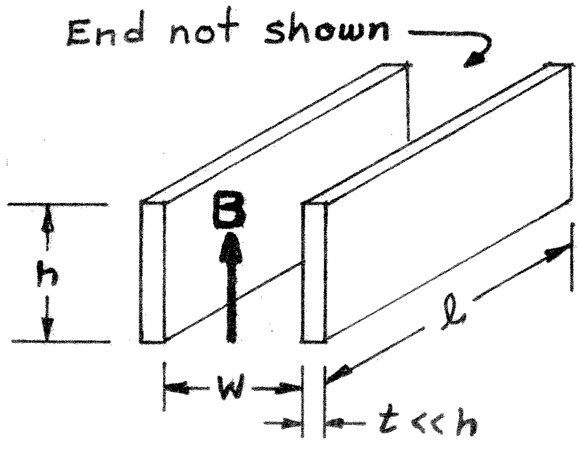
The bending angle $\theta$ is 1.2 mr at 60 GeV.

$$B_G \ell_m = \frac{\theta P}{3\times10^4} = \frac{1.2\times10^{-3}\times 60\times10^9}{3\times10^4}$$

$$= 2400 \text{ Gauss-meters.}$$

B = 600 Gauss for a 4-meter bending length.

The magnet will be split into two sections; each 2 meters long, using 1" × 1/8" copper bars spaced 1" apart.




$t = 1/8"$
$h = 1" = 0.0254$ m.
$W = 1" = 0.0254$ m.
$\ell = 2$ m.

$$K_o = \frac{\tan^{-1}(h/w)}{(h/w)} = 0.7854$$

$$L = 0.8\times K_o \times \ell = 0.8\times0.7854\times2 = 1.26\ \mu H$$

$$I = 125\times B\times\frac{1}{K_o}\times W = 125\times600\times\frac{1}{0.7854}\times0.0254$$

$$= 2426 \text{ Amps.}$$

two considerations; to be on the safe side time wise and yet large enough to minimize the required voltage, which is proportional to the time derivative of this current. The magnet was split into two sections to further fit the parameters to available circuit components from both a voltage and cost standpoint.

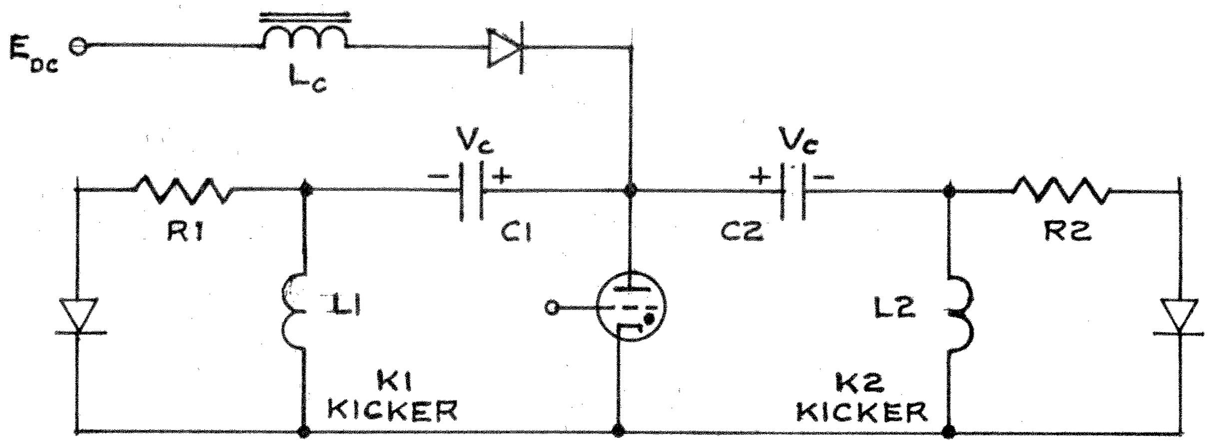



FIG. 2

The circuit used is different from the typical series R-L-C configuration and might be described as a "good news and bad news" type circuit. The "good news" or advantage is that during the current rise from zero to maximum, the storage capacitor discharges thru the magnet and switch with very low resistance in the circuit; i.e., a very high-Q circuit. This results in a smaller storage capacitor and less initial capacitor voltage being required to produce a given peak magnet current. The magnet voltage is negative during this time so that the shunt diode does not conduct.

At the current peak the voltage drops to zero (di/dt = o) and then begins to rise in the positive direction. This allows the diode to conduct and for a time current is flowing thru both the diode and thyratron switch. During this period the capacitor is accumulating a negative charge to insure thyratron turn-off.

In order to adjust this negative voltage to the desired value, the circuit must be operated in the "overdamped" mode. This means that the current decay follows an exponential fall off and is many times longer than the