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THE LAMPF LINE D FAST DEFLECTOR SYSTEM*

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Introduction

The Weapons Neutron Research Facility is only one of many experimental areas which utilize the 800 MeV proton beam from LAMPF. Designated as Line D, this area may use entire beam pulses of 500 μs width at pulse rates up to 12 Hz or it can choose to take the last 5 μs off each pulse at a 120 Hz rate. This paper describes the deflection system employed to accommodate the latter of these two modes of operation.

The deflection of the proton beam into Line D is accomplished in a 1.09 m, 1.25 kG ferrite magnet, pulsed at up to 7000 A, 120 Hz by a 2 ohm 6 section lumped element pulse forming network (pfn). The current pulse into the magnet has a rise and fall time of about 1 μs with a usable flat top portion of 9 μs. This line is tuned to produce a current pulse with ± 0.2% ripple across the flat top portion. The low ripple current is necessary to minimize beam jitter as it enters Line D.

Prototype Design Values

Pulse lines of the sort employed in the Line D fast deflection system are basically lumped element approximations to a finite length of charged transmission line discharging into a matched load, and are frequently designed as N identical L-C ladder sections having lumped inductance and capacitance values (L_ℓ, C_ℓ) that satisfy the equations

$$\sqrt{\frac{L_\ell}{C_\ell}} = Z_0 \quad , \quad \sqrt{L_\ell C_\ell} = \frac{\tau}{2N} \quad , \tag{1}$$

where τ is the desired pulse length, and Z_0 is the impedance level of the circuit, which is fixed if τ and L_ℓ are fixed.

Pulse lines designed according to Eqs. (1) produce load currents shown in Fig. 1, for N = 1 to 7. The initial overshoot is clearly associated with the first section, as it is present in the waveform for N = 1. For our kicker magnet application we wanted to eliminate the overshoot and make as uniform a current as possible. Accordingly we modeled the pulse line on an EAI-280 analog computer and adjusted the inductance and capacitance parameters of each section of the line to achieve the current waveforms shown in Fig. 2. Table 1 summarizes the empirically determined values of L and D that produce the waveforms shown in Fig. 2. The table presents normalized values, i.e., the given values are appropriate to a 1 ohm load and produce a 1 second pulse. To produce a pulse of τ seconds and an impedance level of Z_0 ohms, the table entries should be scaled according to the relations

$$L_{actual} = \tau Z_0 L_{table} \quad ; \quad C_{actual} = \frac{\tau}{Z_0} C_{table} \quad . \tag{2}$$

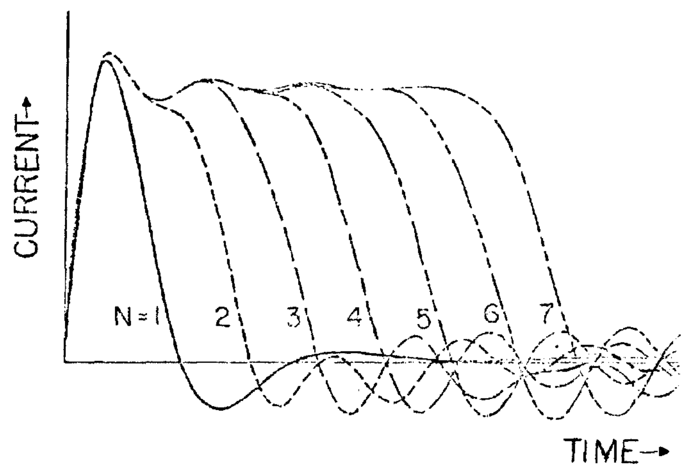

Fig. 1. Load Currents Produced by Conventional Pulse Lines

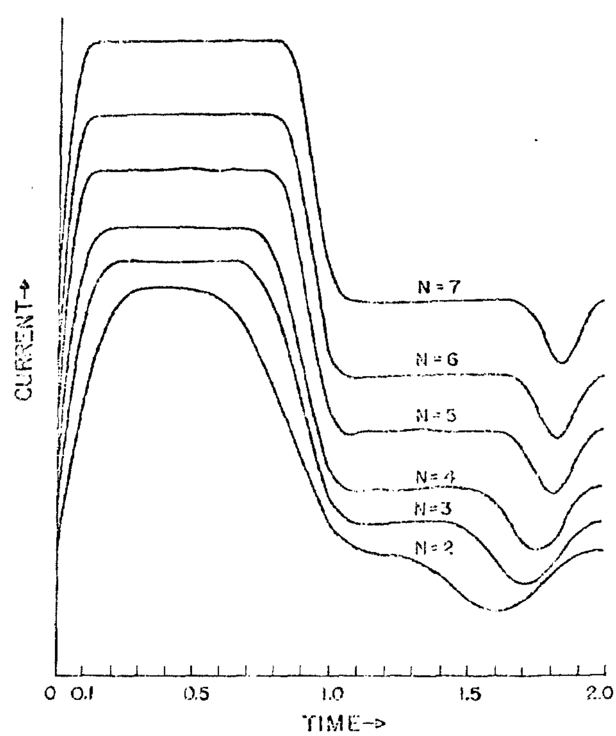

Fig. 2. Load Currents Produced by Analog Modeled Pulse Lines

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TABLE I

PFN Element Values

No. of Sections \ i =		1	2	3	4	5	6	7
2	L_i	.2559	.1388					
	C_i	.1444	.1785					
3	L_i	.1817	.0945	.1172				
	C_i	.1024	.0991	.1733				
4	L_i	.1503	.0721	.0775	.1023			
	C_i	.0818	.0744	.0851	.1517			
5	L_i	.1145	.0581	.0613	.0691	.0968		
	C_i	.0647	.0597	.0662	.0806	.1488		
6	L_i	.1062	.0489	.0491	.0535	.0624	.0878	
	C_i	.0579	.0484	.0521	.0589	.0727	.1378	
7	L_i	.1016	.0445	.0429	.0429	.0486	.0571	.0811
	C_i	.0521	.0442	.0432	.0456	.0531	.0659	.1261

The Line D kicker magnet has a nominal design inductance of 2.67 µH. A pulse length of 12.5 µs was desired, so the impedance level of the line was determined as $Z = L_{1,\text{table}}/\tau L_{\text{magnet}} = 1.99\ \Omega$. The pulse line was then designed using the nominal values given in Table 1 for N = 6.

Construction Details

The pulse network is shown pictorially in Fig. 3, which shows it to be a stack of coaxial capacitor sections with the inductors connected in series down the center of the stack. Each of the sections is double walled and water cooled, while the interior of the entire stack and the thyratron switch is forced-air cooled. Each capacitor in the upper level of each of the six sections is connected to the section above it through individual plugs. The inductors are connected in the same way so that the stack may be broken and lifted apart at any joint without removing any capacitors or inductors. It is only necessary to remove the screws in the outer flange at the point the stack is to be broken and to lift the line apart.

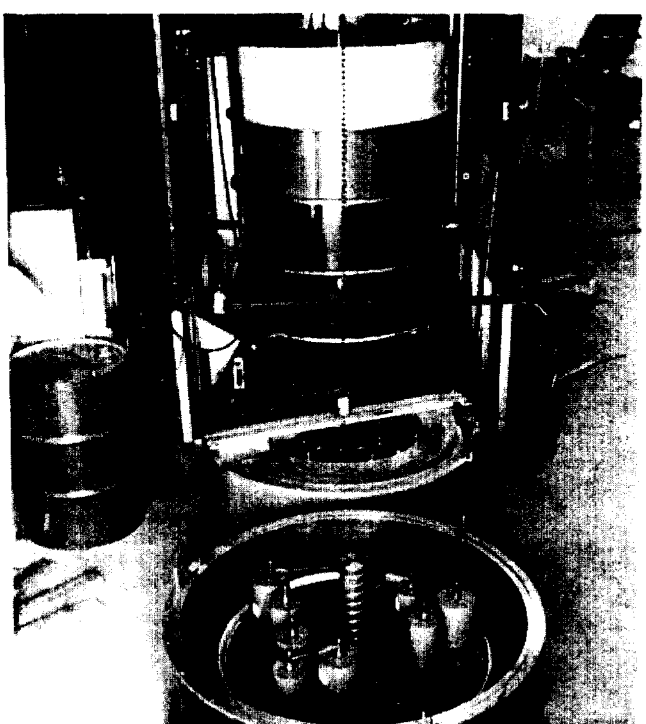

Fig. 3. The Pulse Forming Network as Fabricated

This coaxial construction provides a very low inductance shielding for the inductors, hence all the L and C may be assumed to be in the lumped elements.

At original assembly the six capacitor sections were set to the values indicated by the analog computer simulation. These values were adjusted by employing four different capacitor values: 0.05, 0.02, 0.01 and 0.001 µµF. The capacities were measured with a digital capacitance meter and adjusted to three place accuracy. It was not felt that the inductor values could be measured with the same accuracy as could the capacitors, hence the capacitances were accurately set and the inductors were then adjusted for the desired pulse shape. The computer simulation was used at each step of inductor tuning to predict the next step. After final tuning the inductance values were measured as accurately as the equipment on hand would permit and were found to be almost exactly the values predicted by the original computer simulation. The resultant pulse shape was exactly as shown by simulation.

One of the main areas of concern in this high peak, high average power application was the design of the 2Ω load resistor. Several different configurations were considered, and in the end it was concluded that a cheap, simple unit could be made if some degradation in rise time could be tolerated. The final load resistor design is composed of sections of very thin-walled stainless steel tubing immersed in a cooling water jacket. The 2.5 µH inductance of this load resistor does degrade the pulse rise time but by subsequent adjustment of C_1, C_2 and C_3 the resultant pulse has a rise time of 3 µs, with 6.5 µs flat top. The current ripple on the flat top is ±0.2%. This unit is very compact, inexpensive, and can easily be replaced.

System Description

The magnet pulser used for the Line D fast deflector system is shown schematically in Fig. 4. While this is not the most efficient system from a power consumption standpoint, it has many features which make its flexibility very attractive. The added power dissipation of the hard-tube charge control system essentially doubles the average power consumption over that which would be required with a conventional resonant charge system. However, the use of the EIMAC 4CW 100,000 D hard-tube system allows delayed charge, fault interruption, charge programming on a pulse to pulse basis and closed loop control over the charge on the pulse line. This flexibility, in a system which must operate with the overall LAMPF facility on a minimum interference basis, makes the added power consumption a small price to pay for the operational ease provided. The following paragraphs provide a description of the operation of the control and firing system.

At initial turn on the hard tube in the charge control loop is biased off, and thus no charge is applied to the pulse forming network (pfn). The first firing pulse from the accelerator control system enables the charge control loop after a preset charge delay but does not fire the thyratron since the charge-OK signal is not at the proper logic level. After the charge delay, the enable signal sent to the hard tube modulator (HTM) pulses the bias to zero and the screen grid to 2000 V, allowing charging current to flow into the pfn. When the pfn voltage reaches a level preset by the control potentiometer the charge control signal is removed, turning off the switch tube by restoring the 500-V bias and removing the 2000-V screen grid signal. At this point in time the logic system sees a charge enable signal, and zero output from the charge control system, indicating that the loop is active and the line charge is proper. The thyratron may then fire on the next firing pulse from the main accelerator control system. For this initial pulse the entire charge on the pfn is accomplished during a relatively short interval between charge enable and the firing pulse; this requires very high peak power from the switch tube and would severely shorten switch tube life. In order to maximize tube life by minimizing peak power requirements while still supplying the required average power, all succeeding pulses are charged in a different way, described below.

The firing of the thyratron and the resulting drop in voltage at point A is coupled to the switch tube bias flip-flop by C_1, removing the bias from V_1. With zero bias and zero screen voltage the switch tube then begins to conduct as a diode and starts to recharge the pulse line at a very low current until the charge delay time elapses. The charge control system then applies 2000 V to the HTM screen grid to bring up the line charge to the proper level. When the pfn reaches proper charge level the 2000-V screen signal is removed and the bias is restored to the HTM. The line is now charged and the charge control system is turned off, awaiting the next firing pulse. By choosing L_1 such that the "free" charge time through V_1 is long compared to the pulse interval and by delaying the closed loop charge enable signal to allow maximum free charge, the high peak current or demand charge interval is minimized. This reduces wear and tear on the switch tubes.

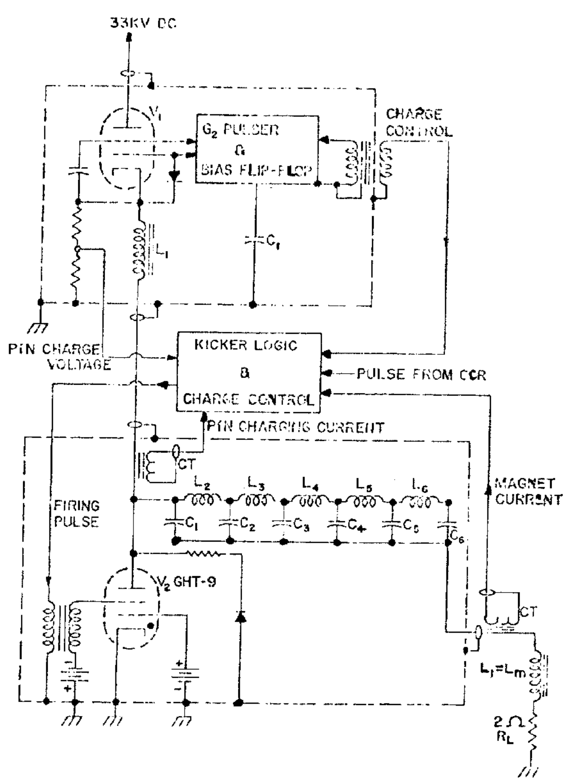

Fig. 4. Magnet Pulser Schematic

As previously pointed out, the thyratron is not fired unless the line charge is proper. Inputs into the kicker system logic also allow for fast inhibit of firing in the event of other accelerator problems. The thyratron current is monitored by the logic system and compared on a pulse-to-pulse basis with the firing signal from the accelerator control timer. If the two do not exactly coincide, then the charge and firing systems are inhibited and a digital counter is advanced one count, indicating a misfire. After such a count the previously described charging sequence must start again. In the event of 10 such misfires the logic locks out the charge system until manually checked and reset, either by computer or accelerator operator.

Another feature of this control system is its ability to be programmed to different current outputs on a pulse-to-pulse basis. An analog signal may be used in place of the set point potentiometer and stepped to different voltages on a pulse-to-pulse basis, which would allow kicking to different beam lines, greatly diversifying the experimental area.

Conclusion

This system has been subjected to extensive testing at full power. A total of 10^8 pulses have been fired at the 120 Hz rate. Several runs of 8-12 hours duration have been accomplished with some capacitor overheating being the only problem of significance. After several hours running it was found that some of the 0.05 μF capacitors became overheated and on several occasions did explode. None of the other sizes of capacitors showed excessive heating. There were no failures of any other size capacitor. A new design for the 0.05 μF unit has been made, providing for more plate area, better heat flow from the interior of the capacitor to the cooled tank walls, and higher temperature processing. The new design should eliminate capacitor overheating as a major problem.

While the peak currents are of similar magnitude to those found in other accelerator applications and the 120 Hz rate is much higher, the usual kicker requirement is for pulses with much faster rise time than the 1-3 μs used here. In these cases the same simulation and basic construction techniques are entirely applicable but certainly a load resistor with extremely low inductance would be required for the faster rise time pulses. However, most of these will not require the load resistor to handle the 100 kW of average power, and should be easier to design from that standpoint.

Reference

[1] R. Faulkner and R. Cooper, "The LAMPF Line D Fast Deflector System," LA-6748-MS (in preparation), Los Alamos Scientific Laboratory.