STUDY OF PULSE STRETCHING IN HIGH CURRENT POWER SUPPLIES USING MULTIPULSE TECHNIQUES

Robert C. Trendler

Fermi National Accelerator Laboratory
Batavia, Illinois 60510

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SUMMARY

Considerable interest exists at Fermilab to increase the pulse width of the Neutrino Focusing Horn to permit an increase in beam spill length from twenty (20) microseconds to one (1) millisecond. Two techniques to do this have been examined: 1) A high current transformer, and 2) Increased bank capacitance using the multi-power supply technique. The transformer is the most straightforward conceptually; it is, however, a complicated device requiring sizable changes to the existing horn power supply. This alternative will be briefly reviewed. The second scheme involves pulsing a 20 KV 200 KA power supply to establish the required load current and then maintaining this current by the sequential pulsing of a number of low voltage high current power supplies. This alternative will be discussed in detail with the results of tests performed on the Fermilab Focusing Horn System.

INTRODUCTION

The existing horn, power supply, and interconnections can be best explained by referring to Figure 1; a schematic representation of the salient parts of the horn circuit network.

As can be seen, the total pulse power supply is comprised of three smaller supplies or banks (for details of each of these supplies and the total supply, see Reference 4). Present operation requires triggering all series ignitrons simultaneously and then later firing all crowbar ignitrons simultaneously to terminate the pulse. This method of operation gives a horn current and bank voltage wave shape as shown in Figure 2. The component values are those of the existing system. As can be seen, the nominal 10% ΔI time is approximately 60 μ s.

To provide the required 1 ms 10% ΔI time, both a pulse transformer and a sequentially fired multi power supply were considered.

Figure 1

Figure 2

PULSE TRANSFORMER

Figure 3 shows a schematic representation of a pulse transformer installed in our power supply. This scheme is being actively pursued in view of the CERN success in procuring a transformer.⁵ Figure 4 demonstrates the expected system behavior with 12.6 KV on the 2400 uf capacitor bank and a turns ratio of 32. The transformer characteristics used in making this calculation were those specified by CERN for their transformer.

Figure 3

Figure 4

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MASTER

MULTI-POWER SUPPLY

An examination of Figure 1 shows that the two power supply techniques could be used to extend the pulse width. The first bank of high voltage capacitors is fired and delivers its stored energy to establish the magnetic field and full operating current. When the current reaches its maximum value and the time rate change of current is zero, a lower voltage high current power supply is triggered, and then couples to the horn system terminals. It delivers its stored energy to supply the I^2R losses of the circuit. The current then increases again slightly, and when the di/dt equals zero, the third low voltage high current supply is triggered to supply the I^2R losses.

A direct extension of this discussion can be applied to the existing power supply. In this case, each bank is operated independently, and the series tubes are fired at different times, so as to give a longer effective pulse width.

Circuit Equations

Referring to Figure 1, the initial pulse current waveshape can be determined from the solution of the differential equation:

$$i(t) = \frac{V}{L\omega} e^{-\alpha t} \sin \omega t \quad \text{For Pulse 1,}$$

where

$$\omega = \left[\frac{1}{LC} - \left(\frac{R}{2L} \right)^2 \right]^{1/2}$$

$$\alpha = \frac{R}{2L}$$

where,

V = capacitor bank voltage

R = circuit resistance

L = circuit inductance

C = bank capacitance

The secondary pulses can also be derived from more complex equations:

$$i(t) = I_0 e^{-\alpha t} \left[\cos \omega t + \left(\frac{1}{\omega} \sin \omega t \right) \left(\frac{V_1}{L_1 I_0} - \alpha \right) \right]$$

For Pulse 2, where

$$\alpha = \frac{R_1}{2L_1}$$

$$\omega = \left[\frac{1}{L_1 C_1} - \left(\frac{R_1}{2L_1} \right)^2 \right]^{1/2}$$

where,

I_0 = Circuit current at time of second pulse firing

V_1 = Voltage on secondary pulse capacitor banks

R_1 = Circuit resistance

L_1 = Circuit inductance

C_1 = Secondary bank capacitance

Figure 5 represents the composite Horn current waveshapes for the actual circuit component parameters, comparing single pulse and multiple pulsing operation.

Figure 5

In this case, the nominal 10% ΔI time is approximately 150 μs . This represents some improvement. Also, since banks 2 and 3 operate at lower voltage, new lower voltage, higher capacitance capacitors could be procured with the same physical dimensions as the existing capacitors. The capacitance of banks 2 and 3 could then be increased from 800 μf 7 KV to 3850 μf without increasing the physical size of the capacitor bank. Operation with this bank arrangement and compared to single pulse operation is shown in Figure 6. The 10% ΔI time is 300 μs .

Figure 6

The usual stated requirement for horn current pulse width is 1 millisecond. The discussion above indicates that a 1 millisecond pulse would require considerably more effort. Additional banks (5 total) would have to be added, each firing sequentially as shown in Figure 7. This solution is very expensive and would require a considerable amount of equipment.

Figure 7

Some Technical Problems

The preceding discussion implies a possible solution to the longer pulse requirement, but, several problems need to be resolved before successful operation could be assured. The first problem is the most serious and associated with the characteristics of the ignitrons themselves. Ignitrons, being a plasma device, are bilateral during the time the plasma is established. Also, the time to extinguish the arc within the tube can be long; i.e., depending on the tube type, circuit parameters, peak current, etc., 100 μ s to 10 seconds. The characteristics of our ignitrons will have to be tested. It's expected though, that a diode bank will be required in series with each tube to prevent the subsequent banks from discharging into the preceding bank capacitors.

Another difficulty is associated with the high voltage required for Pulse 1, nominally 12 KV. This is considerably above that required for single pulse operation, i.e., 6 KV. The higher voltage will doubtless require arduous tube conditioning and increased frequency of tube voltage breakdowns with the consequent reduced operating efficiency. Different higher voltage ignitron types are being examined for possible use. Other problems are associated with system control, i.e., separate charging power supply control, tests for system failures, etc.

Tests were performed on the horn power supply at low currents (~40 KA) to measure circuit behavior when firing each of the three banks separately.

Figure 8 is a calculated plot showing the circuit behavior of the multipulse scheme compared to a normal pulse for the single horn case.

Also shown is a photo of the actual horn current (lower trace) and Bank 3 voltage (upper trace). Bank 3 was the first bank fired. Note that the Bank 3 voltage does increase when subsequent banks are fired. This demonstrates that the tubes do behave bilaterally after having been once fired.

This leads to the conclusion that horn current pulse width with the present circuit is not markedly widened as a result of simple multipulsing, and that diodes in series with the series ignitrons would be an important addition for minimized charging voltages.

ACKNOWLEDGEMENTS

I would like to acknowledge William A. Williams and Dennis Williamson of the Neutrino Department for their help in making the tests.

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Figure 8