KICKER for the SLC ELECTRON DAMPING RING

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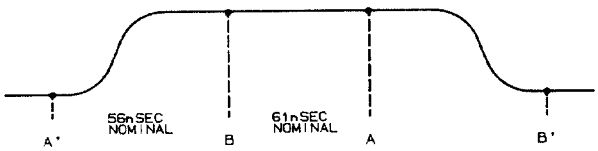
The SLC electron damping ring requires two kickers each providing a 5 mr kick at 1.2 GEV to pairs of electron bunches spaced 61.63 nsec apart. The exact shape of the kick is unimportant, but the specification of Figure 1 applies to the field the bunches see.



	INJECTION KICKER			EXTRACTION KICKER		
	B	A	B'	A'	B	A
RELATIVE AMPLITUDE	1	.999 1.001	.001	5×10^{-4}	1	.001 1.001
AMPLITUDE JITTER	$<10^{-3}$	$<10^{-3}$			10^{-4}	5×10^{-4}

Figure 1

To meet this specification, a coaxial magnet with a characteristic impedance of 12.5 ohms was designed to produce a 203 gauss-meter kick. The energy to generate and maintain this field is stored in a pair of 50 ohm coaxial cables each 145 ft. long. These cables are pulse charged to 60 - 65Kv, then switched across the magnet with a pair of thyratrons, illustrated in Figure 2. The installation is shown in Figure 3.

The magnet is a travelling-wave kicker in which the E-field is electrostatically shielded from the beam pipe which sees only the B-field. It generates a 900G field in a 2.35 x 2.35cm aperture at 2600 amps.

Stackpole 2285 ferrite was selected following extensive tests of 4 types in which u vs B was measured. The 2285 reached a B equilibrium faster than the other ferrites. From this u vs B data and an estimated center conductor to shield spacing, the inductance was calculated to be 696nH/M which dictated 4454pf/M for a 12.5 ohm magnet.

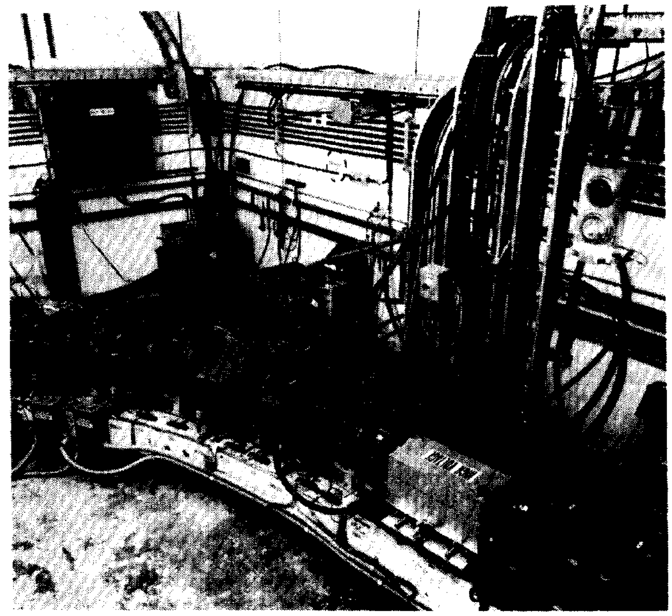
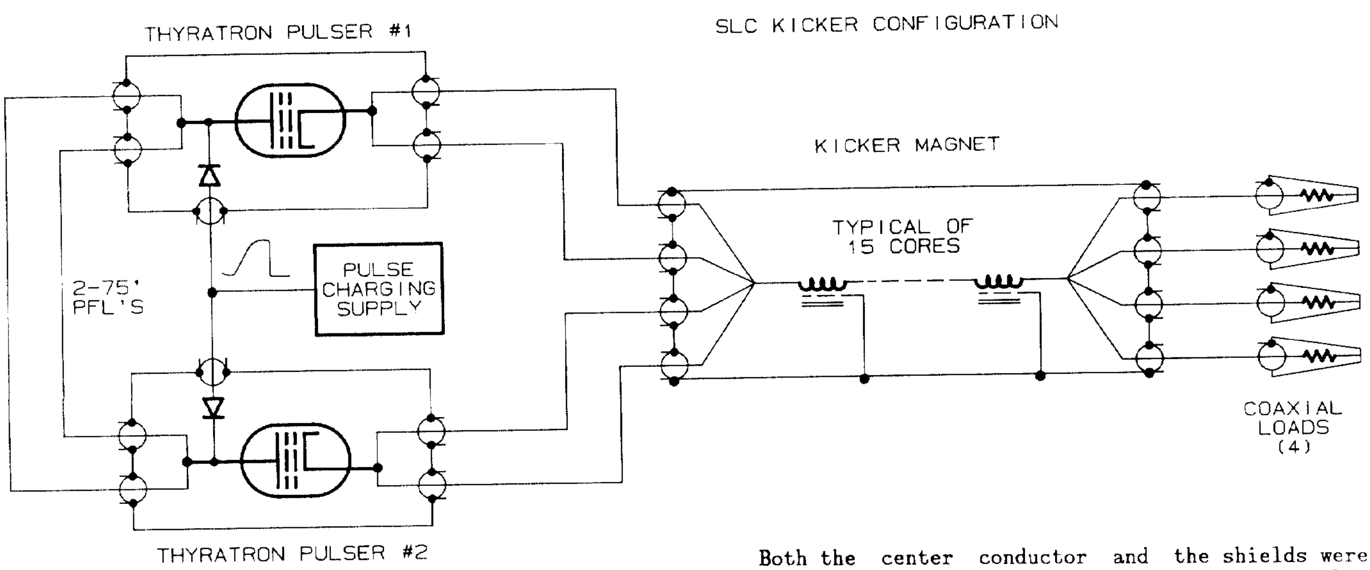


Figure 3

The center conductor was machined to the calculated diameter to give this capacitance given the k = 3 of the potting compound. On a network analyser, the finished magnet gave the transmission response shown in Figure 4, flat +/-3dB from DC to 100mHz. The sharp transmission cutoff at 135 mHz is due to the "graininess" of the 15 ferrite sections. The measured transmission delay of the magnet is 25nS.

To prevent ferrite erosion, the E-field from the 33kV pulsed center conductor is shielded from the ferrite. Each core is insulated from its electrostatic shield by a .062in thick layer of potting, so the core sees only its own dB/dt voltage of 2kV.



Both the center conductor and the shields were electropolished. In addition, extreme care was taken to achieve 100% adhesion of bubble free potting material to the electrode surfaces. Attention was

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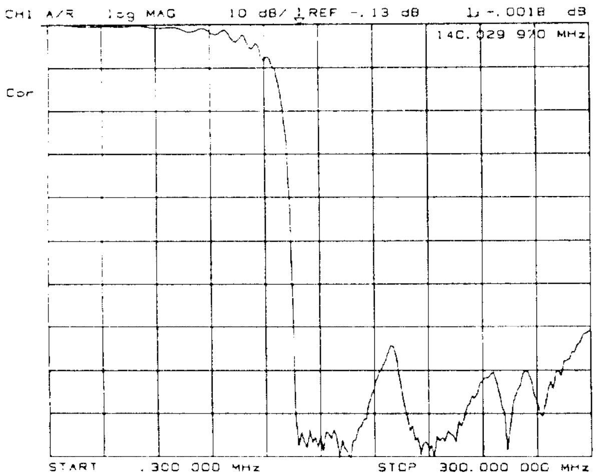

Figure 4

given to cleanliness, surface preparation, and vacuum potting with liquid slowly introduced from the bottom up.

The selection of a deuterium thyratron for the pulser switch is predicated on the need for a di/dt of 2 x 10^{11}amps/sec at a 120 Hz rate. The latest version of the CX1671D from EEV is a three-gap hollow anode thyratron with a staggered gap design which will switch at half this rate. Thus we use two tubes in parallel. To maintain the integrity of the 12.5 ohm system, each tube is enclosed in an oil filled coaxial housing designed for a nominal 25 ohm impedance. Trigger circuits, filament and reservoir supplies are in a cylinder mounted to the thyratron cathode flange. The close spacing of the housing to the thyratron and cathode housing as required by a 25 ohm structure gave us some concern over the effects of sparking between the two. Oil flow of ~1gpm between the tube and housing negate the buildup of conducting fingers in the insulating oil.

To provide power to filaments, reservoir, and trigger circuits with minimal reflections from the pulse, two insulated conductors extend from the bottom of the housing through the cylindrical enclosure on the cathode flange and out the top of the housing where each conductor becomes the secondary turn of a toroidal excitation transformer (see Figure 5).

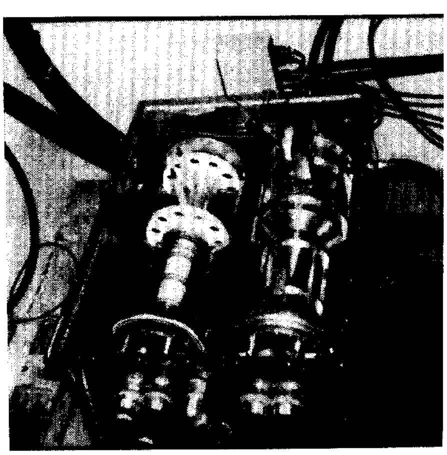

Figure 5

These transformers generate 30Khz currents in the conductors. Inside the cathode enclosure, the conductors pass through another set of transformers which couple the power into the filament and trigger supplies, and the reservoir supply. DC is applied to both filament and reservoir to minimize jitter. Since these two conductors or skewers are orthogonal to the pulse wavefront, they see only the electric field between the housing and the outer conductor. Due to the coaxial geometry, the currents produced by these fields cancels and the power is transferred undisturbed by the pulse.

For triggering, a fast rising 1.5Kv pulse is applied to grid G0 while grid G1 is held to -150v. Within 20ns, approximately 25amps are flowing through G0 (plasma has formed around the cathode). At this point, G1 is pulsed to 1.3Kv and conduction begins. As the gaps sequentially break down, charge redistribution occurs across the remaining gaps which accounts for the two "pre-pulses" in the output current prior to the main pulse. The trigger pulse is generated by discharging a capacitor into the grid circuits with a series string of SCR's. The trigger circuit capacitor is charged via a voltage multiplier to develop approximately 1700v open circuit, zener regulated to 1500v. To operate reliably at 120Hz, the initial charging current must exceed the SCR latching current, therefore we must interrupt the capacitor charging current until the SCR string has recovered. This is done by placing optically coupled FET switches in series with the charging resistor which hold off the charging current for the duration of the trigger pulse (↓50us).

The pulse forming line PFL determines the duration of the kicker pulse (see Figure 6). The PFL and thyratrons form a conventional line-type pulser delivering energy to a matched load.

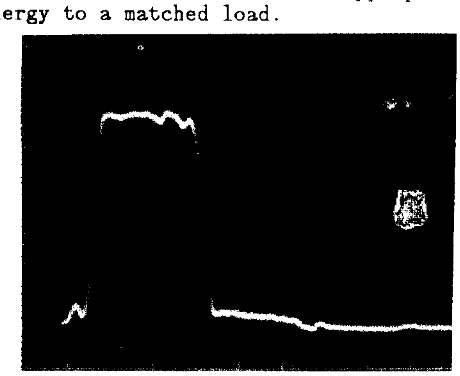

Figure 6

The cable selected for the PFL is a 39mm 50 ohm polyethylene coax made by Felten & Guilleaume. It uses a .7mm semiconductive polyethylene screen around the center conductor to enhance its high voltage properties and several layers of aluminum foil enclosed in a copper braid as an outer conductor. With this construction, most of the pulse current is carried on the inner foil which minimizes radiated energy. Attenuation in this cable is lower than RG/220 below 170mHz but above 170mHz the semiconductive screening degrades its performance. The cable is rated for continuous pulse operation at 70kv.

The PFL cables are pulse charged from both ends in 12 usec using resonant charging. The supply is decoupled from the cables by a series string of high voltage diodes spiraled in a plane around the anode such that each diode is located in its proper electric field. This technique requires no additional compensation.

The PFL charging supply employs a double resonant charging scheme to minimize power dissipation and allow operation at high repetition rates. As shown in Figure 7, a 2uf capacitor bank is resonantly charged from a manually adjustable DC power supply. A deQ-ing winding is included on the resonant charging reactor to stop the charging process on command from the voltage regulator. Once charged, the capacitor is discharged into the primary of a stepup transformer having a turns ratio of 1 to 17. The secondary charges the PFL charging voltage through decoupling diodes.

Each 50 ohm load is conservatively designed to operate at 33kV peak with a 500 watt average power dissipation. The resistance elements are 10ohm carbon-ceramic discs, 4-3/8in in diameter, supplied by the Stackpole Carbon Co. Two stacks of 10 discs each are connected in parallel to provide 50ohms. See Figure 9.

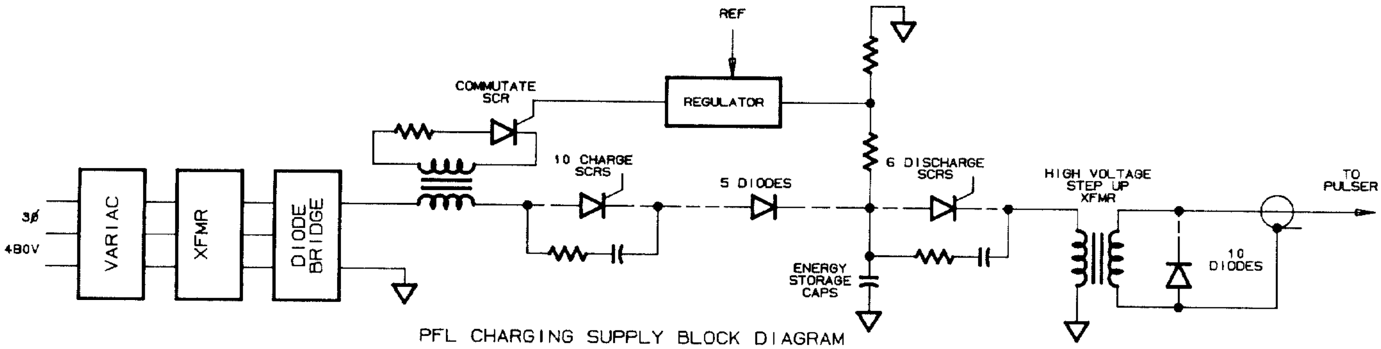

Figure 7

Power supply operation is straight forward. The CHARGE SCR's are triggered and the capacitor bank voltage rises according to:

$$V_t = V_p(1-\mathrm{Cos}(wt))$$

where V_p is the dc supply output voltage. A measure of the capacitor bank voltage is compared to the reference in the voltage regulator. When the two are nearly equal, the deQ-ing SCR is triggered. This causes a reduction in the voltage across the reactor which reverse biases the charging SCR's. Diodes in series with the charging SCR's prevent the snubber capacitors from charging in the reverse direction since the capacitor voltage is now almost twice the DC supply voltage.

Some 50 to 60uSec before the kicker is pulsed, the capacitor bank is discharged into the primary of the H.V. output transformer. This causes the secondary voltage to rise according to:

$$V_o = V_c \times N(1-\mathrm{Cos}(w_o t))$$

where V_c is the capacitor bank voltage, N is the transformer turns ratio, and w_o is the resonant frequency which is set by the PFL and capacitor bank capacitance and the leakage reactance of the transformer. The transformer achieves full output in 25 uSec. Free-wheeling diodes shunt the secondary winding to clamp the reverse voltage swing after the PFL has been charged.

During normal operation, the capacitor bank is charged to 4400 volts to charge the PFL to 65kV. Repeatability of this voltage appears to be 2×10^{-4} over a several hour period. Typical waveforms are shown in Figure 8. Circuitry is provided to prevent overcharging of the PFL should the thyratrons fail to conduct. A measure of the load current is monitored. Should a current pulse not be detected following the charging of the PFL, subsequent triggers are inhibited until 2 seconds have elapsed. This gives the PFL time to discharge to a safe value through the gradient grid resistive divider before it is topped off with another pulse.

Physically, the charging supply is scattered about. The H.V. transformer resides in an oil tank adjacent to the thyratron pulser to minimize capacitance across the secondary winding. The capacitor bank and discharge SCR's are on the wall near the output transformer. The remainder of the supply is in a relay rack in the upstairs equipment gallery.

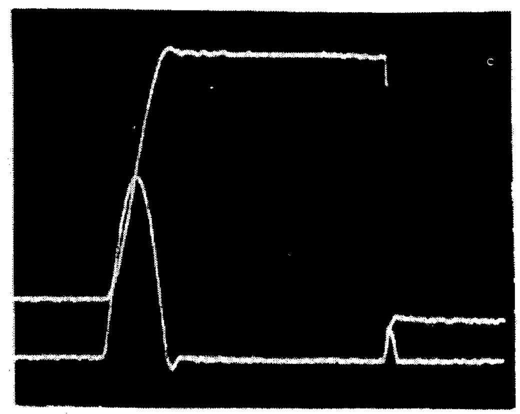

Figure 8

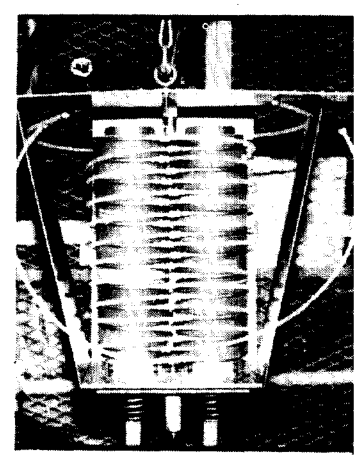

Figure 9

Cooling is provided by water-cooled copper plates between the discs. Geometry of the current return path and input cable connection was determined empirically to give maximum bandwidth. The frequency response is flat below 50mHz. Each load is provided with a .01ohm coaxial current viewing resistor.

The authors would like to thank those individuals both at SLAC and Fermilab whose efforts and talents made the the development and installation of this system possible.