An Upgraded Proton Injection Kicker Magnet for the Fermilab MIR

J. Dinkel, R. Reilly
Fermi National Accelerator Laboratory*
P.O. Box 500, Batavia, Illinois 60510

I. INTRODUCTION

In order to maximize the efficiency of the injection process into the Main Injector Ring, the beam gap required for the extraction and injection kickers can be reduced. A switching magnet which will achieve full field within 1% on the order of 30 to 40 nSec is required to achieve efficient transfers of beam between Booster and the MIR with the removal of only one bunch from the Booster ring. The magnet designed to perform this task is a 25Ω traveling wave device which reaches its full field of 136 Gauss in 30 nSec. The field is developed across an aperture of 102 mm, 51 mm in width, by a pulse current of 1200 amps. To minimize reflections, the termination resistor has become an integral part of the magnet structure.

II. DESIGN PARAMETERS

6 batches of 8 GEV beam will be injected vertically into the MIR from the booster. The trajectory of this beam must be bent upward 1.05 mR to place it on the equilibrium orbit of the MIR. Rise and fall times are specified to insure that the circulating beam is not disturbed by the transition field at the beginning and end of the pulse. Relevant design parameters are listed in Table 1.

Beam aperture - 101.6 mm (H) x 50.8 mm (V)
Kick angle - 1.05 mR vertical
∫B·*dl* - 340 g-m
Field rise time - <50 nSec
Field fall time - <150 nSec
Field flattop - 1.60 nSec
Field flatness (ΔB/B) - ±1%
Repetition rate - 15 Hz

Table 1

To meet these requirements, three independent kicker systems will be employed. On a practical basis, the operating voltage for the magnet is limited by the peak voltage to which the cable PFL may be reliably charged in order to achieve a reasonable PFL lifetime. We have found that operating the PFL at 60 kV provides longevity of the cables. If we choose a 25Ω system, then the peak current is 1200 amps. With a gap of 111.1 mm between pole tips, we can achieve a flux of 136 gauss in that gap. To develop the required kick, a magnetic length of 2.5 meters is required. To achieve a reasonable rise time, three 83.3 cm long kicker magnets are used. The inductance as calculated from aperture dimensions is 598 nH. The field propagation time through the magnet can be calculated from the inductance and the characteristic impedance as:

$$T_p = L_m / Z_o = 598/25nSec = 24nSec$$

In order to operate as a traveling wave magnet, capacitance must be present between the high voltage conductor and the ground plane. To achieve an impedance of 25Ω, the required capacitance is :

$$C_m = L_m / Z_0^2 = 598/25^2\,nF = .957nF$$

The magnet parameters are summarized in Table 2

Peak current - 1200 A
Field at peak current - 136 G
Impedance - 25 Ω
Gap height - 111.1 mm
Gap width - 63.5 mm
Magnetic length - 75.8 cm
Field rise time - <30 nSec
Inductance - 598 nH
Capacitance - 957 pF
Field flatness on mid plane - ±1%

Table 2

. The magnet uses "C" shaped ferrite pole pieces to efficiently guide the flux into the gap. The material is CMD5005 which was chosen after extensive testing[1]. The dimensions have been chosen to minimize the time dependent reluctance drop in the ferrite and to maximize the flux penetration into the ferrite material. The propagation velocity of the magnetic wave which penetrates the ferrite poles of the magnet can be calculated for CMD-5005 using:

$$V_f = 3x10^8/\sqrt{\mu\varepsilon} = 3x10^8\sqrt{1000x12} = 2.74x10^6\,m/Sec$$

Since the width of the pole piece is 0.75 inches (.0191m), the resonance would be 72 MHz which is above the magnet cutoff frequency. No shaping of the pole tips is necessary to obtain a field flatness of 1 % on the mid plane.

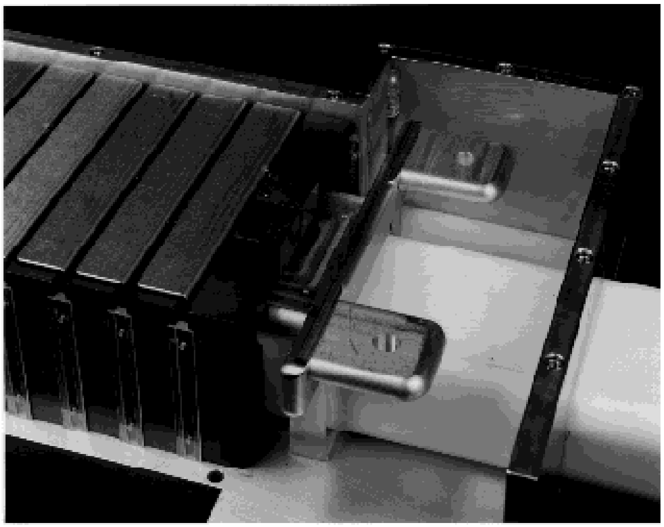
III. Magnet Design

Each magnet is made up of 24 ferrite pole pieces 1 inch wide and spaced .250 inches apart. In order to distribute the required capacitance along the axis of the magnet, "Z"

----

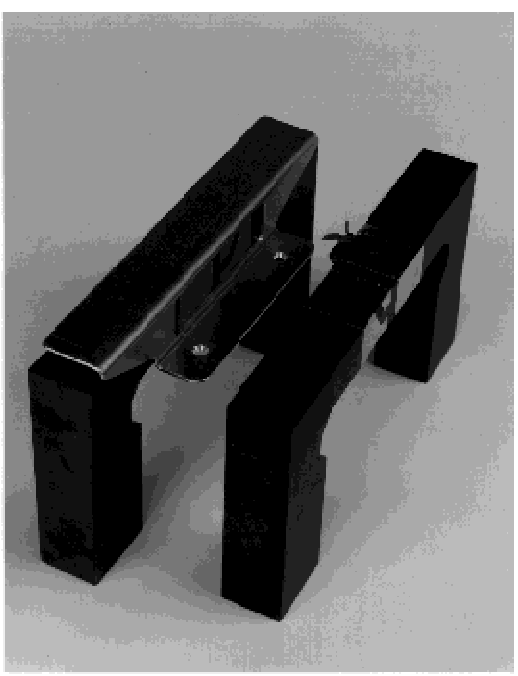
* Operated by the Universities Research Association, Inc. under contract with the U.S. Department of Energy.

plates are installed along the high voltage bus extending between consecutive pole pieces to form parallel plate capacitors with the ground plane. This is shown in Figure 1. Each of these capacitors in addition to the stray capacitance of the high voltage bus provides the required 40 pF per cell to achieve the 25Ω characteristic impedance..



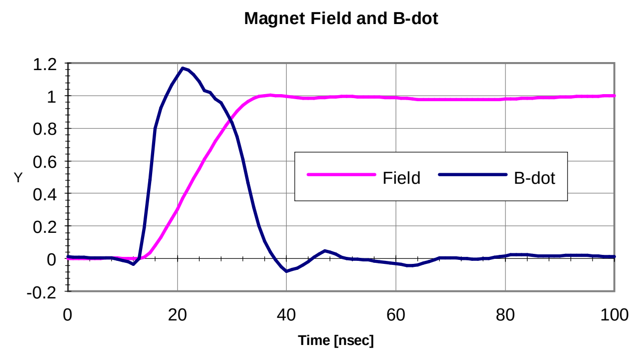
Ferrite pole pieces with "Z" plates installed
Figure 1

The displacement current which flows into the capacitors formed by the "Z" plates must pass between two adjacent ferrite pole pieces which greatly increase the series inductance of this capacitor. This inductance lowers the

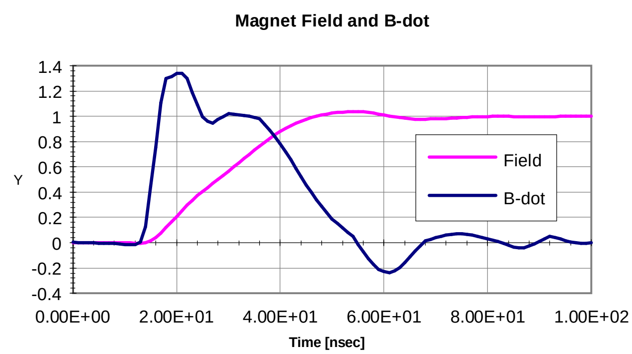


Pole pieces with cross-coupling and "Z" plates
Figure 2

natural resonant frequency of the individual cells which degrades the transient performance of the magnet. To negate this effect, cross coupling windings have been added between adjacent pole pieces to act as a shorted turn on this pseudo-inductor[2]. A window is provided in each "Z" plate to accommodate these windings as pictured in Figure 2. The windings are .002 inch adhesive backed copper foils bonded to the ferrite pole pieces. Copper straps 0.125 inch in width are soldered to these foils to provide the interconnections. The effect of these windings is striking as seen by comparing Figures 3a and 3b. We have also found that nearly twice the calculated shunt capacitance is necessary to achieve the required impedance of 25Ω without the cross coupling windings.



Normalized ∫B*dl* and field with cross coupling
Figure 3a

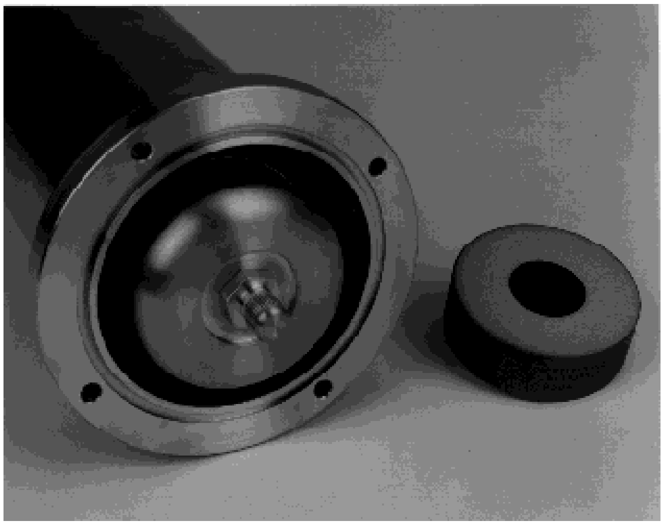


Normalized ∫B*dl* and field without cross coupling
Figure 3b

The 25Ω load consists of two stacks of 10 - 5Ω resistive washers clamped in a coaxial housing. The clamping force of 1500 lbs. required to interface these washers is provided by a 1 inch diameter G-10 rod with 3/8-16 Keenserts installed with epoxy into each end. From a heat dissipation standpoint, the worst case operating scenario is a burst of 6 pulses once every 2.4 seconds. This requires that 175 watts be dissipated in the load. Although full power tests have not been performed on this magnet yet, preliminary heat transfer calculations indicate that we can expect a temperature rise of 9^{o}C. The two stacks are connected to the high voltage bus using louvered contact bands as shown in

Figure 4. Wide band current viewing resistors are provided on each load resistor which have sensitivities of 5 mv/A.

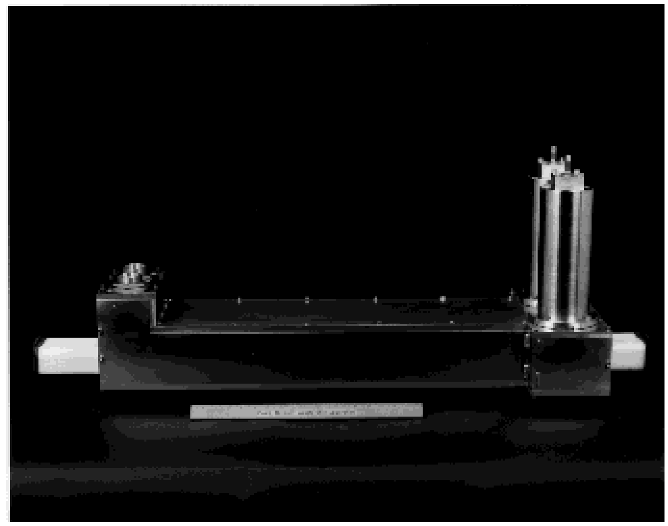
We had originally planned to use commercially available connectors to couple the RG/220 cables into the magnet, but tests on the first prototype indicate unacceptable reflections due to their high inductance. At this point, we are examining ways to modify these connectors into a low inductance device.



Load resistor and Resistive Washer
Figure 4

The magnet and load resistor assembly are potted with Sylgard 184 clear silicone rubber. This material has reasonable heat transfer properties, a dielectric strength of 450 volts/mil, and a relative dielectric constant of 2.7. Since the potting compound also serves as the "Z" plate capacitor dielectric, the required spacing between "Z" plate and the cover is 0.260 inches which puts a nominal voltage stress of 125 volts/mil in the potting material at full voltage.

The magnet which is shown in Figure 5 has a physical length of 40 inches. The 50 inch ceramic beam tube has been recycled from a previous kicker which has the same aperture.



Proton Injection Kicker magnet
Figure 5

IV. Acknowledgments

The authors would like to thank Clifford Foster, Jay Hoffman, and David Tinsley for their help in the fabrication of this magnet.

References

1. Jensen, C. et al., "Comparison of ferrite Materials for Pulse Applications", IEEE Transactions on Magnetics, Vol. 31, No. 1, January 1995
2. Dinkel, J. et al., "A Precise High Field Injection Kicker Magnet for the Fermilab Tevatron", Ninth IEEE International Pulsed Power Conference, June 1993