Fermilab

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STUDY OF HORN PULSE STRETCHING
Using
MULTIPULSE TECHNIQUES

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June 8, 1976

Introduction

Several alternatives exist to increase the Horn current pulse width:

1) A high current transformer
2) Increase bank capacitance
3) Other schemes, i.e., flywheel energy storage, etc.

Scheme 1, the transformer, is the most straightforward conceptually; it does, however, involve a complicated transformer, sizable changes to the existing horn power supply, and considerable cost. This alternative is discussed in Reference 3. Scheme 2, increased bank capacitance, is the discussion of this paper. Other schemes have been looked at, but not studied in any detail.

The Problem

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 pulsed 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 60μ seconds.

A Possible Solution

An examination of Figure 1 shows that the two power supply technique 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.

Figure 3 represents the composite Horn current waveshapes for the actual circuit component parameters, comparing single pulse and multiple pulsing operation.

The appendix provides the derivations of the appropriate equations to describe the current wave shape.

In this case, the nominal 10% ΔI time is approximately 150μ seconds. This represents some improvement. Also, since banks 2 and 3 operate at lower voltage, new lower voltage, new lower voltage capacitors could be procured with the same physical dimensions as the existing capacitors. The capacity of banks 2 and 3 could then be increased from 800 μf 7KV to 3850μf without increasing the physical size of the capacitor bank. Operation with this bank arrangement and compared to single pulse operation is shown in Figure 4. The 10% ΔI time is 300 μ seconds.

The usual stated requirement for horn current pulse width is 1 millisecond. The discussion above shows that with the banks arrangements indicated, 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 5. This solution is very expensive and would require a considerable amount of equipment.

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 tube type, circuit parameters, peak current, etc., 100μ seconds 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 horn system failures, etc.

SYSTEM COSTS

Three different schemes have been examined. The first, Figure 3, entails only diodes in series with each tube. The second, Figure 4, requires diodes and new capacitors for two banks. The third, Figure 5, and the most ambitious, requires diodes, new capacitors for the two existing banks, and five new banks of capacitors and ignitrons, along with additional controls, ignitron firing circuits, crowbar resistors, power supplies, decoupling networks, diagnostics, cabling, and a place to put all this equipment.

These costs are roughly estimated and compared in Table 1.

APPENDIX

Refer to Figure 1 for the following discussion.

For pulse 1

$$LSI(s) + RI(s) + \frac{1}{CS}(I(s) + q(0^+)) = 0$$

but $\quad q\frac{(0^+)}{CS} = -\frac{V}{S}$

then $\quad I(s) = \frac{V}{L}\,\frac{1}{s^2 + \frac{R}{L}s + \frac{1}{LS}}$

Completing the square and taking the inverse LaPlace.

$$i(t) = \frac{V}{LW}\,e^{-\alpha t}\sin\omega t \qquad \text{FOR PULSE 1}$$

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

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

For Pulse 2

$$L(SI(s) - i(0^+)) + RI(S) + \frac{1}{CS}(I(S) + q(0^+)) = 0$$

but $i(0^+) = I_o$

and $\frac{q(0^+)}{CS} = -\frac{V}{S}$

then $$I(S) = I_o \frac{S + \frac{V}{LI_o}}{S^2 + \frac{R}{L}S + \frac{1}{LC}} = I_o \frac{S}{\Delta} + \frac{\frac{V}{LI_o}}{\Delta}$$

then $\frac{S}{\Delta} = \frac{\alpha}{\alpha t}\left(\frac{1}{\Delta}\right)$

also $$f(t) = \frac{1}{2\pi j}\int_{C-j\infty}^{C+j\infty} F(S)e^{st}ds$$

$$\frac{\alpha}{\alpha t}f(t) = \frac{1}{2\pi j}\int_{C-j\infty}^{C+j\infty} S\ F(S)e^{st}ds$$

Therefore, taking the inverse LaPlace

$$i(t) = I_{oe}^{-\alpha t}\left[\cos \omega t + \left(\frac{1}{\omega}\sin \omega t\right)\left(\frac{V}{LI_o} - \alpha\right)\right]$$ for Pulse

Where

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

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

References

1. F.A. Nezrick, "Fermilab Neutrino-Horn Focussing System," Fermi National Accelerator Laboratory, TM-555, 2224.000 - March, 1975.

2. B.H. Smith, L.L. Reginato, J.W. Robinson, W.L. Dexter, "The Flat-Topping Power Supply for the 2XIIB Containment Magnet," Lawrence Livermore Laboratory, University of California.

3. R.C. Trendler, "Results of Horn Transformer Studies to Provide a One Millisecond Horn Pulse," Fermi National Accelerator Laboratory, TM-666, May, 1976.

4. R. Winje, "A 230 KJ Pulsed Power Supply," IEEE Transactions on Nuclear Science, Vol. NS-22, No. 3, Fermi National Accelerator Laboratory, June, 1975.

TABLE 1

Scheme 1 (See Figure 3)

Diode Banks (15 Required)	30 k
Controls modifications	1 k
Total	31 k

Scheme 2 (See Figure 4)

Diode Banks (15 Required)	30 k
Capacitors (2 x 30 bank = 60 total)	100 k
	130 k

Scheme 3 (See Figure 5)
(Building Additions not included)

Ignitrons (10/bank - 5 banks = 50) =	75 k
Capacitors (30/bank - 7 banks = 210) =	350 k
Firing Circuits =	20 k
Charging Supply =	25 k
All Other (controls, cabling, etc.) =	30 k
	500 K
GRAND TOTAL ------	661 k

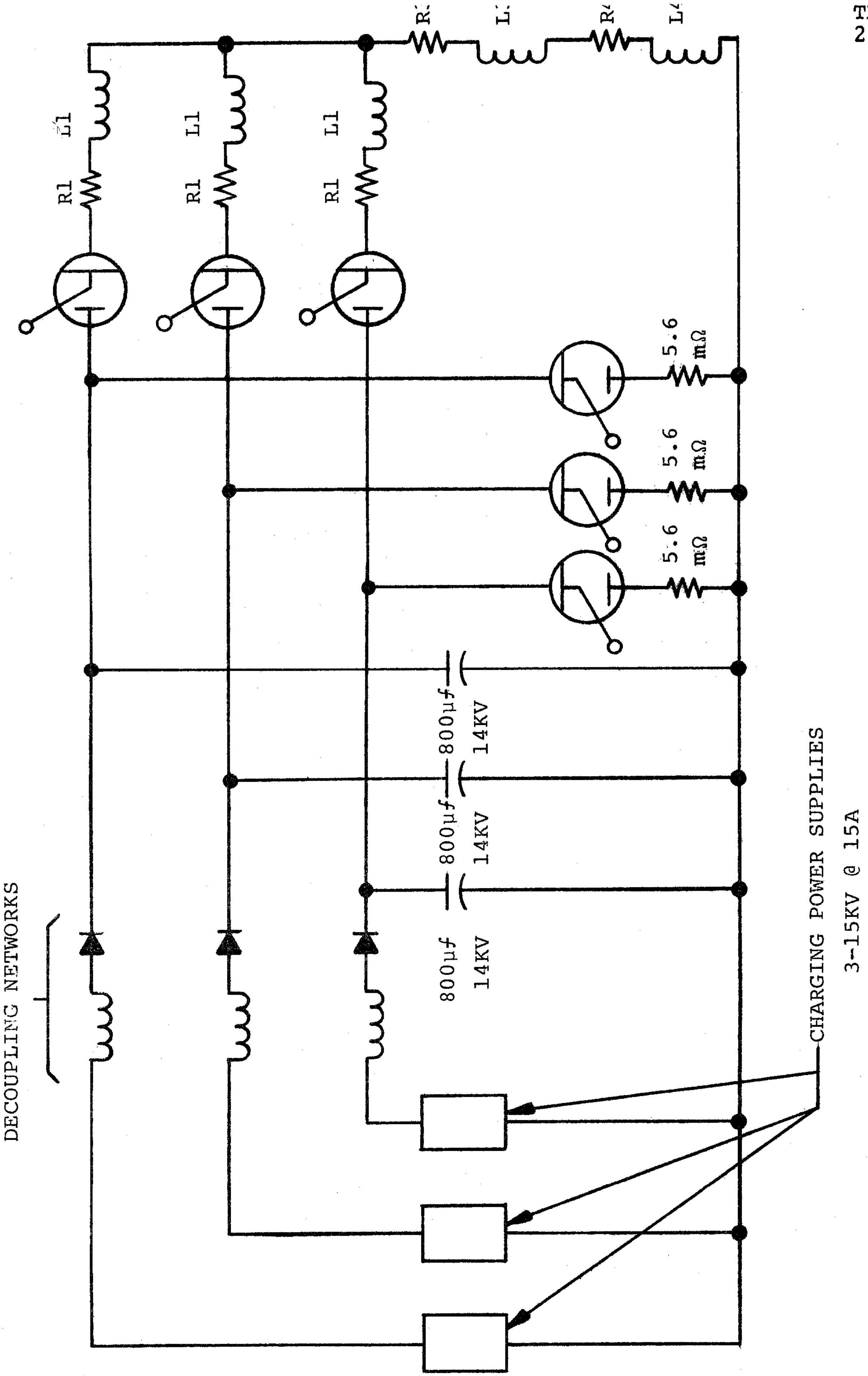
R1
L1
5.6 mΩ
800µf
14KV
DECOUPLING NETWORKS
CHARGING POWER SUPPLIES
3-15KV @ 15A

Figure 1

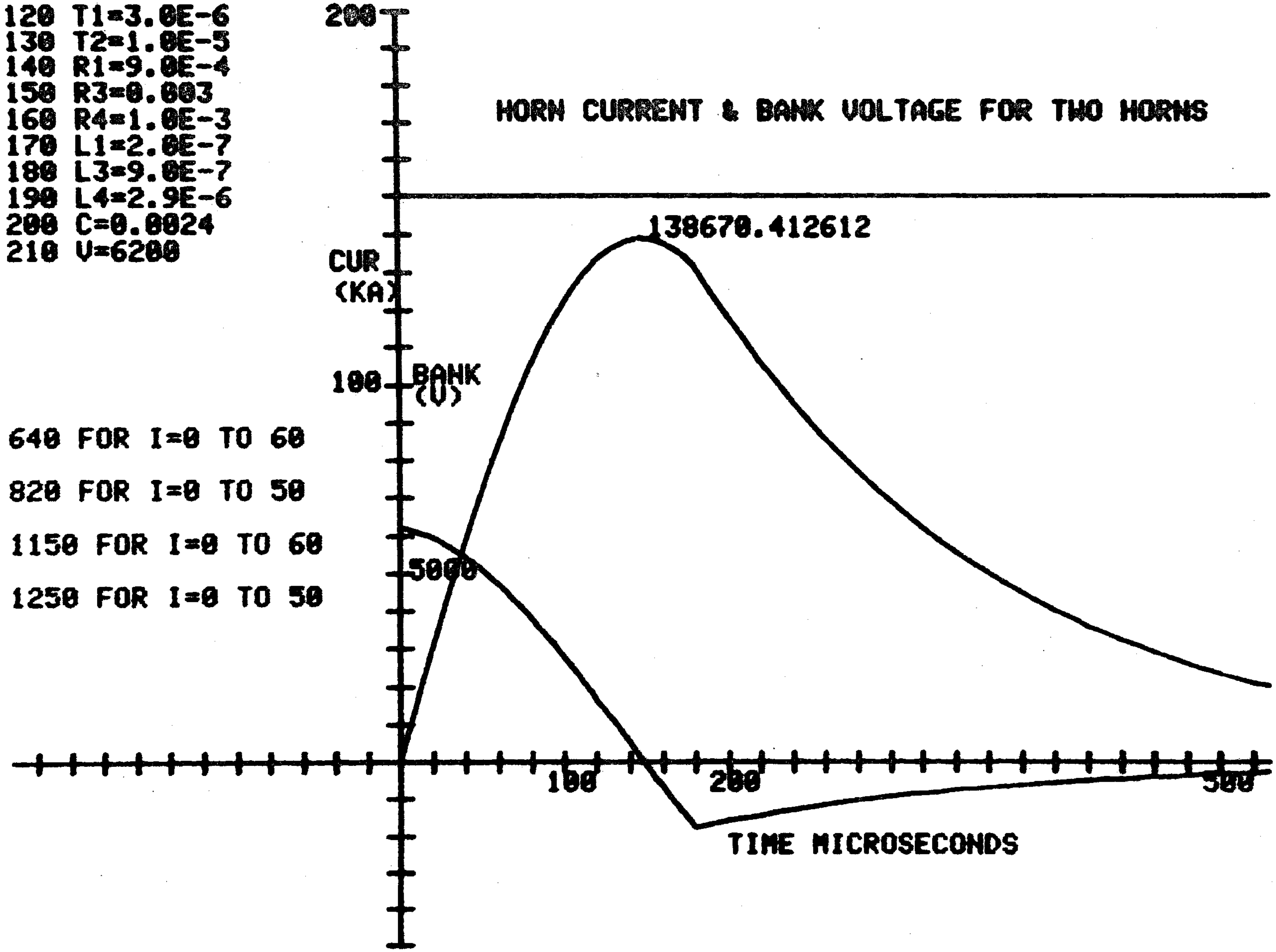

FIGURE 2

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```
120 T1=5.0E-6
130 R1=0.0027
140 R3=0.003
150 R4=1.0E-3
160 L1=6.0E-7
170 L3=9.0E-7
180 L4=2.9E-6
190 C=8.0E-4
200 V=11500

720 T1=5.0E-6
730 R1=0.0027
740 R3=0.003
750 R4=1.0E-3
760 L1=6.0E-7
770 L3=9.0E-7
780 L4=2.9E-6
790 C=8.0E-4
800 V=5800

1590 T1=1.0E-5
1600 R1=9.0E-4
1610 R3=0.003
1620 R4=1.0E-3
1630 L1=2.0E-7
1640 L3=1.0E-6
1650 L4=2.9E-6
1660 C=0.0024
1670 V=6300

670 FOR I=0 TO 24

690 FOR I=0 TO 11

1010 FOR I=0 TO 10
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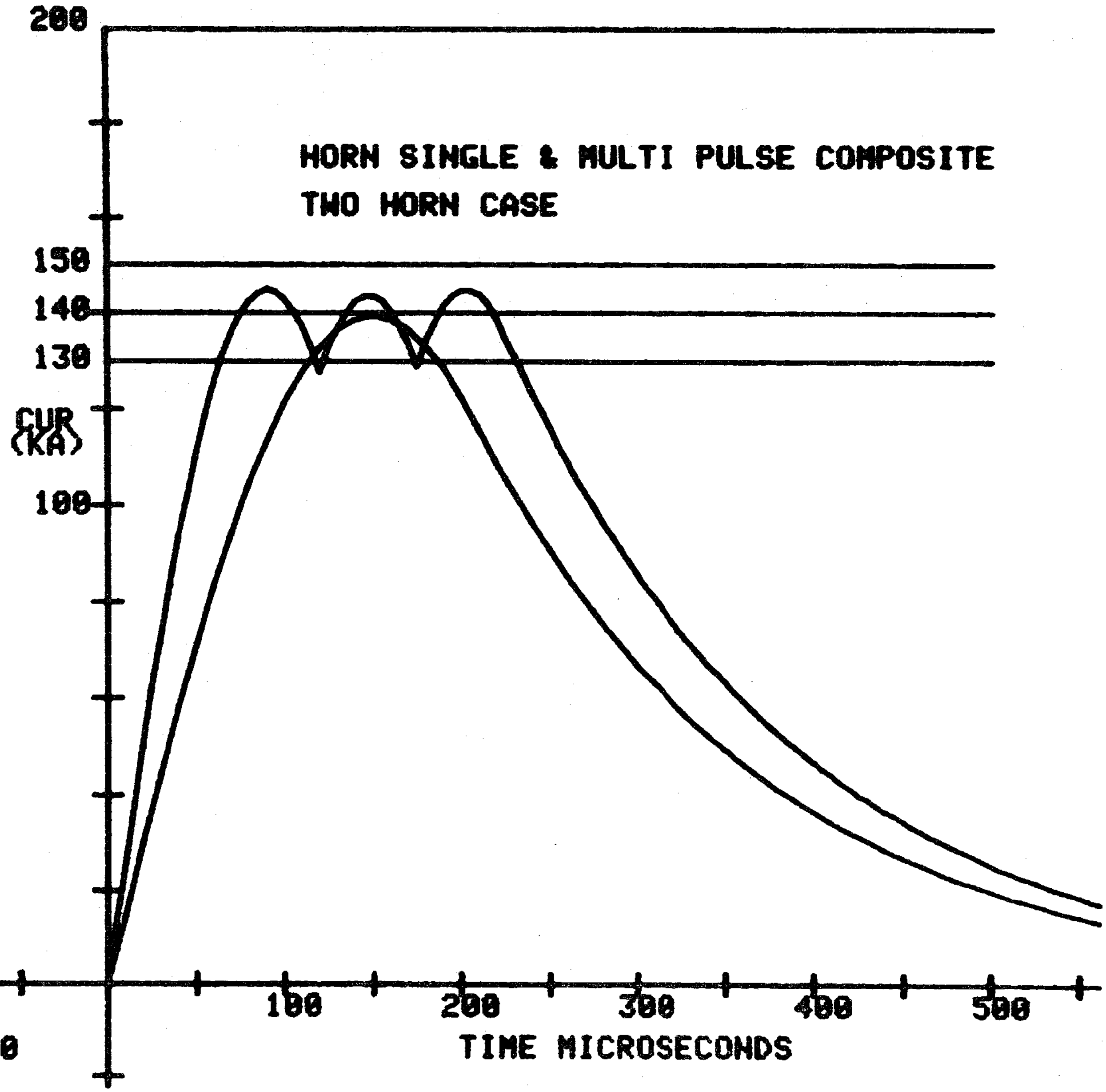

FIGURE 3

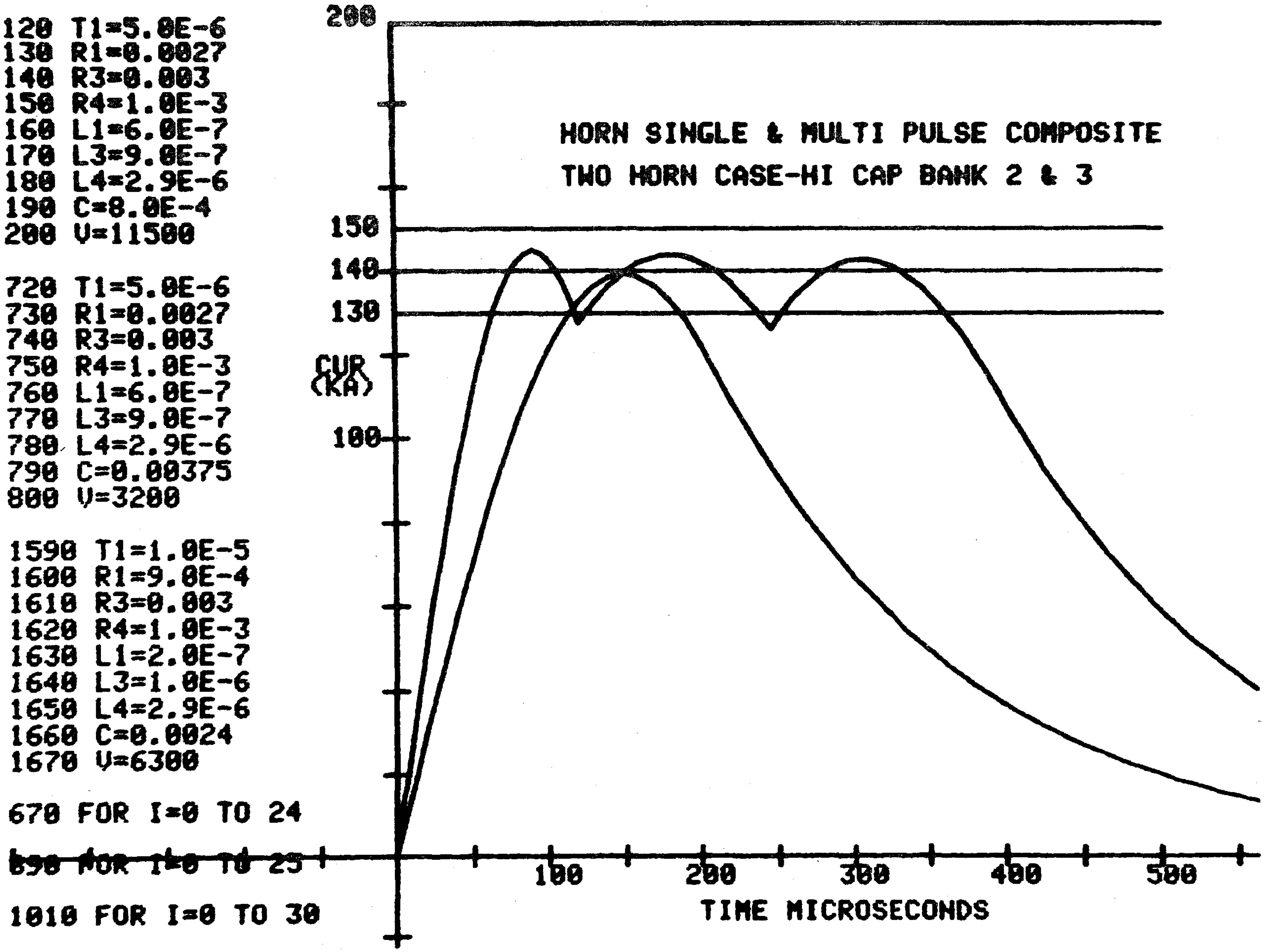

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FIGURE 4

```
120 T1=5.0E-6
130 R1=0.0027
140 R3=0.003
150 R4=1.0E-3
160 L1=6.0E-7
170 L3=9.0E-7
180 L4=3.0E-6
190 C=8.0E-4
200 V=11500

710 T1=5.0E-6
720 R1=0.0027
730 R3=0.003
740 R4=1.0E-3
750 L1=6.0E-7
760 L3=9.0E-7
770 L4=3.0E-6
780 C=0.00375
790 V=3200

660 FOR I=0 TO 24

890 FOR I=0 TO 25

1060 FOR I=0 TO 35

1200 FOR I=0 TO 45
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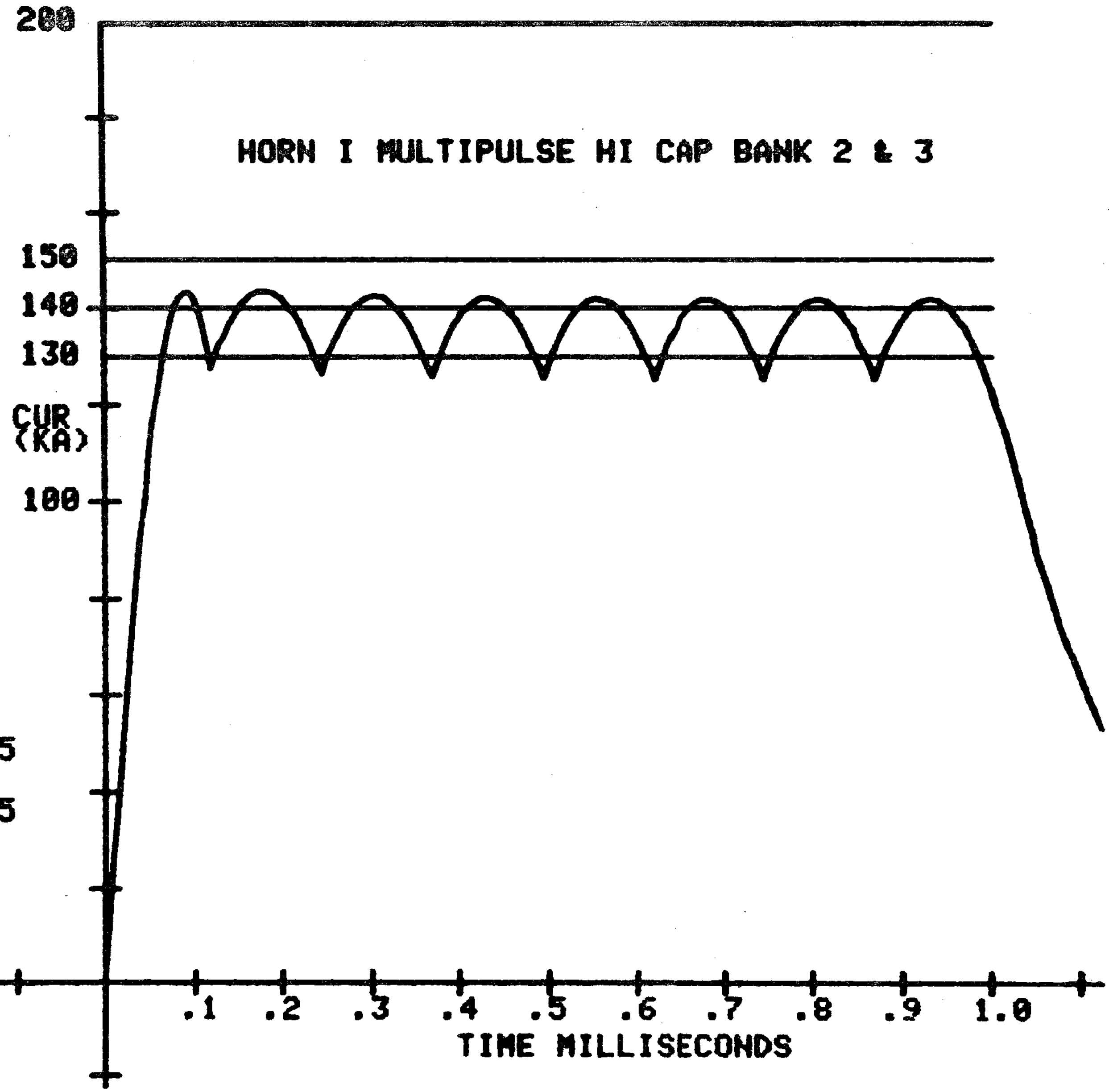

FIGURE 5