SLC KICKER MAGNET LIMITATIONS *

R. Cassel, A. Donaldson, T. Mattison
G. Bowden, J. Weaver, F. Bulos
Stanford Linear Accelerator Center,
Stanford, California 94309

and D. Fiander
CERN

Abstract

The SLC Damping Ring kicker magnets requires a fast magnetic field rise time of 58 nsec, a peak field of 800 gauss, a pulse amplitude stability of 0.01 %, and a reasonable operational lifetime. The original Kicker magnets designed by SLAC and at FERMI were not able to fulfil the SLC kicker requirements. Extensive studies were conducted to determine the limitation in the magnets, response of the ferrite in kicker magnet, and the modifications needed to improve the kicker magnet performance. The paper details the SLAC and FERMI kicker magnets limitation of performance.

Background

The SLAC, SLC damping rings not only require a fast kicker magnet rise time (58 nsec), wide pulse (100 nsec) a large kick (320 gauss-meters), and regulation requirements (0.01%) but the space allocated in the damping rings for the kickers was to short (46 cm) for a conservative kicker magnet design. The resulting high magnetic field of 800 Gauss requires the use of a ferrite loaded kicker magnet. With these restrictive parameters the magnet limitation become the performance driver in the kicker system. With the inherent jitter the thyratron used in the kicker systems (approximately +- 200 psec) the slope (dB/dt) of the kicker field at extraction time must be less than 0.05% /nsec compared to the peak dB/dt of approximately 3% /nsec to achieve the 58 nsec rise time.

Basic Physics of ferrite kickers

From basic physic principal it is clear to the first order that to proved the required magnetic kick, the energy required is proportional to the square of the magnetic kick amplitude, linear with the cross sectional area of the kicker field and inversely proportional to the length of the magnet.
Joules = (gauss-m)^2*(area)/(length)
Therefore the shorter the magnet the more joules are required and with a fixed rise time, the more power is required. The minimum voltage needed on the kicker magnet however is related to the magnetic kick, the effective width of the gap and inversely to the rise time. Volts = (gauss-meters)* (effective width)/(rise time). What this first order equations infer is that the minimum voltage on a kicker magnet is independent of the length of the magnet or <u>more important independent of any attempts that are made to change the impedances by adjusting the capacitance of the magnet or pulser</u>. For the SLC case the absolute minimum voltage independent of the design is 20 kv with a minimum energy of approximately 1 joule. <u>The only effective parameter to reduce the voltage needed on the magnet is to reduce the effective width of the gap</u>. The minimum voltage or joules is fixed by these simple concepts. The actual values can be much larger depending on the design.

Magnet types.

The original SLAC kicker magnet was a slab ferrite construction using the ferrite as an isolator and attempting to use the ferrite capacitance to produce a transmission line magnet. Figure 1 It was not understood that this construction in fact dose not produce a transmission type magnet but a magnet that looks electrically like a lumped inductor. The reason for the lumped inductor effect is because the fields in the ferrite can travel lengthwise down the magnet which produces a field at the end of the magnet delayed only by the speed of light from the front of the magnet independent of the amount of capacitance.

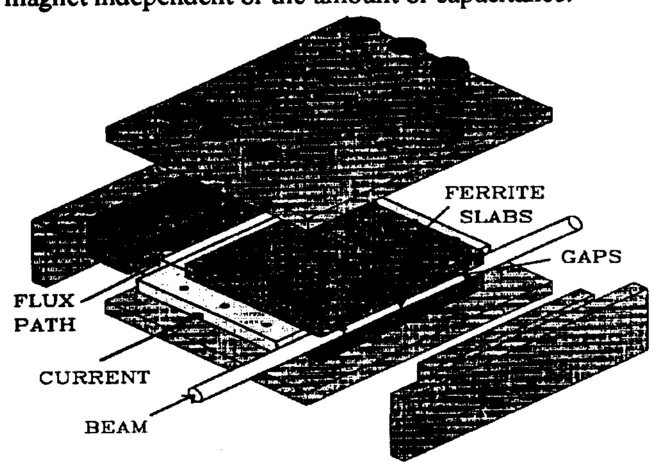

Figure 1
Slab SLAC Kicker Magnet

* Work performed under U.S. Department of Energy Contract DE-AC03-76SF00515
0-7803-0135-8/91$01.00 ©IEEE

The effect can clearly be seen by observing the delay of a pulse propagating in the magnet by probing the field along the magnet. Figure 2

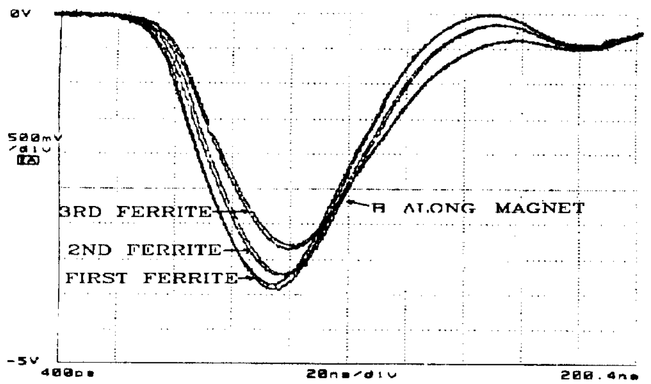

Figure 2
Three Ferrite Slab SLAC Kicker

A true propogation delay only occurs when there is a break in the ferrite. The effect on the magnetic field waveform of a lumped inductor magnet is to have the integral of the field rise with a exponential time constant determined by the effective magnet inductance divided by two time the line impedance. (t = L/2*Z) The exponential response means that without voltage pulsed wave shaping the magnetic field integral will take at least 4 time constants or approximately 80 nsec to be flat enough to meet the 0.01% stability requirement. This exponential behaver means that the SLAC magnet field waveform cannot be made flat enough to meet the specifications for the SLC electron damping ring. To produce a true transmission or delay line kicker magnet, the magnet must be divided into isolated section so that the magnetic field cannot propagate along the magnet without being delayed by the capacitance in the magnet. Figure 3

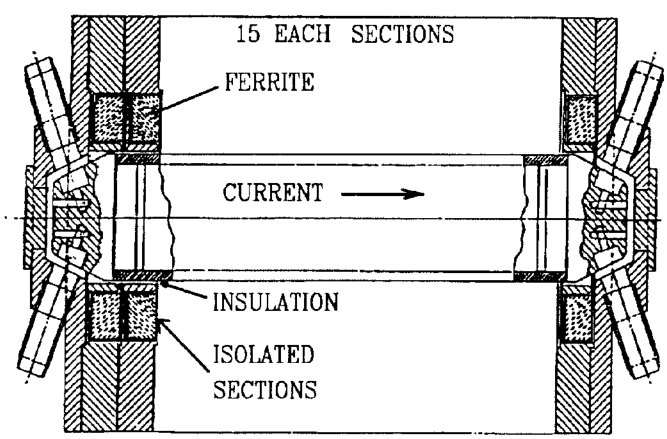

Figure 3
FERMI magnet design

The kicker magnet made by FERMI lab for SLC was of this type of construction and as expected it exhibits the propagation delay of transmission type magnet. Figure 4

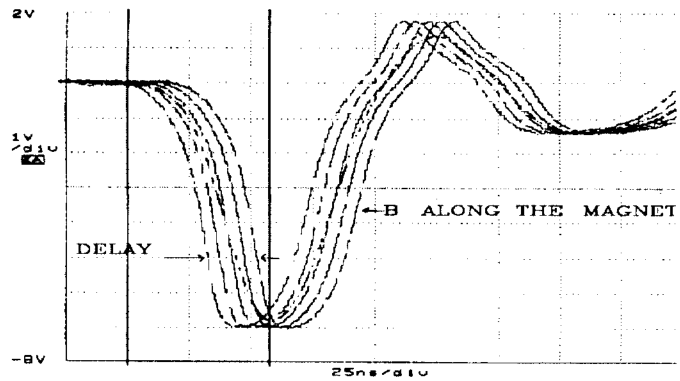

Figure 4
15 section FERMI Kicker

A transmission line is characterized by it impedance and delay. $Z^2 = L/C$ and $T^2 = L*C$ which infers that $T*Z=L$ For the FERMI magnet Z = 17 ohms and T > 30 nsec. Although the magnet transit time is short enough to meet the SLC requirements the magnet is not matched to the pulser cables which is 12.5 ohms. This results in a reflection from the load end which causes a rise in current at the end of the pulse producing an unacceptable dB/dt at the beginning of the pulse during extraction. (Figure 5)

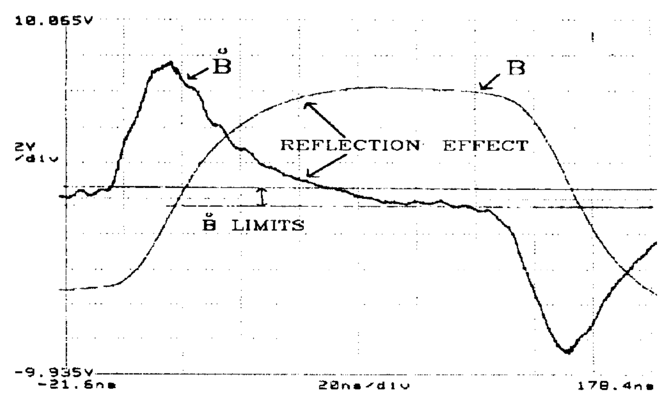

Figure 5
FERMI Mismatched Impedance

Both present kicker magnets SLAC and FERMI types produce an unacceptable dB/dt characteristic due to there inherent design deficiencies.

Ferrite material

In both the SLAC magnet and FERMI magnet the chose of ferrites and ferrite path length were not optimal. In the SLAC magnet the ferrite was chosen to have a high permeability, however the ferrite path length was made long in the believe that the additional capacitance would make the magnet a transmission line magnet. The combination of

high permeability and long path length results in a unacceptably high stored energy. The FERMI magnet use a low permeability thinking that the low permeability would be stable and help to match the impedance of the magnet to the pulser. In reality the change in permeability verse field strength was very large and that combined with the long ferrite path length selected to produce a large enough capacitance resulted in the magnet having to much stored energy and to high characteristic impedance. The high impedance causes an increase in field at the end of the pulse due to a reflection from the load cables. The ferrite material and path length chosen did not proved the performance required.
The preferred ferrite design would be to have a high permeability ferrite and a short path length to maximize the fields and at the same time minimize impedance changes due to changes in permeability.

There was considerable concern that the frequency response losses or dispersion in the ferrite was causing the problems with magnet shape. Simulation were made and tests performed to establish these effects. Although dispersion is evident in all the ferrites when the rise time is made fast enough, the dispersion effects and frequency response are secondary to impedance mismatch and lumped inductor effects.
There has been no indication that the ferrites losses or frequency response is effecting the pulse shape substantially and that if the impedance is corrected the magnetic response will not be adequate.

Stray Fields

Another effect which was overlooked is stray magnetic fields. Stray fields in the FERMI magnet are much larger then expected. The result is a larger stored energy in the magnet and therefor a longer transit time than expected. Field plots of the FERMI kicker magnet revealed that field penetrated the gaps in the structure and increases the transit time by as much as 20%. (Figure 6) Unfortunately very little can be done to eliminate these fields since they are inherent in the design mechanical design.

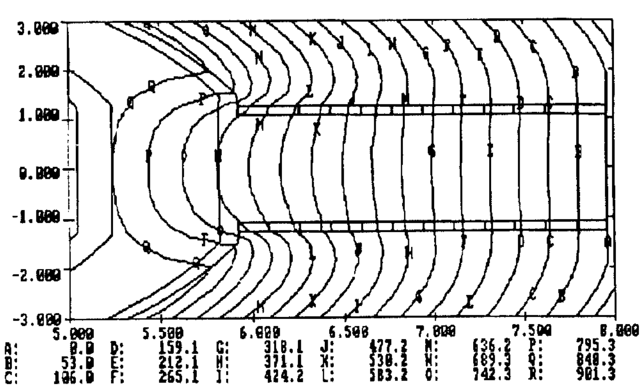

Figure 6
Stray Fields in FERMI Kicker

Field compression

The stored energy or the transit time of the magnet can be reduced by a small amount without changing the central magnetic field by reducing the effective width of the field. This was accomplished by what we call a flux gasket. The gap magnetic fields are restricted by a small amount at the top and bottom of the gap by use of a conductor. With the short pulses of the kicker a conductor can shields and shapes the magnetic field. The results of the flux gasket is to reduce the stored energy by a small amount which decreases the transit time of the magnet. (Figure 7)

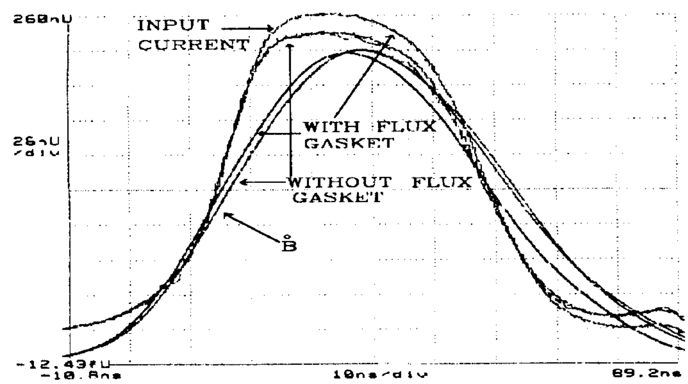

Figure 7
Flux Gasket Delay Change

Conclusion

The SLC kicker magnetic pulse shape problems are in essence design problems of not including what constitutes a transmission type magnet, under estimating the effect of changes in permeability of the ferrite, and not appreciating the amount of stray inductance in the magnet. The short magnet length compounded the problems by requiring more current and thereby a lower magnet impedance. With this accumulated design knowledge we have been able to designed a new magnet which takes into account all of these shortcomings producing a magnet which is match to the pulser and a transmission type magnet.

To every complex problem there is an answer that is simple, neat and Wrong.

References

[1] F. Bulos, et al., "Some Fast Beam Kicker Magnet Systems at SLAC", Proceedings of the 1987 IEEE Particle Accelerator Conference, p. 1884.

[2] T. Mattison, et al., "Operational Experience with SLC Damping Ring Kickers", elsewhere in these Proceedings.

[3] T. Mattison, et al., "Status of the SLC Damping Ring Kickers Systems", elsewhere in these Proceedings.