LINAC PULSED QUAD POWER SUPPLY

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Abstract
Fermilab is updating the Linac by replacing one-half of the system in order to double the beam energy. Quadrapole magnets are used to focus the proton beam as it travels through the Linac. This paper describes the power supply used to drive the magnets. The pulsed quadrapole supply generates a 2 ms half sine wave pulse flat on top for 450 μs within +/- 0.2% of the maximum current of 200 amps. The flattop is achieved by a third harmonic circuit added to the resonant discharge circuit. Charge recovery is included in this system with > 70% being recovered. A total of four pulsers are powered from one main supply. Remote control systems are used to operate, send, and receive data. Each pulser unit common floats for minimum noise transmission. Safety and minimum noise transmission were factors included in the design of the complete system.

INTRODUCTION

Previous designs for this type of application have used the basic resonant discharge circuit. The upgrade system needed more pulse width and better regulation. Drift due to system component aging and the required pulse width forced the design towards a different approach. The 3rd harmonic scheme was pursued to achieve a flattop which produces greater system flexibility. The quadrapole magnet has an inductance of 1.8 mh and 0.5 ohms. Discharge energy is 108 joules pulsed at a 15 Hz rate. The quadrapole power supply (QPS) system was designed with a modular regulator chassis such that a defective unit with charged components can be replaced safely. The main supply is a phase controlled brute force filtered supply capable of storing 4 kilo joules. The 3 phase controller was used to enable greater flexibility and accuracy when the output is changed from 100 % to 25 % of full output. A 3 bay rack contains 8 pulsers, 2 main supplies, 2 control crates, and 1 smart rack monitor.

THEORY OF OPERATION

A simplified schematic shown in Fig. #1 shows the main components, voltage loop, and current feedback loop. The brute force supply consists of a 3 phase controller, delta wye transformer, bridge rectifers, and

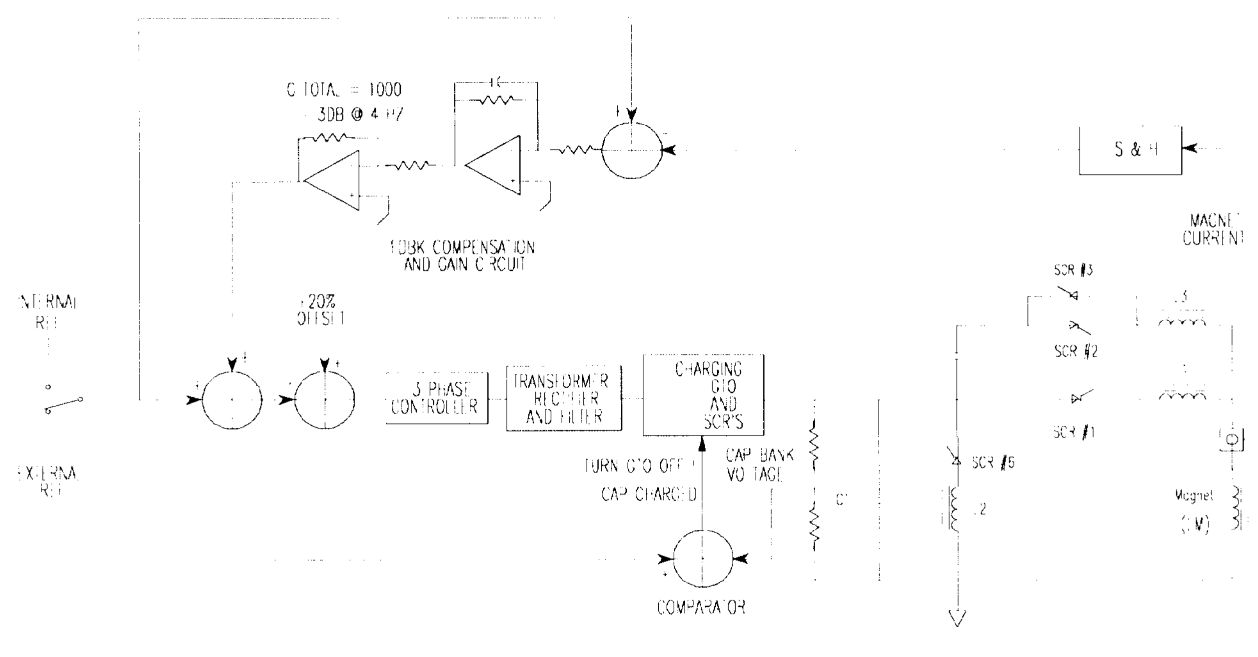


Figure #1

LC filter. The transformer secondary is capable of 1130 Vrms line to line. Final operation allowed us to connect up to the 90% tap (1017). The LC filter has a pole of 4 Hz to minimize noise generated and AC line disturbance.

Choosing the 1/2 wave pulse width of 2 ms, a L1 of 1mh, and the magnet inductance of 1.8 mh are the first decisions in the pulser design.

$$\omega_o = 2\pi f = 1.57x10^3 \quad Rad/Sec \qquad (1)$$

The energy storage cap is chosen by:

$$C = \frac{1}{(2\pi f)^2 (L1 + Lmag)} = 144 \ \mu f \qquad (2)$$

The impedance to discharge current is:

$$Z_0 = \sqrt{L/C} = \sqrt{2.8 \text{ mh} / 144 \text{ mf}} = 4.4 \text{ W} \qquad (3)$$

For the 3rd harmonic circuit:

$$3\omega_0 = 4.71x10^3 \text{ Rad / Sec(4)} \qquad (4)$$

Solving for the amplitude of the 3rd harmonic by taking the 2nd derivative of the following equation and setting the function equal to 0.

$$f(t) = Sin\, \omega t + A\, Sin\, 3\, \omega t \qquad (5)$$
$$A = 1/9$$

The 3rd harmonic reduces the peak current by 1/9 therefore the charge voltage on the main cap (C1) will need to be a factor of about 1.1 higher.

$$V_c \approx 1.1 x I\ peak\ x(Z_0 + R_{cable} + R_{mag}) \qquad (6)$$
$$\approx 1.1x200x(4.4 + 0.2 + 0.5) = 1122 \quad volts$$

The equivalent circuit that the 3rd harmonic circuit capacitor has to match is shown in figure #2

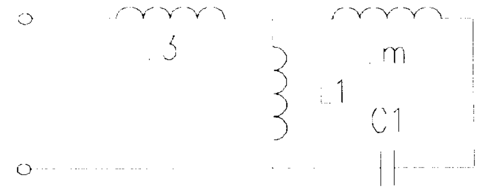


Figure #2

$$X_{eq} = X_{L3} + \frac{X_{L1}(X_{LM} + X_{C1})}{X_{L1} + X_{LM} + X_{C1}} \qquad (7)$$

The equivalent circuit impedance at the 3rd harmonic is 7.116 ohms therefore the reactance of C3 must be equal to this value.

$$C_3 = \frac{1}{3\,\omega_0\, X_{eq}} = 30 \ \mu f \qquad (8)$$

The actual magnet current needed is 175 amps. The third harmonic current will be about 1/9 of this current or 19.4 amps.

Circuit analysis plots were done using spice with various component changes. The circuit could be

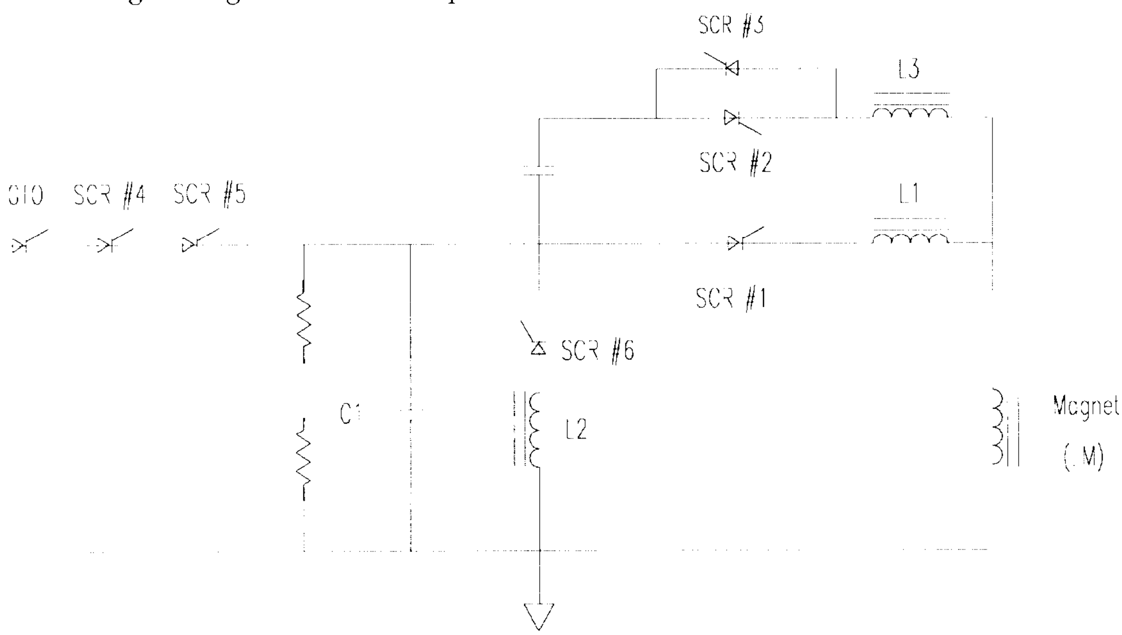


Figure #3

configured without L3 if one put an initial charge on C3. This change would mean a floating supply is needed to charge this cap. Due to simplicity and reliability L3 was left in the circuit and C3 starts the cycle with a 0 volt charge. Changing the gap in L3 allows one final method to adjust the flattop width.

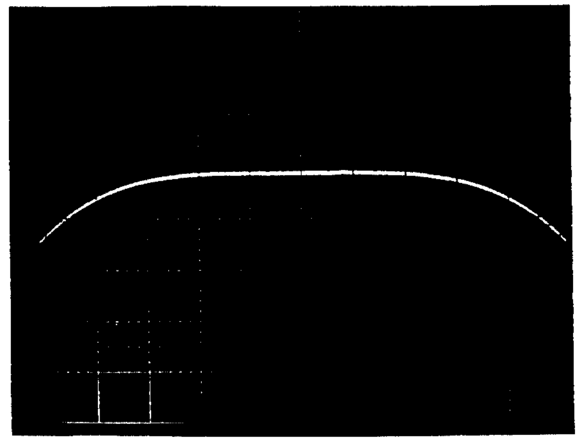
The energy discharge cap (C1) is charged by turning on SCR #4, #5, and the GTO as shown in figure #3. After the loop comparator is satisfied a stop charge is applied to the GTO to end the charge cycle. The discharge cycle generates magnet current and is started by turning on SCR #1. After a small delay SCR #2 is gated on, this generates a faster rise in the magnet current and produces the charge needed on C3 for flattop. When the current in SCR #2 drops to 0, then SCR #3 is turned on which generates the current needed to produce a flattop current wave form in the magnet. Adjusting the turn on time also adjusts the tilt during flattop. SCR #2 is turned back on after SCR #3 shuts off to discharge C3. Charge recovery is initiated by gating SCR #6 on which allows the current to flow through L2 which resonates with C1 and flips the charge on this cap.

IMPLEMENTATION

Minimum noise would be transmitted if one had a true bipolar source. Therefore the pulser common was made to float so that both leads of the cable could bounce with the signal producing a smaller noise signal in the shield of the cable. Due to the capacitance to ground of the large components a true bipolar source was not achievable. However there is a significant noise signal difference in the shield if one grounds the common lead going to the magnet.

A control crate contains 4 timing modules, 4 regulator modules, 1 control module, and 1 power supply module. The system will operate with this crate in the stand alone mode or in a computer controlled mode. Monitor signals are available at the front panel to aid in system checkouts.

Operation of 8 pulsers have been running for 1 year with very good results. The waveform shown was taken from a unit operating at a flattop current of 175 amps.



Magnet current showing flattop current
200 ma/div @ 50µs/cm

Acknowledgments

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