Fast TEM Kicker with MOSFET Solid State Driver

Alfredo Saab*, Michael Kogan and Tomás Russ
MIT - Bates Accelerator Center
21 Manning Rd., Middleton, MA. 01949

Abstract

The design of a fast transverse electromagnetic (TEM) kicker for use in the Bates Pulse Stretcher Ring is described. It provides a 1 mrad/m. kick for a 1GeV electron beam, with transition times below 25 ns. and a 1% flat top. The +/- 10 KV. driver uses a novel switching technique, based on MOSFET power transistors, which allows complete control over the kicker timing and simplifies the construction greatly. Calculations show that the reliability of such a driver is orders of magnitude better than present designs.

I. DESCRIPTION

The MIT-Bates Pulse Stretcher Ring is designed to expand the linac duty cycle (now < 1%) to 85% or greater. A linac pulse of 1.2 μs is injected into the ring, filling it twice. Two kicker deflectors are turned on at injection time, and then turned off very fast to minimize circulating beam losses [1].

Table 1. Kicker Specifications

Bend Angle	1 mR
Kick interval	1.33 μs
Energy range	200- 1100MeV
Repetition Rate	20 Hz. - 1000 Hz.
Active aperture	8 mm
Gap	40 mm
Available length	1.1 m.
Rise time	< 50 ns.
Fall time	< 25 ns.
Flat top	1 %

Relevant design specifications are shown in Table 1. Critical parameters are the fall time, which must stay below 25 ns., and flatness inside and outside the kicking interval, to be kept within 1% of the pulse height. This last restriction led us to consider minimum reflection schemes. Fig. 1 shows the chosen configuration: when firing, a pair of switches close and deliver complementary polarity high voltage pulses through the kicker plates into matched terminators. Because (on first order approximation) the system is perfectly matched, no reflections are produced. Energy is supplied by two DC HV power supplies with low series inductance capacitors as charge reservoirs. After the injection period, the switches open and the deflection field is abruptly removed.

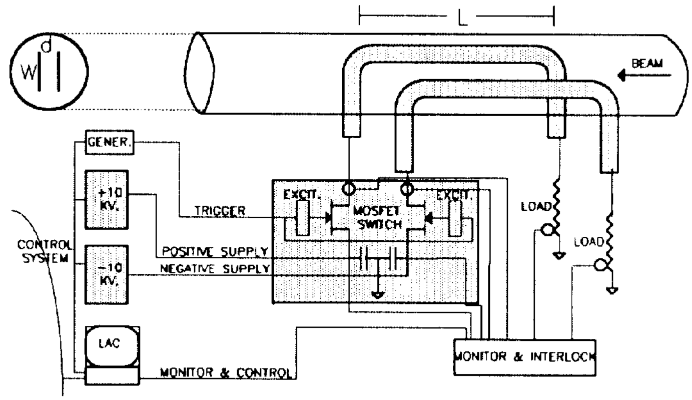

Fig. 1 - T.E.M. Kicker Block Diagram

If the kicker plates' voltage and current are related by their characteristic impedance Zo, a wave travels along them in TEM mode, producing transverse B and E fields. Electric and magnetic deflection forces are identical and, if the wave moves against the beam, additive.

II. KICKER DEFLECTION PLATES

The kicker deflection plates consist of a pair of parallel plates of width W, length L, and gap d (Fig. 1). The surrounding vacuum chamber is far enough removed from the plates to ignore its shielding effects on the electromagnetic fields inside the deflector. Maxwell's equations can be applied to calculate analytically the deflecting electric and magnetic fields for this geometry[2]. The angular deflection can be calculated to be:

$\Phi = p_T/p_L$, where pT and pL are the transverse and longitudinal momenta. For identical electrical and magnetic contributions, it is easily shown that:

$\Phi = 2.B.L.c / E(eV)$, where B is the magnetic field, E the electron beam energy, and L the length of the plates. For our case:

$\Phi = 1.10^{-3}$, $L = 1$ m., $E(eV) = 1.10^{+9}$, and B = 16.67 Gauss, which renders an applied force of $F = 8.10^{14}$ N, and an electric field $E = 5.10^{5}$ V/m. For d = 4 cm., V = 20,000 V. If Zo = 100 Ω, I = 200 A.

A plot of the deflecting magnetic field B = f(x) in the region where the beam will actually be present (+/- 8 mm.) with the vertical displacement y used as parameter shows that the B field variations are < 1.5 % within the active aperture (Fig. 2).

0-7803-0135-8/91$03.00 ©IEEE

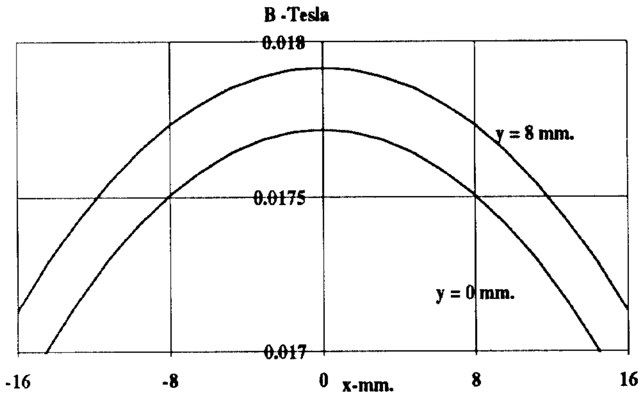

Fig. 2 - Field variations in the active region (+/- 8 mm.) of a pair of parallel kicker plates (W = 8 cm., d = 4 cm.).

Characteristic Impedance Calculations

The distributed inductance L and capacitance C can be calculated for the proposed kicker plate geometry by the analytical evaluation of the integrals for the magnetic field and for the voltage drops at x= 0 (Fig. 3). In our case, for a 100 Ω impedance d/W equals aproximately .5, justifying previous assumptions of W = 8 cm. for d = 4 cm. Notice that this differs from the standard approximation of Zo for parallel plates (377*d/W) by almost a factor of 2.

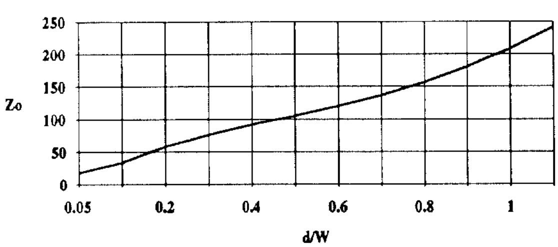

Fig. 3 - Characteristic impedance as a function of plate dimensions.

III. DRIVER SWITCH CIRCUIT

Power Section

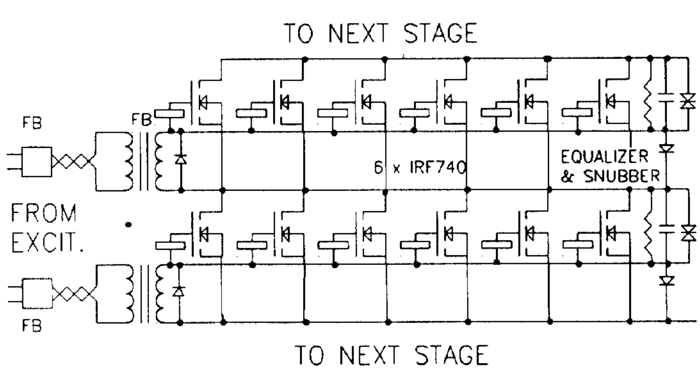

Fig. 4 - Kicker driver power section schematic (2 of 26 sections shown).

As shown in Fig.1, the kicker driver pulses the deflection plates by closing a pair of complementary polarity switches. Switch design is critical to obtain the rise time, fall time and flat top characteristics.

Given the recent availability of reliable and inexpensive power MOSFETs (Metal Oxide Semiconductor Field Effect Transistors), the switch was designed around them. MOSFETS' advantage over other devices (thyratrons, spark gaps) is that they can be turned off from the control port, without having to withdraw the main current. As majority carrier devices, MOSFETs need no charge accumulation or depletion (except for that in the oxide layer) to turn them on and off, and rise/fall times are very fast, on the order of 10/20 ns. Another crucial advantage of MOSFETs is their ability to operate at maximum voltage and current or at avalanche (voltage breakdown) without damage. Bipolar transistors suffer from well known second breakdown effects under these conditions. In any power switch, energy accumulates in the stray inductance of the circuit, causing overvoltages at turn off. MOSFETs can absorb this energy, a significant addition to system reliability. The main challenge in designing a MOSFET HV switch is that the maximum current/voltage combination for a commercial device is of about 20A. /1000 V. Therefore several devices have to be connected in parallel/series to reach 10000 V/ 200 A. as needed for each polarity switch. A "merit coefficient" for comparison was developed considering the maximum V_D and I_D, and the Miller charge for each device, to find the optimal for the switch. After analyzing all available types, a 400V. /10A. (40A. peak) device was chosen as the main component.

A switch has a total of 26 stages in series, each stage made of 6 parallel MOSFETs (see Fig. 4), giving a theoretical capacity of 10400V. / 208A. An RC and diode network equalizes the voltage among stages when the switch is off, with the diode isolatlng the equalizing network when the switch turns on. A protection MOV absorbs any energy spikes in each stage. Current sharing among paralleled MOSFETs is automatic due to the positive temperature coefficient of their channel resistance.

Stray inductance and capacitance on the PC board and MOSFET packaging are integrated to form a 50 Ω transmission stripline by placing the PCB at the correct distance above a ground plane.

Excitation Circuit

Each stage is driven by a pulse transformer, through a stabilizing ferrite bead. The 26 pulse tranformers have their primaries driven in parallel by a single low voltage, high current MOSFET. The design of a pulse transformer with very low leakage inductance is crucial to transporting the firing pulse to all stages. Tight coupling between primary and secondary windings with simultaneous HV isolation is obtained by using a single turn hollow conductor secondary, with the primary wound inside. The excitation circuit is shown in Fig. 5. The main MOSFET driver (IRFZ34) is moved by a push pull MOSFET stage (IRFZ1O and IRF9Z1O), in turn driven by high speed-bipolar transistors. The differentiating network on the transistor bases allows them to be turned on only enough to charge the MOSFET's gate capacitance. The bipolar transistors are then turned off, avoiding storage time problems. The MOSFETs stay on thanks to the charged gate capacitance. The input trigger signal (J1) is processed by CMOS logic, all-owing for an INHIBIT signal to be connected at J2.

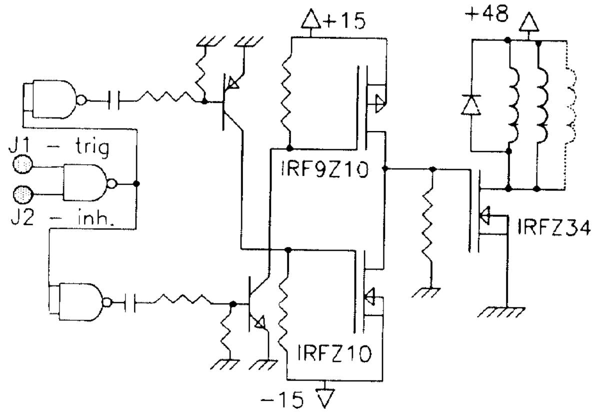

Fig. 5 - Simplified schematic of excitation circuit

Load Design

The 50 Ω/ 3 KW. terminators were designed in-house, due to the lack of available high power, high voltage loads on the market. Standard carbon composition 2W. resistors were arranged in a cylindrical configuration, as 12 stages of 6 resistors each. A connector is attached to the top of this cylinder through an impedance matching cone. The bottom of the cylinder is connected to the return tank through beryllium copper RF contacts. Dimensions of both cylinder and tank give the correct 50 Ω impedance. A voltage sampler resistor divider is brought up to the load top for monitoring purposes.The entire load is in oil to increase power handling capacity and provide HV operation. An oil circulating pump and oil/water heat exchanger will be used for continuous power operation.

IV. MEASUREMENTS

Measurements of the kicker deflection plates drive signals are shown in Fig.6 and Fig. 7, indicating that the specifications can be met with the present design. The critical fall time is around 15 ns. (from 90% to 25% of full scale). Flat top is within 1%. When operating with the kicker plates, difference in arrival time of the two pulses produce a ringing effect on the rising tedge, which is compensated by delaying slightly the beam injection until it has been damped.

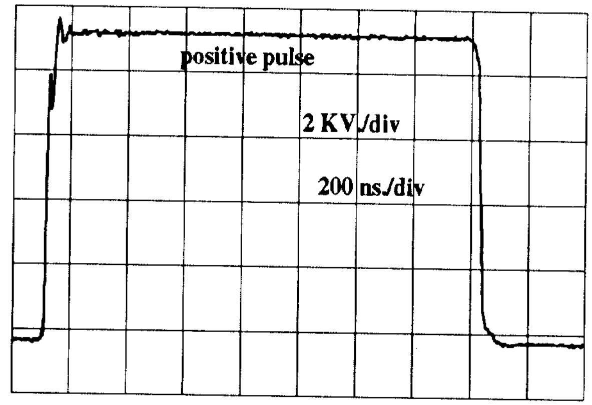

Fig. 6- Scope trace of the full positive driving pulse.

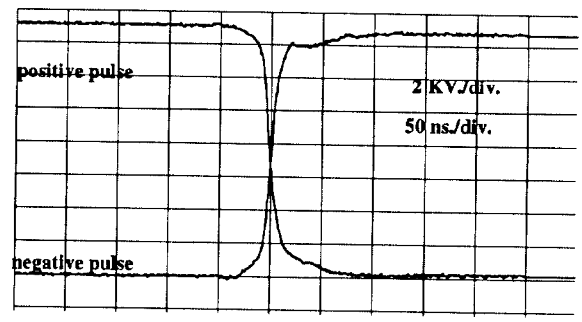

Fig. 7 - Detail of the fall time waveform for both kicker driving pulses.

V. CONCLUSIONS

A kicker design for the Bates Pulse Stretcher Ring has been shown which results in simple and reliable operation through the use of new techniques. Inexpensive MOSFET switches replace the cumbersome and complex storage line and thyratron scheme. Overall cost of each MOSFET switch hovers around US$1000, with a calculated MTBF of 50000 hrs. An interlock system has been designed and will be tested shortly. An IEEE488 controlled pulse generator and digital scope, together with a distributed power supply controller will be used to control and monitor timing and load signals through the ring control system[3].

VI. REFERENCES

[1] J. Flanz et al. "The MIT- Bates South Hall Ring", Proc. of the 1989 Particle Accelerator Conf., Chicago, Mar. 1989, pp.34

[2] T. Russ et al. " SHR Fast Kickers Design Report", Bates Internal Report., Jan. 1990.

[2] T. Russ et al. " The Bates Pulse Stretcher Ring Control System Design", Proc. of the 1989 Particle Accelerator Conf., Chicago, Mar. 1989, pp.85.

* Now with Stanford Accelerator Center.