UNCLASSIFIED

AD NUMBER

ADB815791

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited. Document partially illegible.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 18 MAR 1946. Other requests shall be referred to Office of Scientific Research and Development, Washington, DC 20301. Document partially illegible.

AUTHORITY

SOD memo dtd 2 Aug 1960

THIS PAGE IS UNCLASSIFIED

Reproduced by
AIR DOCUMENTS DIVISION

HEADQUARTERS AIR MATERIEL COMMAND
WRIGHT FIELD, DAYTON, OHIO

The U.S. GOVERNMENT

IS ABSOLVED

FROM ANY LITIGATION WHICH MAY ENSUE FROM THE CONTRACTORS IN-FRINGING ON THE FOREIGN PATENT RIGHTS WHICH MAY BE INVOLVED.

WRIGHT FIELD, DAYTON, OHIO

RFEL — C
485
A.T.I.
13860

NDRC
Div. 14
OEMsr-262

Radiation Laboratory

Report 953 March 18, 1946

HYDROGEN THYRATRONS IN PULSE GENERATOR CIRCUITS

Abstract

Data are presented on the operating characteristics of hydrogen thyratrons in line-type pulse generator circuits. Photographs of the rate of fall of anode voltage and rise of current at the start of conduction are shown, and graphs of voltage-current-power-impedance relationships permit calculation of energy dissipated per pulse. Data are presented to show that the ionization time depends directly on the gas pressure, and that tube drop depends directly on cathode emission for the ranges of pressure and emission covered by this work. In addition to the operating anode voltage and current, the most important parameter governing tube dissipation is gas pressure. This is demonstrated both calorimetrically and by V-I power plot. Because of the great number of possible variables that govern tube dissipation, most of them uncontrollable, it is impossible to reproduce data with any degree of accuracy.

S. J. Krulikoski, Jr.

Approved by:

Leader, Group 51

Head, Division 5

Title Page
Table of Contents
53 Numbered Pages

1-22525

TABLE OF CONTENTS

HYDROGEN THYRATRONS IN PULSE GENERATOR CIRCUITS

I. Introduction

Measurements of power dissipation, rate of fall of anode voltage ($\frac{deb}{dt}$), and rate of rise of anode current ($\frac{dib}{dt}$) in hydrogen thyratrons have been made to obtain more data on the operation of these tubes in line-type pulse generator circuits. Data were taken under a variety of conditions of pulse duration, pulse repetition frequency, and power level. The measurements were made on Sylvania 4C35 and 5C22 thyratrons, and the data on gas pressure and cathode emission were taken with the standard R.F. pressure gauge and peak emission tester used for testing hydrogen thyratrons. This report presents the data obtained from these measurements of ($\frac{deb}{dt}$), ($\frac{dib}{dt}$), and power dissipation.

No quantitative analysis has been made of these data, except to correlate the measurements with the observations of tubes running on life test.

II. Rate of Fall of Anode Voltage, Rate of Rise of Anode Current, and Tube Drop

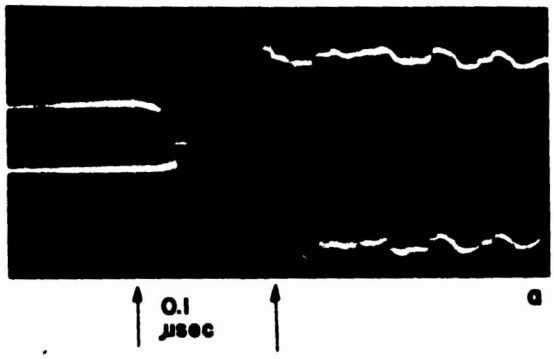
Measurements of $\frac{deb}{dt}$, $\frac{dib}{dt}$, and tube drop, were made with the hydrogen thyratron operating as the switch in a line-type pulse generator circuit. Data on $\frac{deb}{dt}$ were taken by observing the anode voltage at the start of conduction with a 6 $\mu\mu$f capacity divider and a synchroscope with a sweep speed of 10 inches per microsecond. Data on $\frac{dib}{dt}$ were taken by observing the current at the start of conduction through a non-inductive coaxial resistor in the cathode lead of the thyratron. Voltage-current time relationships were determined by using a commutating switch and observing both current and voltage simultaneously on the synchroscope. The tube drop was measured on a cathode ray tube whose vertical deflection plates were connected to the thyratron anode and cathode.

In the following discussion, ionization time is defined as the time taken for the anode voltage to fall from the maximum voltage before conduction to the flat region during conduction, as observed with a capacity divider and synchroscope.

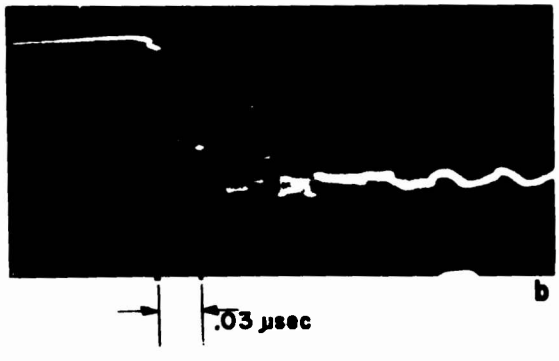
A. Effect of Gas Pressure on $\frac{deb}{dt}$ and $\frac{dib}{dt}$

In Figure 1 and Figure 2 are shown $\frac{deb}{dt}$ and $\frac{dib}{dt}$ on two 4C35 tubes with different gas pressure, run in the same circuit under identical operating

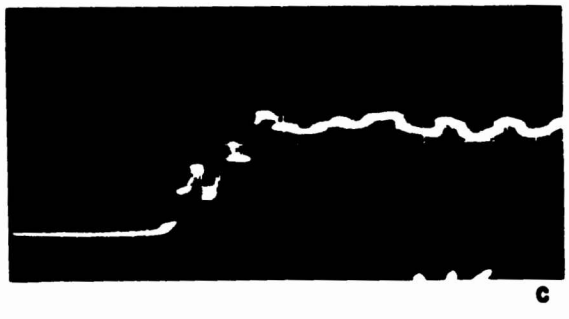
ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START OF 0.5 usec PULSE FOR 4C35 THYRATRON (SYLVANIA -#5278 - 600μ PRESSURE)



FALL OF ANODE VOLTAGE AND RISE OF ANODE CURRENT
e_b = 8.0 K.V.
i_b = 90 A
τ = 0.5 μsec
ν_r = 2000/sec
50 ~ CIRCUIT



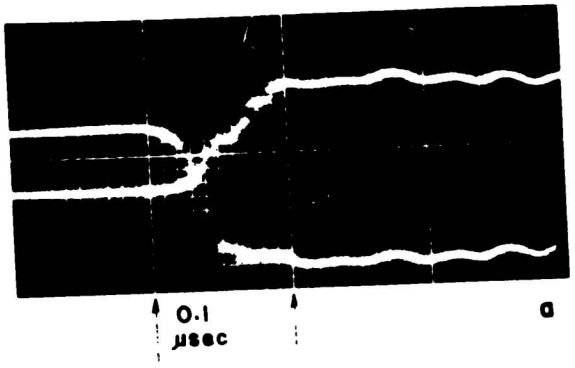
FALL OF ANODE VOLTAGE
e_b = 8.0 K.V.
TUBE DROP ~ 75 VOLTS



RISE OF ANODE CURRENT

FIGURE 1

ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START OF 0.5 usec PULSE FOR 4C35 THYRATRON (SYLVANIA - 48428 - 400μ PRESSURE)



FALL OF ANODE VOLTAGE AND RISE OF ANODE CURRENT

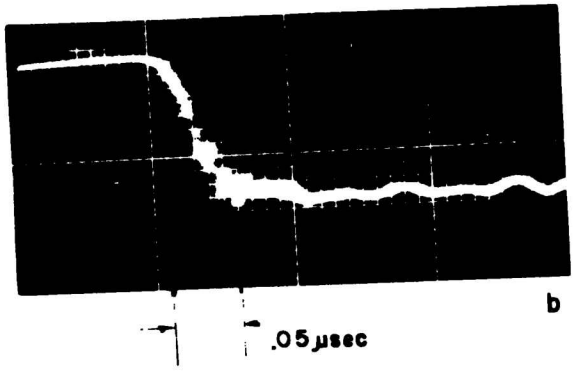
e_b = 8.0 K.V.

i_b = 90 A

τ = 0.5 μsec

ν_r = 2000 / sec

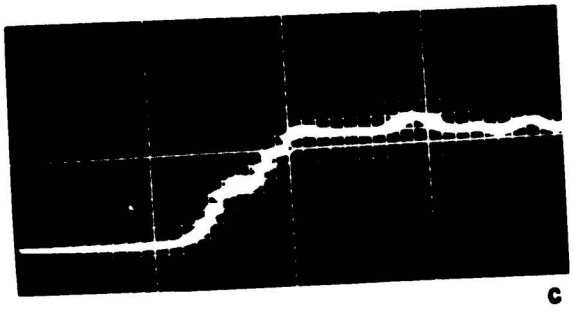
50-Ω CIRCUIT



FALL OF ANODE VOLTAGE

e_b = 8.0 K.V.

TUBE DROP ~ 80 VOLTS



RISE OF ANODE CURRENT

FIGURE 2

conditions. In Figure 4b, the ionization time is about .15 μsec for a gas pressure of 500 μ. In Figure 4a, for a gas pressure of 400 μ, the ionization time is about .05 μsec. Comparing Figure 4a and Figure 4c, $\frac{di_b}{dt}$ is higher for the higher pressure tube.

Figures 5a, 5b, and 5c show $\frac{de_b}{dt}$ and $\frac{di_b}{dt}$ on a 5C22 tube (pressure reading ≈ 500 μ) for three different pulse lengths and repetition frequencies. In Figures 5b, 5d, and 5b, the ionization time is about the same, .05 μsec, although Figures 5a, 5c, and 5e show that $\frac{di_b}{dt}$ is slightly decreased as the pulse length is increased. This decrease in $\frac{di_b}{dt}$ with increasing pulse length is due to the fact that type A networks of three to five sections were used, and the rate of rise of the pulse depends on the time delay per section of the network. In these particular cases, the time delay per section increased with the pulse length, and the rate of rise of the pulse was correspondingly reduced. Figures 6, 7, and 8 show data taken on a second 5C22 tube under the same operating conditions. This tube had a pressure reading of ≈ 300 μ. Figures 6b, 7b, and 8b again show that the ionization time is approximately constant for different pulse lengths and repetition rates, although with the lower gas pressure, it is about .03 μsec as compared to .05 μsec for the 5C22 with higher gas pressure.

Figures 9 and 10 show 2.2 μsec current pulses in five 4C35 tubes operated under identical circuit conditions. These data show that the rate of rise of thyratron current depends to a great extent on the tube as well as the circuit. In Figures 9 and 10, $\frac{di_b}{dt}$ increases with increasing gas pressure.

B Effect of Series Inductance and Shunt Capacity on $\frac{de_b}{dt}$ and $\frac{di_b}{dt}$

Figure 11 shows the effect of the addition of 100 μμf shunt capacity across the thyratron for a low pressure 5C22. (See Figures 6, 7, and 8.) The rate of fall of voltage is not appreciably affected, and the rate of rise of current is slightly increased.*

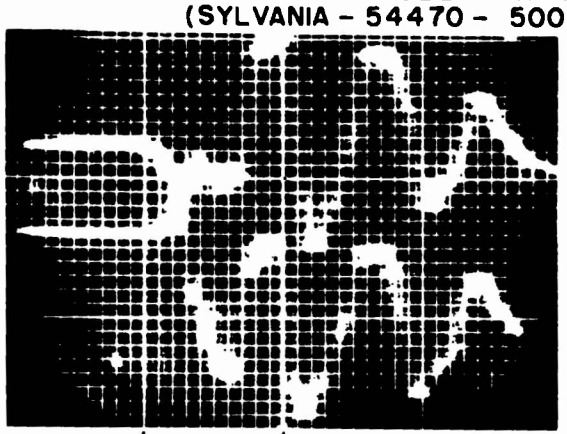
Figure 12 shows the effect of 5 μh inductance in series with the anode lead for a high pressure thyratron. It is difficult to evaluate the effect of the inductance on $\frac{de_b}{dt}$ because of the oscillations, but $\frac{di_b}{dt}$ is greatly reduced.*

C. Thyratron $\frac{di_b}{dt}$ compared to $\frac{dv}{dt}$ of the Output Pulse on Resistance Load

Figure 13 compares the thyratron current pulse and output voltage pulse on resistance load for two circuit conditions of increasing stray shunt

*See Radiation Laboratory Report 51-10/18/45, A Study of 5C22 Cathode Sparking in the Westinghouse SRa Modulator.

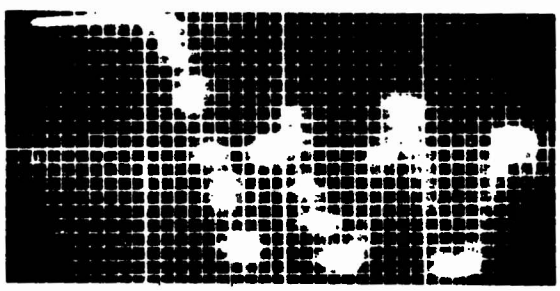
ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START -5
OF 0.25 usec PULSE FOR 5C22 THYRATRON
(SYLVANIA - 54470 - 500 μ PRESSURE)



a

FALL OF ANODE VOLTAGE
AND RISE OF ANODE
CURRENT

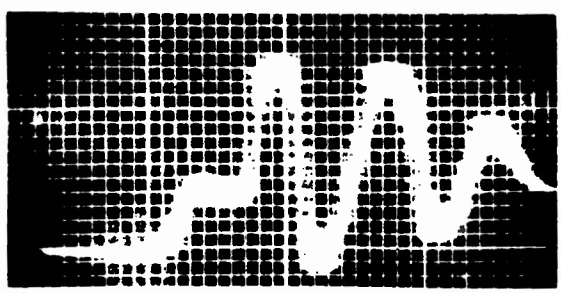
e_b = 16.0 K.V.
i_b = 144 A
τ = 0.25 μsec
ν_r = 3000/sec
50 Ω CIRCUIT



b

FALL OF ANODE
VOLTAGE

e_b = 16.0 K.V.
TUBE DROP ~ 120 VOLTS



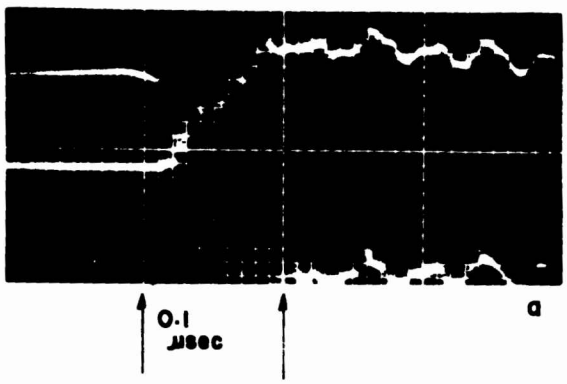
c

RISE OF ANODE
CURRENT

FIGURE 3

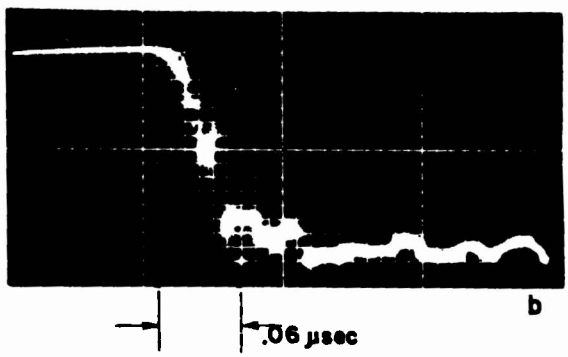
REPORT 953-5

ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START OF 0.5 usec PULSE FOR 5C22 THYRATRON (SYLVANIA - 5447O - 510μ PRESSURE)



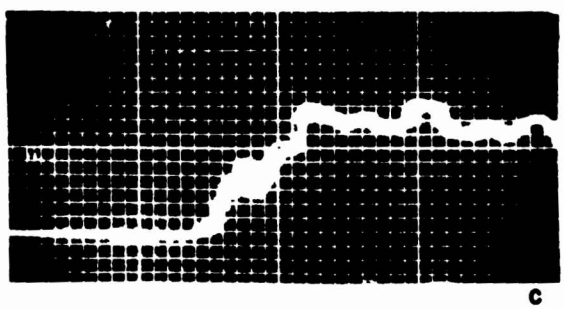
FALL OF ANODE VOLTAGE AND RISE OF ANODE CURRENT

e_b = 16.0 K.V.
i_b = 144 A
τ = 0.5 μsec
ν_r = 2000/sec
50 Ω CIRCUIT



FALL OF ANODE VOLTAGE

e_b = 16.0 K.V.
TUBE DROP ~ 120 VOLTS

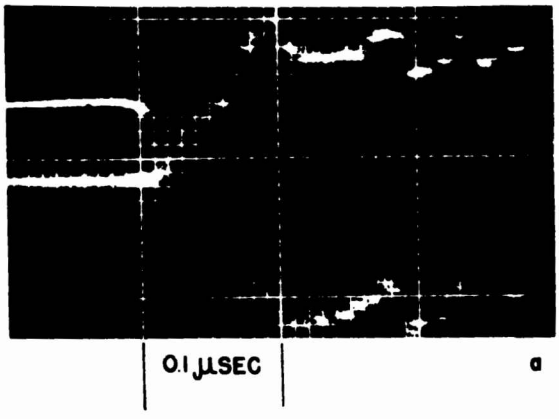


RISE OF ANODE CURRENT

FIGURE 4

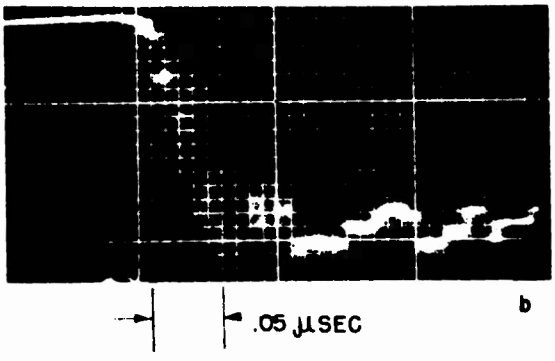
REPORT 953-6

ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START OF 1.1 μSEC PULSE FOR 5C22 THYRATRON (SYLVANIA - 5 4470 - 500μ PRESSURE)



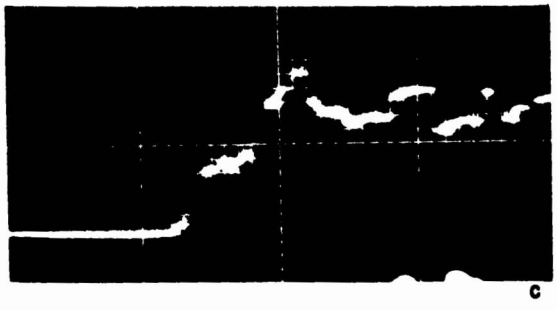
FALL OF ANODE VOLTAGE AND RISE OF CURRENT

e_b = 16.0 KV
i_b = 144 A
τ = 1.1 μSEC
V_r = 1000/SEC
50 Ω CIRCUIT



FALL OF ANODE VOLTAGE

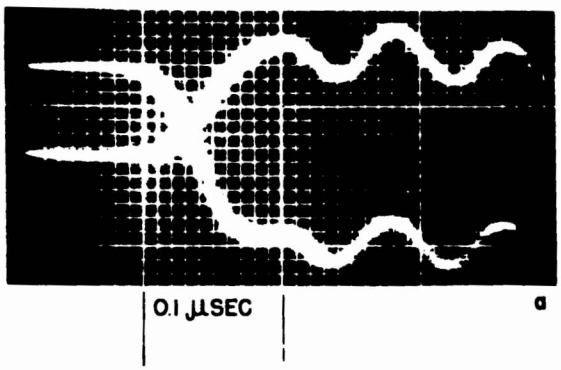
e_b = 16.0 KV
TUBE DROP ~120V



RISE OF ANODE CURRENT

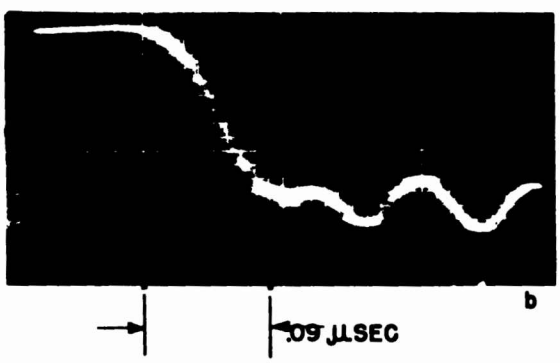
FIGURE 5

ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START OF 0.25 μSEC PULSE FOR 5C22 THYRATRON
(SYLVANIA - 57502 - ≈300μ PRESSURE)



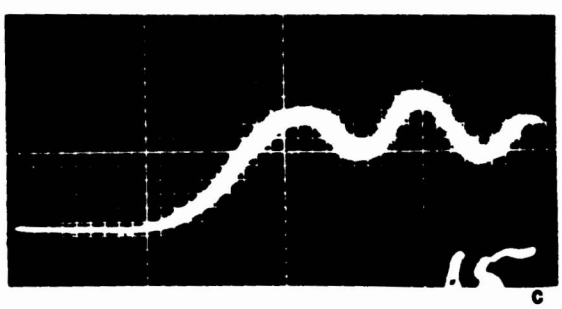
FALL OF ANODE VOLTAGE
AND RISE OF ANODE CURRENT

e_b = 16.0 KV
i_b = 144 A
τ = 0.25 μSEC
ν_r = 3000/SEC
50 Ω CIRCUIT



FALL OF ANODE VOLTAGE

e_b = 16.0 KV
TUBE DROP ~ 125 VOLTS

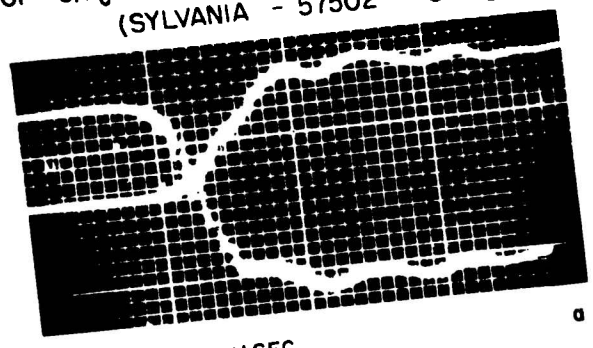


RISE OF ANODE CURRENT

FIGURE 6

REPORT 953-8

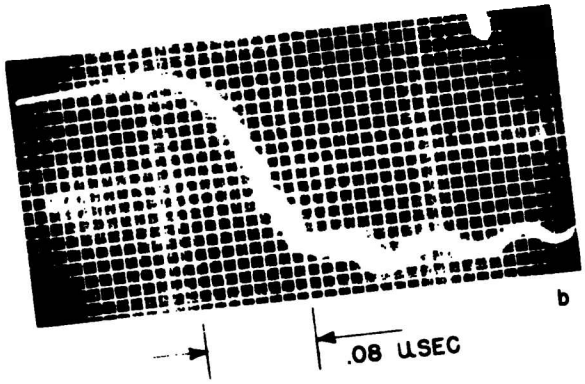
ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START OF 0.5 μSECOND PULSE FOR 5C22 THYRATRON
(SYLVANIA - 57502 - 300 μ PRESSURE)



a

FALL OF ANODE VOLTAGE AND RISE OF ANODE CURRENT
e_b = 16.0 KV
i_b = 144 A
τ = 0.5 μSEC
U_r = 2000/SEC
50 Ω CIRUIT

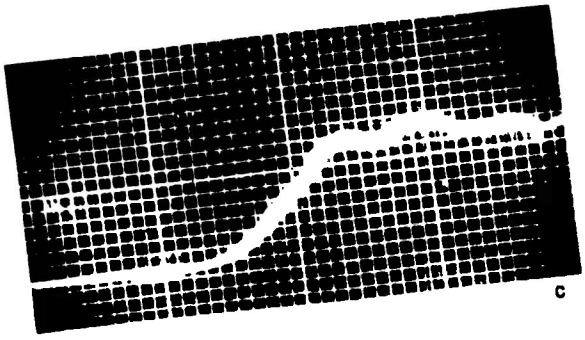
01 μSEC



b

FALL OF ANODE VOLTAGE
e_b = 16.0 KV
TUBE DROP ~ 125 VOLTS

.08 μSEC



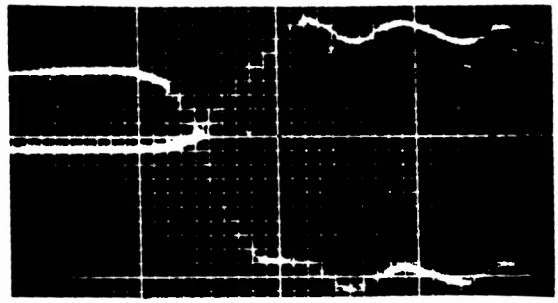
c

RISE OF ANODE CURRENT

REPORT 953-9

FIGURE 7

ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START OF 1.1 μSEC PULSE FOR 5C22 THYRATRON (SYLVANIA - 57502 - 300μ PRESSURE)

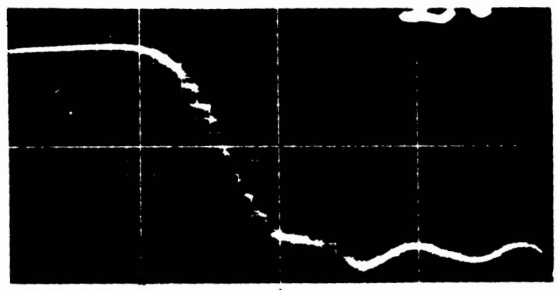


0.1 μSEC

a

FALL OF ANODE VOLTAGE
AND RISE OF ANODE CURRENT

e_b = 16.0 KV
i_b = 144 A
τ = 1.1 μSEC
ν_r = 1000/SEC
50 Ω CIRCUIT

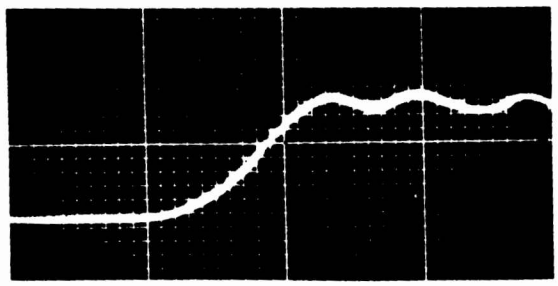


.10 μSEC

b

FALL OF ANODE VOLTAGE

e_b = 16.0 KV
TUBE DROP ~ 125 VOLTS



c

FIGURE 8

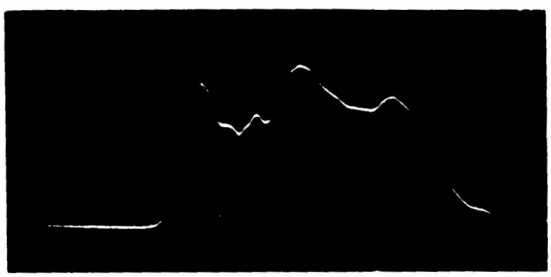
REPORT 953-10

a

\# 48428

380 MICRONS PRESSURE

61 VOLT EMISSION DROP AT 90A



b

\# 461974

450 MICRONS PRESSURE

50 VOLT EMISSION DROP AT 90A

c

\# 5278

650 MICRONS PRESSURE

50 VOLT EMISSION DROP AT 90A

4C35 THYRATRON CURRENT PULSE SHAPE AS A FUNCTION OF GAS PRESSURE

e_b = 8.0 KV

i_b = ~90A

τ = 0.25 μSEC

U_r = 1000/SEC

FIGURE 9

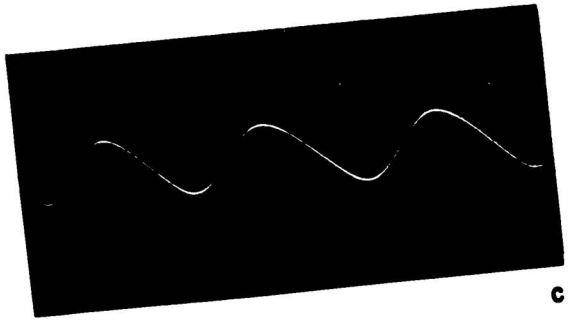
REPORT 953-11

a

52341
680 MICRONS PRESSURE
130 VOLT EMISSION
DROP AT 90A

b

52558
820 MICRONS PRESSURE
66 VOLT EMISSION
DROP AT 90A



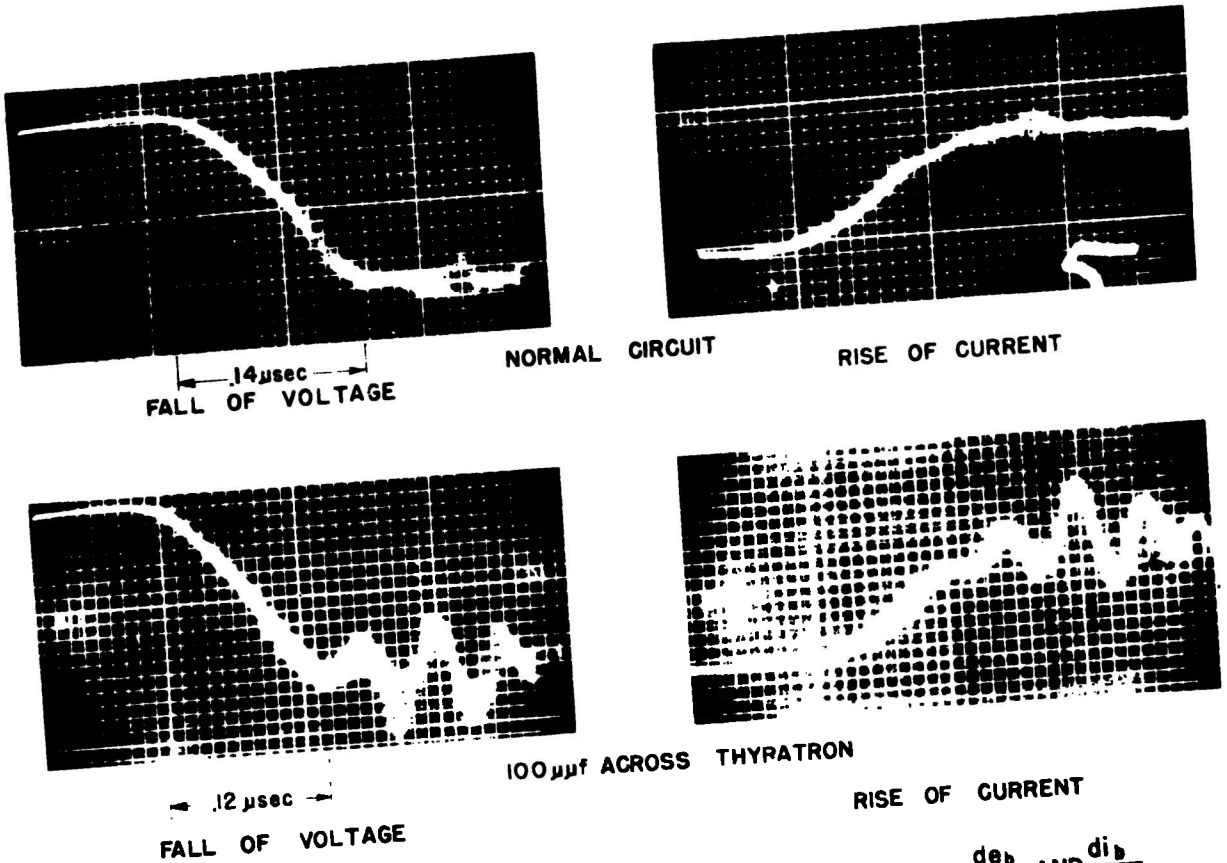
c

5 MC
SWEEP CALIBRATION
SIGNAL

4C35 THYRATRON CURRENT PULSE SHAPE AS A FUNCTION OF GAS PRESSURE

e_b = 8.0 K.V.
i_b = ~ 90 A
τ = 0.25 μsec
ν_r = 1000/sec

FIGURE 10



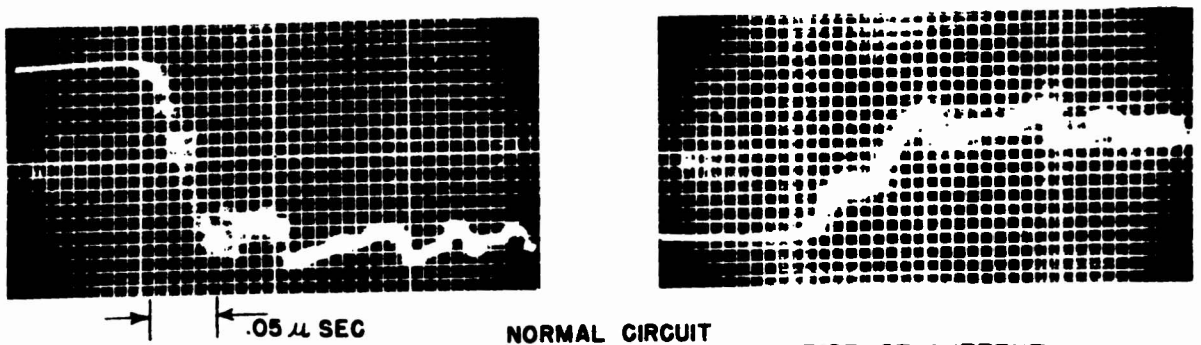
EFFECT OF SHUNT CAPACITY ACROSS THYRATRON ON $\frac{de_b}{dt}$ AND $\frac{di_b}{dt}$

e_b = 16.0 K.V. τ = 0.5 μsec

i_b = 144 A ν_r = 1000/sec

(SYLVANIA 5C22 - 57502 - 300μ PRESSURE)

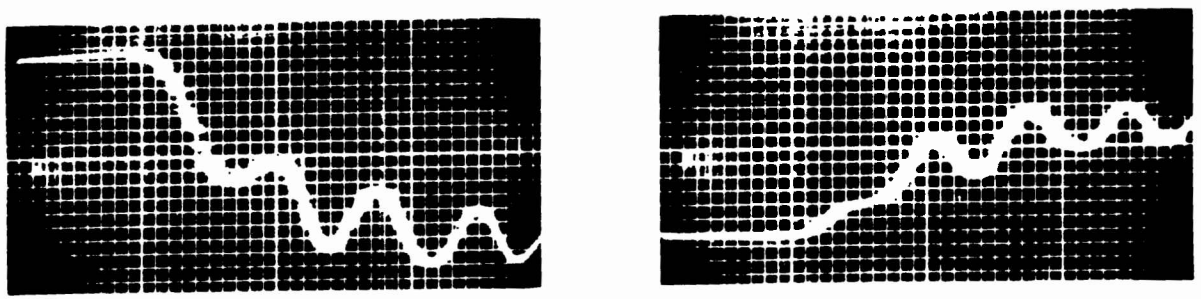
FIGURE 11



NORMAL CIRCUIT

FALL OF VOLTAGE

RISE OF CURRENT



5μh SERIES L

FALL OF VOLTAGE

RISE OF CURRENT

EFFECT ON $\frac{de_b}{dt}$ AND $\frac{di_b}{dt}$ OF ANODE INDUCTANCE IN SERIES WITH THYRATRON

e_b = 16.0 KV τ = 0.5 μ SEC

i_b = 144 A V_r = 1000/SEC

(SYLVANIA 5C22 - 5751I - 600μ PRESSURE)

FIGURE 12

←0.2 μSEC→

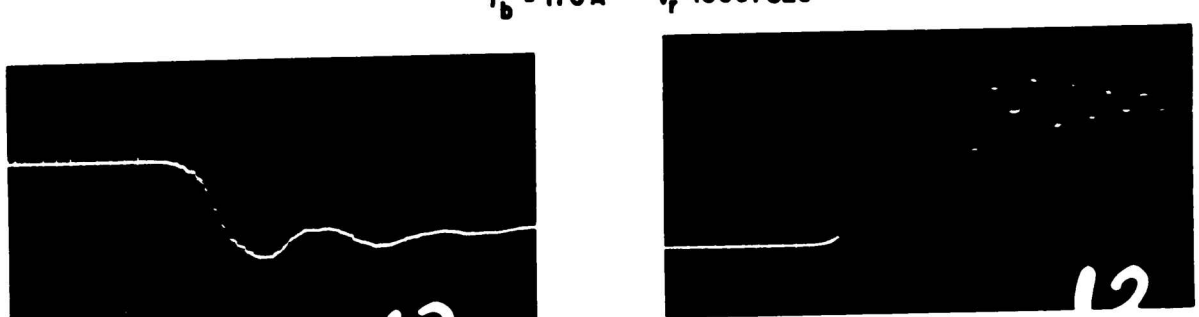
NORMAL CIRCUIT

OUTPUT VOLTAGE ON R-LOAD

THYRATRON CURRENT

e_b = 16.0 KV T = 1.1 μSEC

i_b = 170 A V_r = 1000/SEC



100 μμf ACROSS THYRATRON

OUTPUT VOLTAGE ON R-LOAD

THYRATRON CURRENT

COMPARISON OF 5C22 CURRENT PULSE AND OUTPUT VOLTAGE PULSE

FIGURE 13

capacity across the cathode-anode in the 4C35, a hydrogen thyratron.

These data show that $\frac{di_b}{dt}$ in the thyratron is greater than would be expected from the network because of the stray shunt capacity across the thyratron. This stray capacity, charged to full switch voltage, is discharged through the thyratron, and all the energy is dissipated in the thyratron. It is evident in Figure 13 that the discharge current of this capacity does not appear at the load.* For this reason, measurements of thyratron $\frac{di_b}{dt}$ should be made at the thyratron and not on the load voltage pulse.

D. Effect of Operating Power Level on $\frac{de_b}{dt}$

Figures 14, 15, and 16 show $\frac{de_b}{dt}$ and $\frac{di_b}{dt}$ on a 4C35 operated in a 50 ohm circuit with anode voltages of 5.0, 7.0, and 2.0 kv. Of necessity, $\frac{de_b}{dt}$ varies with the anode voltage, but the ionization time is the same for all three operating points.

III. Tube Drop

In Figure 17 is shown the anode-cathode tube drop for a 4C35 operated at 1.1 usec pulse duration, and increasing peak current in a 50 ohm circuit. For this tube, the anode-cathode tube drop is nearly constant for increasing peak current.

In Figure 18 is shown the anode cathode tube drop on two 4C35 tubes, operated under identical conditions of 1.1 usec pulse duration, but with different values of measured cathode emission. In these two tubes with approximately equal gas pressure, the tube drop varies directly with the emission drop.

Figures 19 and 20 compare the tube drop on three 4C35 tubes with the emission drop as measured with the standard thyratron peak emission tester. These data show that the anode-cathode tube drop can be approximately determined from the measured cathode emission.

Figure 21 shows the anode-cathode tube drop on three 5C22 tubes.

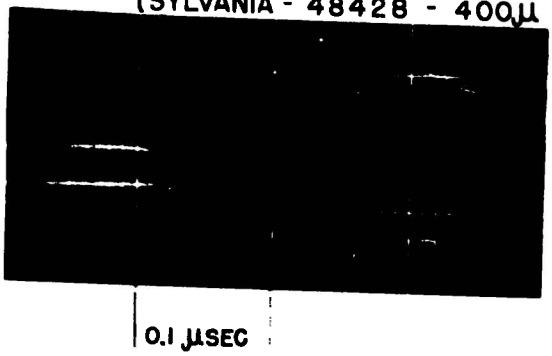
IV. Dissipation Measurements

A. Power vs time for a single pulse and voltage-current-power-impedance relationships at start of conduction

Figures 22 - 28 show graphs of power vs time for a single pulse, and voltage-current-power-impedance relationships at the start of conduction.

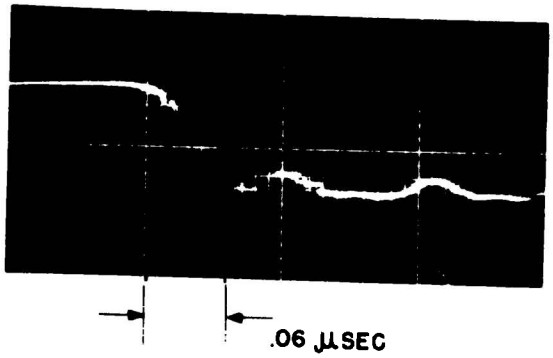
*See Radiation Laboratory Report 828, Pages 14-17.

ANODE VOLTAGE - CURRENT - TIME RELATIONSHIPS AT START OF 1.1 μSEC PULSE FOR 4C35 THYRATRON (SYLVANIA - 48428 - 400μ PRESSURE)



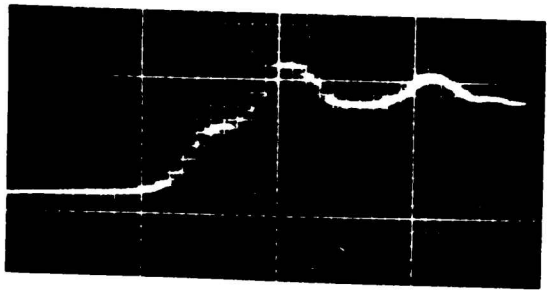
FALL OF ANODE VOLTAGE AND RISE OF ANODE CURRENT

e_b = 8.0 KV
I_b = 85A
T = 1.1 μSEC
V_r = 1000/SEC
50 Ω CIRCUIT



FALL OF ANODE VOLTAGE

e_b = 8.0KV
TUBE DROP ~ 80V

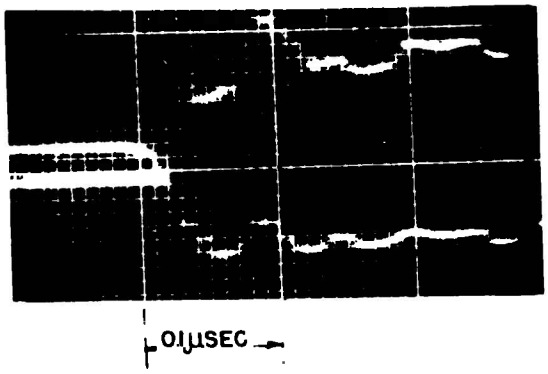


RISE OF ANODE CURRENT

FIGURE 14

ANODE VOLTAGE — CURRENT — TIME RELATIONSHIPS AT START OF 1.1μSEC PULSE FOR 4C35 THYRATRON

(SYLVANIA — 48428 — 400μ PRESSURE)



FALL OF ANODE VOLTAGE AND RISE OF ANODE CURRENT

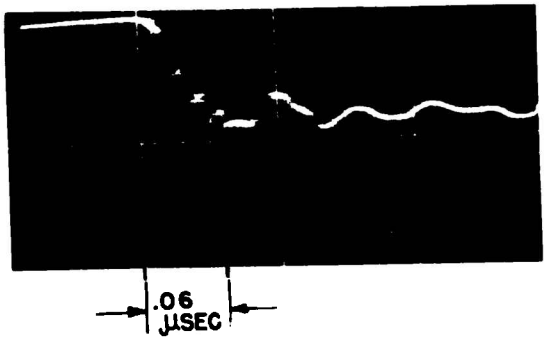
e_b = 4.0 KV

i_b = 38A

τ = 1.1μSEC

V_f = 1000/SEC

50Ω CIRCUIT



FALL OF ANODE VOLTAGE

e_b = 4.0 KV

TUBE DROP ~ 75V

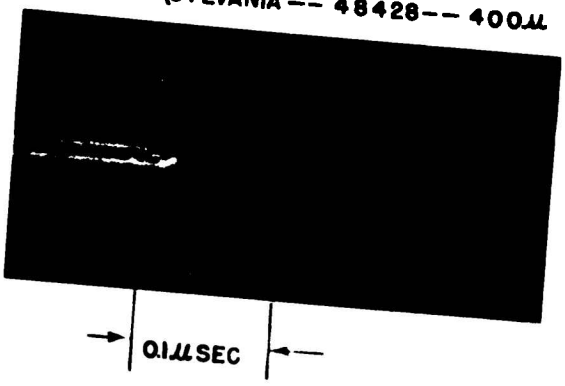
RISE OF ANODE CURRENT

FIGURE 15

REPORT 953-18

ANODE VOLTAGE — CURRENT — TIME RELATIONSHIPS AT START OF 1.1 μ SEC PULSE FOR 4C35 THYRATRON

(SYLVANIA — 48428 — 400 μ PRESSURE)



FALL OF ANODE VOLTAGE AND RISE OF ANODE CURRENT

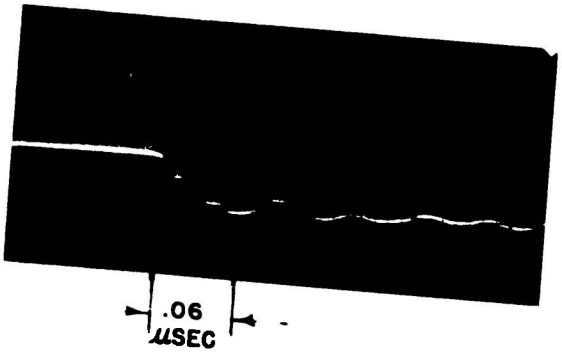
e_b = 2.0 KV

i_b = 17A

τ = 1.1 μ SEC

ν_r = 1000/SEC

50 Ω CIRCUIT



FALL OF ANODE VOLTAGE

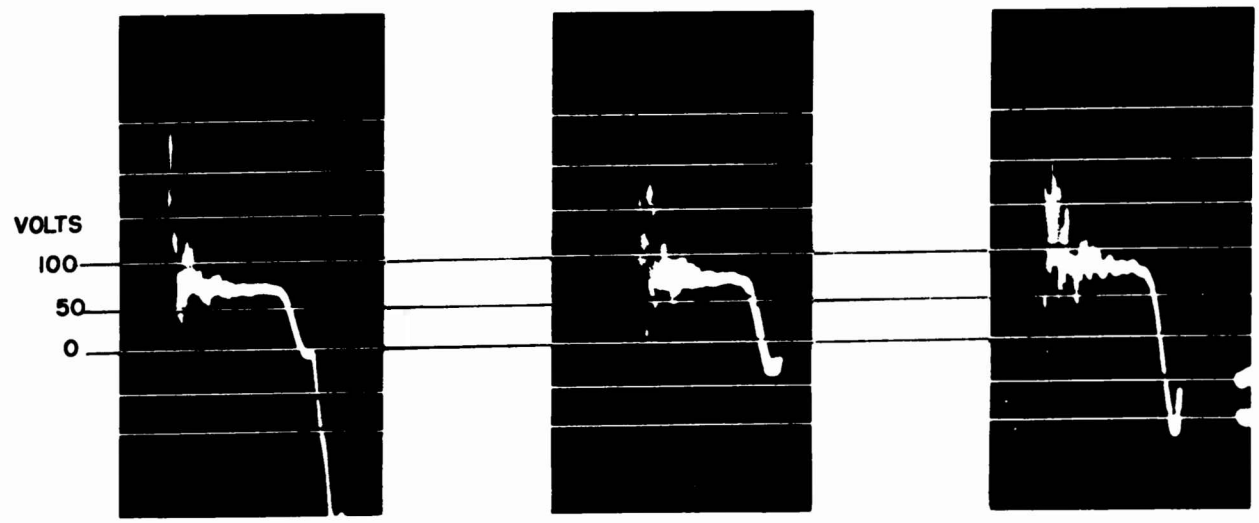
e_b = 2.0 KV

TUBE DROP $\sim$ 75 VOLTS

RISE OF ANODE CURRENT

FIGURE 16

REPORT 953-19



TUBE DROP ~75 V
e_b = 2.0 KV
i_b ~ 17A

TUBE DROP ~ 75 VOLTS
e_b = 4.0 KV
i_b ~ 38A

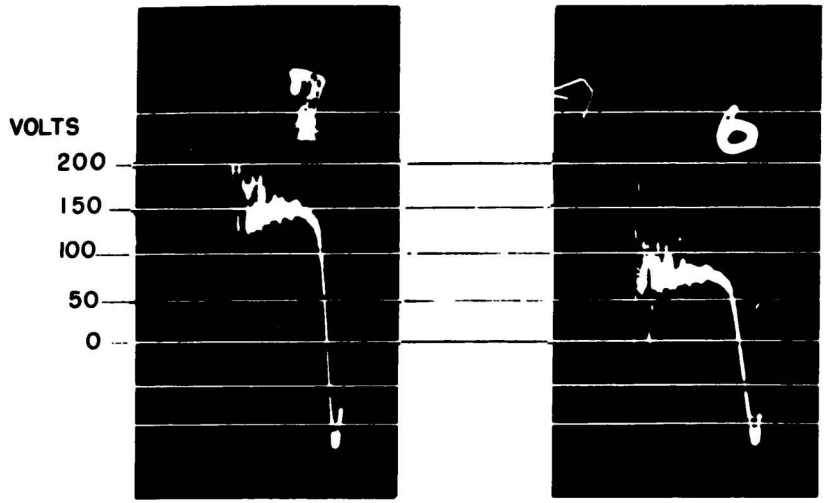
TUBE DROP ~ 80 V
e_b = 8.0 KV
i_b ~ 85A

τ = 1.1 μSEC
ν_r = 1000/SEC
50 Ω CIRCUIT

ANODE - CATHODE VOLTAGE DROP DURING PULSE FOR 4C35 HYDROGEN THYRATRON
(SYLVANIA - 48428 - 400μ PRESSURE)

FIGURE 17

ANODE-CATHODE VOLTAGE DROP DURING PULSE FOR 4C35 HYDROGEN THYRATRONS



\# 52341

TUBE DROP ~ 150 VOLTS
EMISSION DROP = 130 VOLTS
AT 90A
GAS PRESSURE = 680μ
e_b = 8.0 KV
i_b = ~90A
τ = 1.1 μSEC
U_r = 1000/SEC

\# 5278

TUBE DROP ~ 75 VOLTS
EMISSION DROP = 50 VOLTS
AT 90A
GAS PRESSURE = 650μ
e_b = 8.0 KV
i_b = ~90A
τ = 1.1 μSEC
U_r = 1000/SEC

FIGURE 18

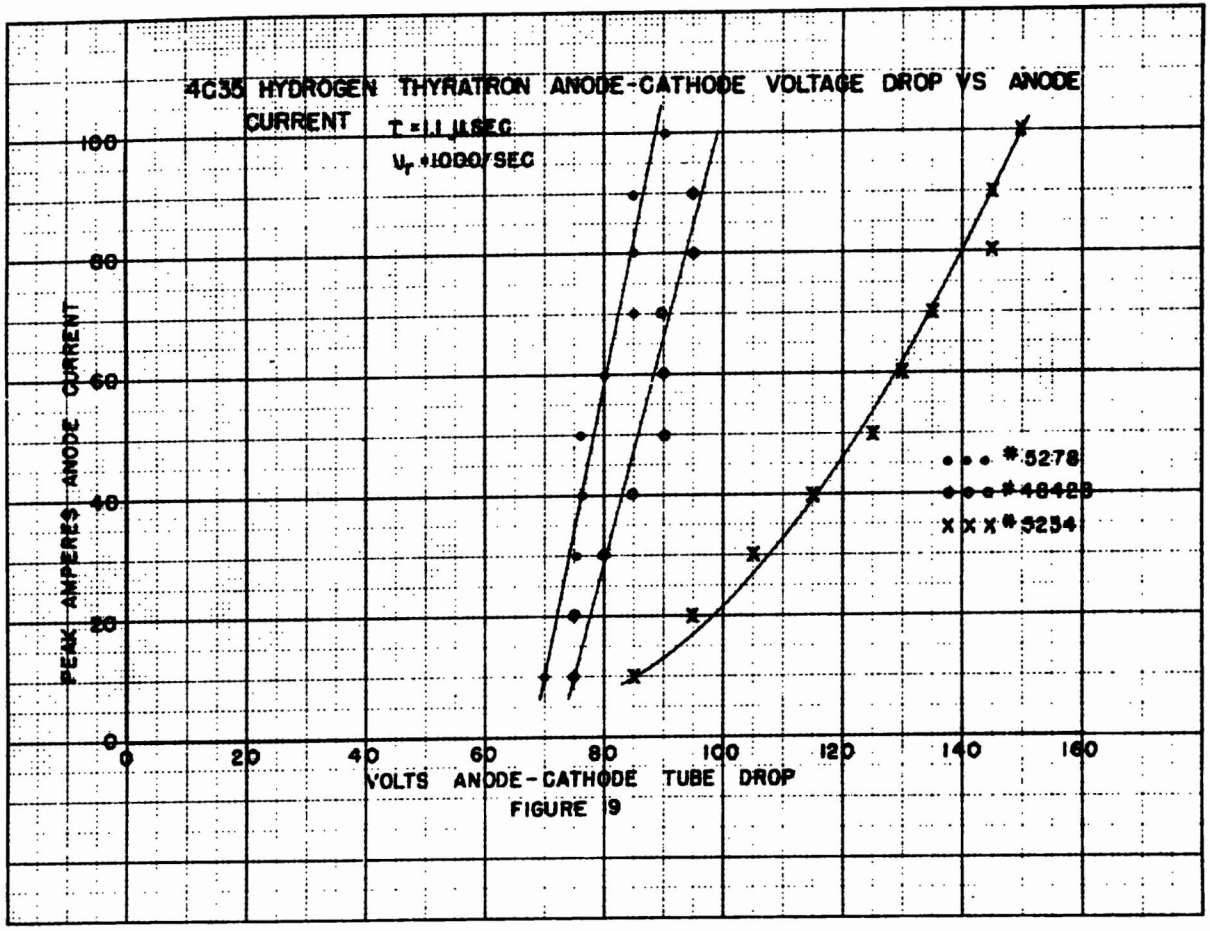


FIGURE 9

REPORT 953-22

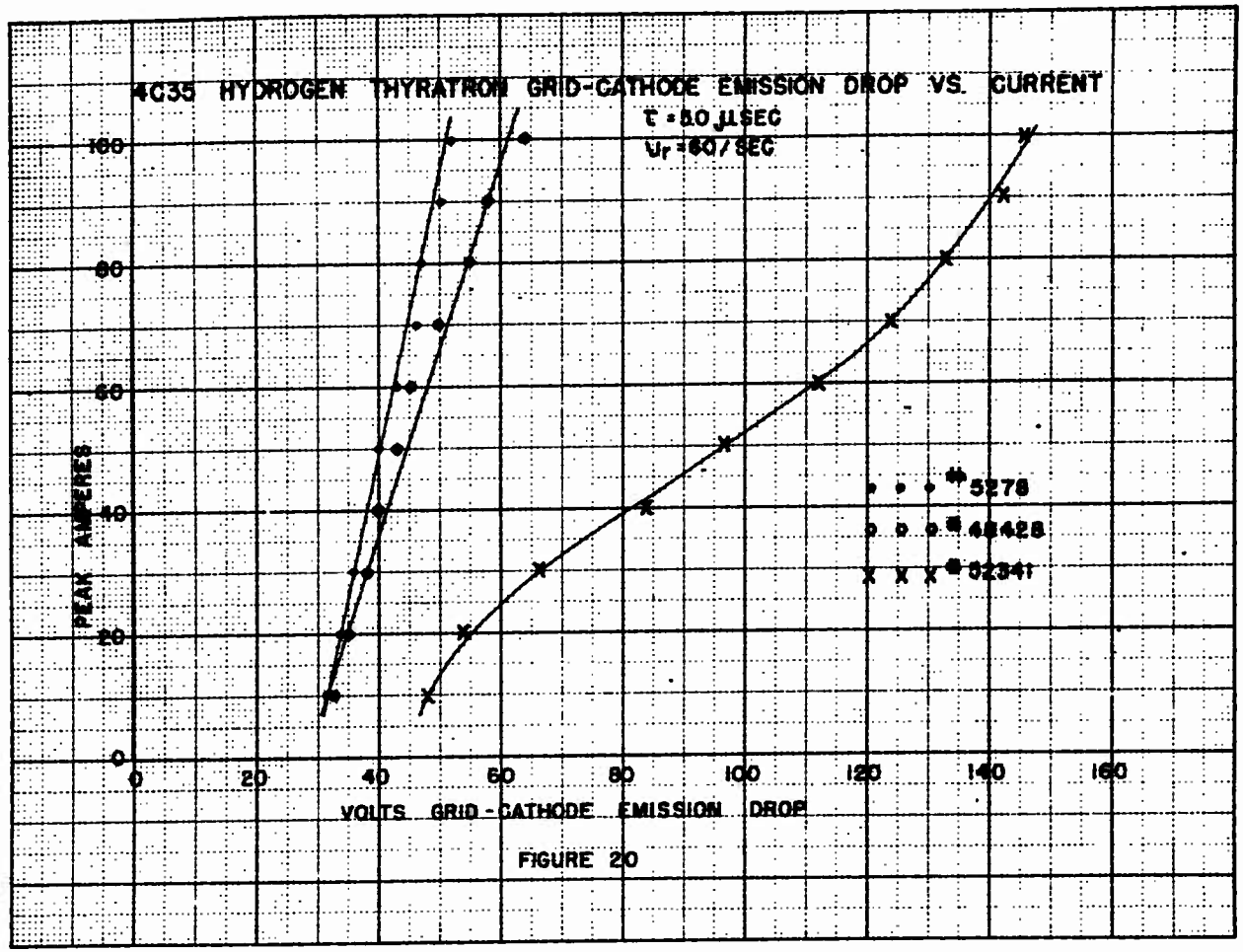
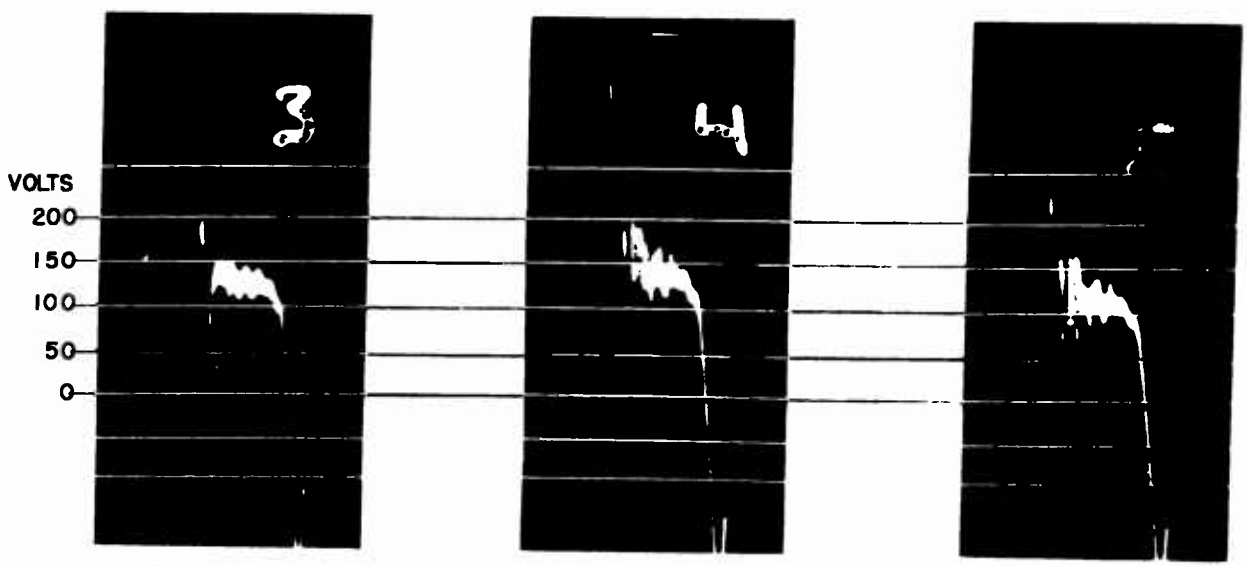

4C35 HYDROGEN THYRATRON GRID-CATHODE EMISSION DROP VS. CURRENT
t = 5.0 μSEC
Ur = 60 / SEC
PEAK AMPERES
0
20
40
60
80
100
120
140
160
VOLTS GRID-CATHODE EMISSION DROP
5278
48428
52341

FIGURE 20

ANODE - CATHODE VOLTAGE DROP DURING PULSE FOR 5C22 HYDROGEN THYRATRON



57502

TUBE DROP ~ 130 VOLTS

57511

TUBE DROP ~ 140 VOLTS

54470

TUBE DROP ~ 120 VOLTS

e_b = 15.0 KV
I_b = 140
τ = 1.1 μSEC
V_r = 1000/SEC

FIGURE 21

REPORT 953-24

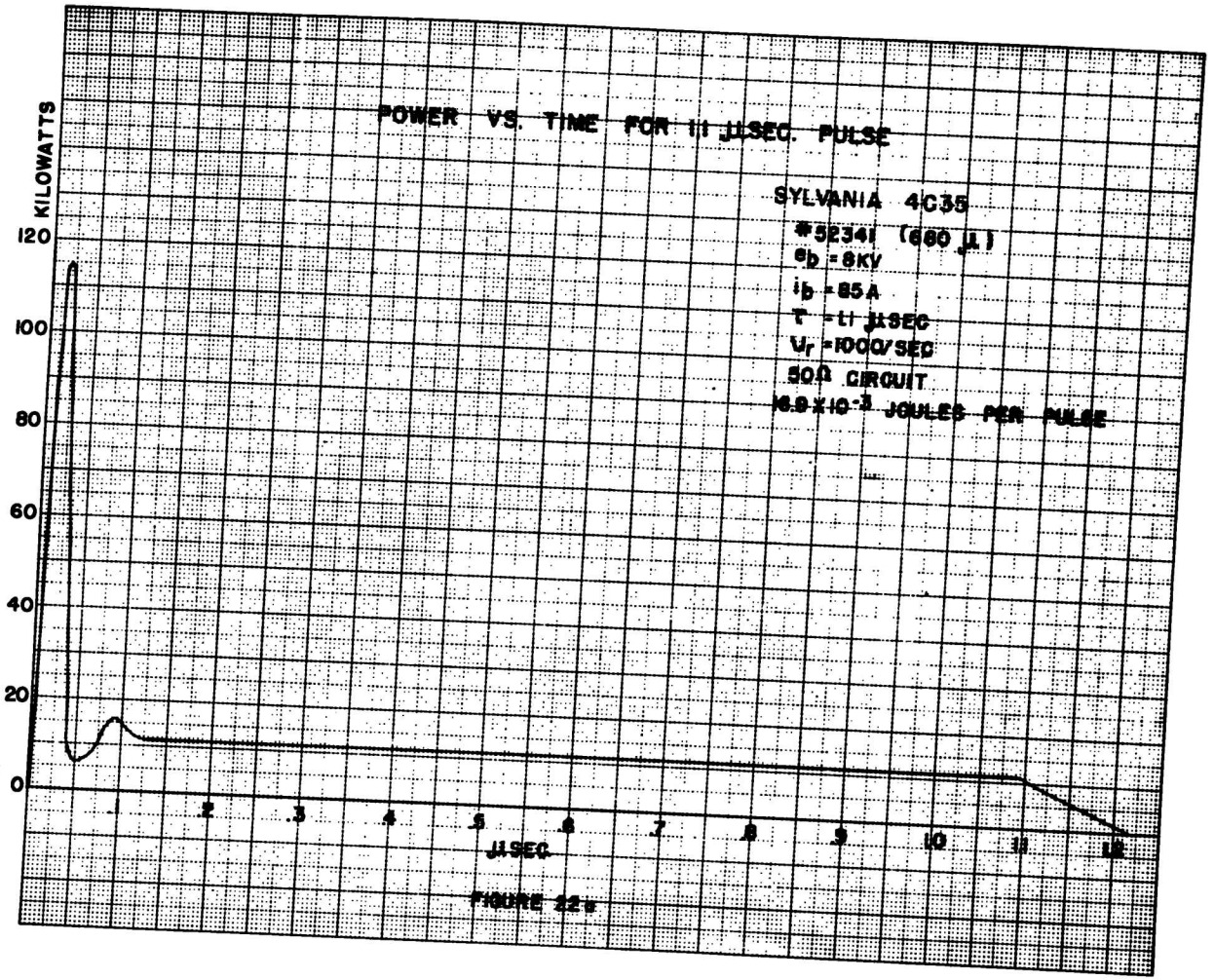

POWER VS. TIME FOR 11 μSEC. PULSE
SYLVANIA 4C35
#52341 (680 μ)
e_b = 8KV
i_b = 85A
τ = 11 μSEC
V_r = 1000/SEC
50Ω CIRCUIT
6.9 x 10⁻³ JOULES PER PULSE
KILOWATTS
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
μSEC

FIGURE 22a

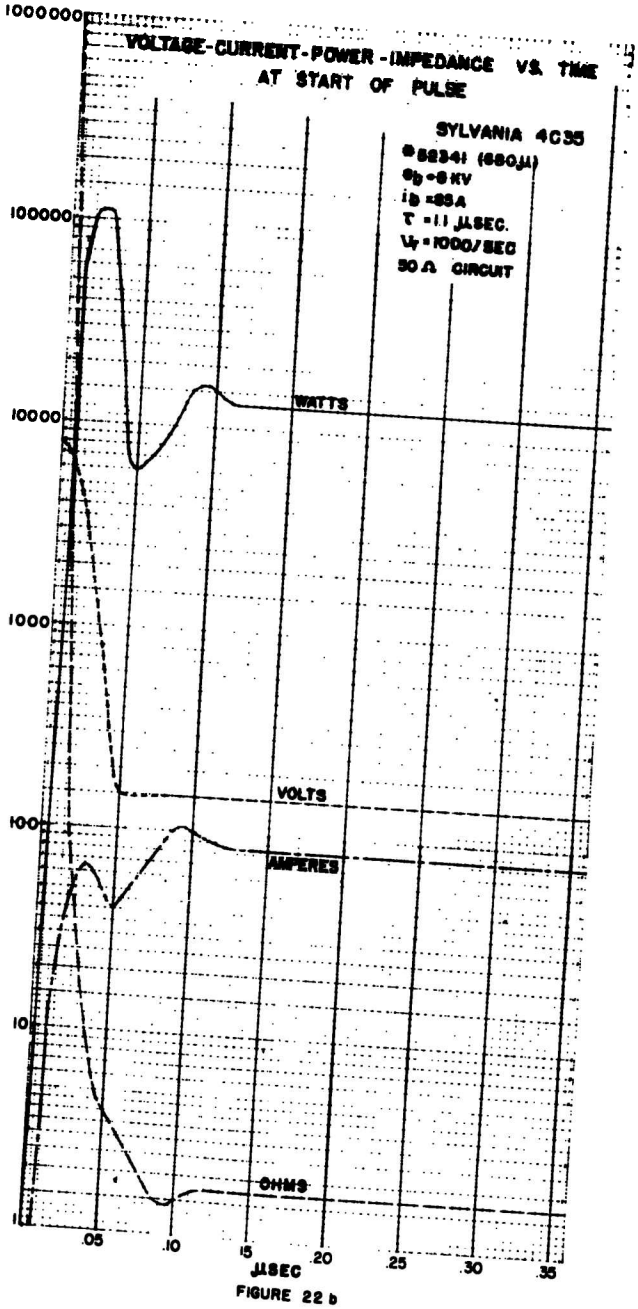

VOLTAGE-CURRENT-POWER-IMPEDANCE VS. TIME
AT START OF PULSE
SYLVANIA 4C35
6834 (680μ)
e_b =8 KV
i_b =8A
τ =1.1 μSEC.
ψ =1000/SEC
50 Ω CIRCUIT
1000000
100000
10000
1000
100
10
1
WATTS
VOLTS
AMPERES
OHMS
.05
.10
.15
.20
.25
.30
.35
μSEC

FIGURE 22 b

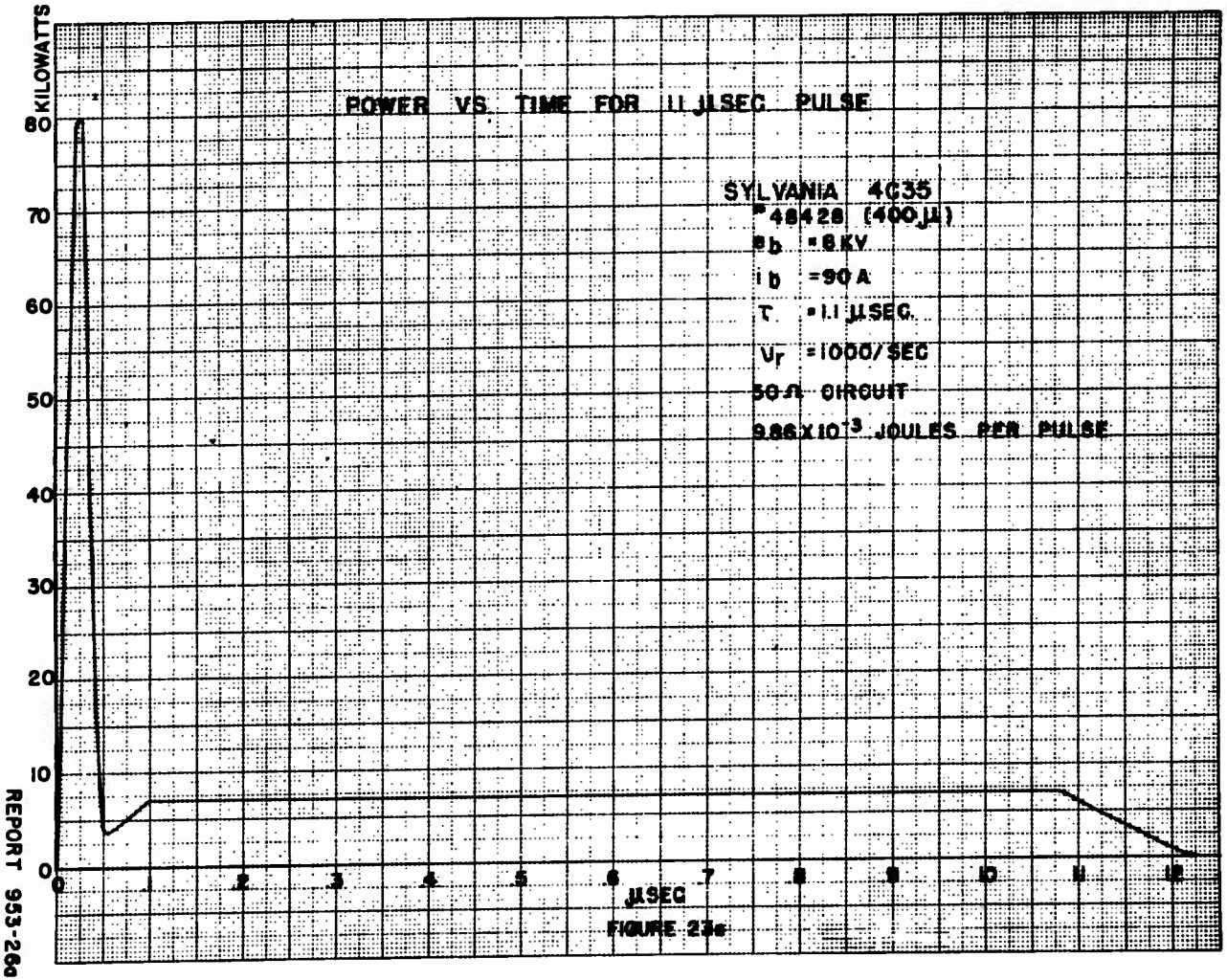


FIGURE 23a

REPORT 953-26a

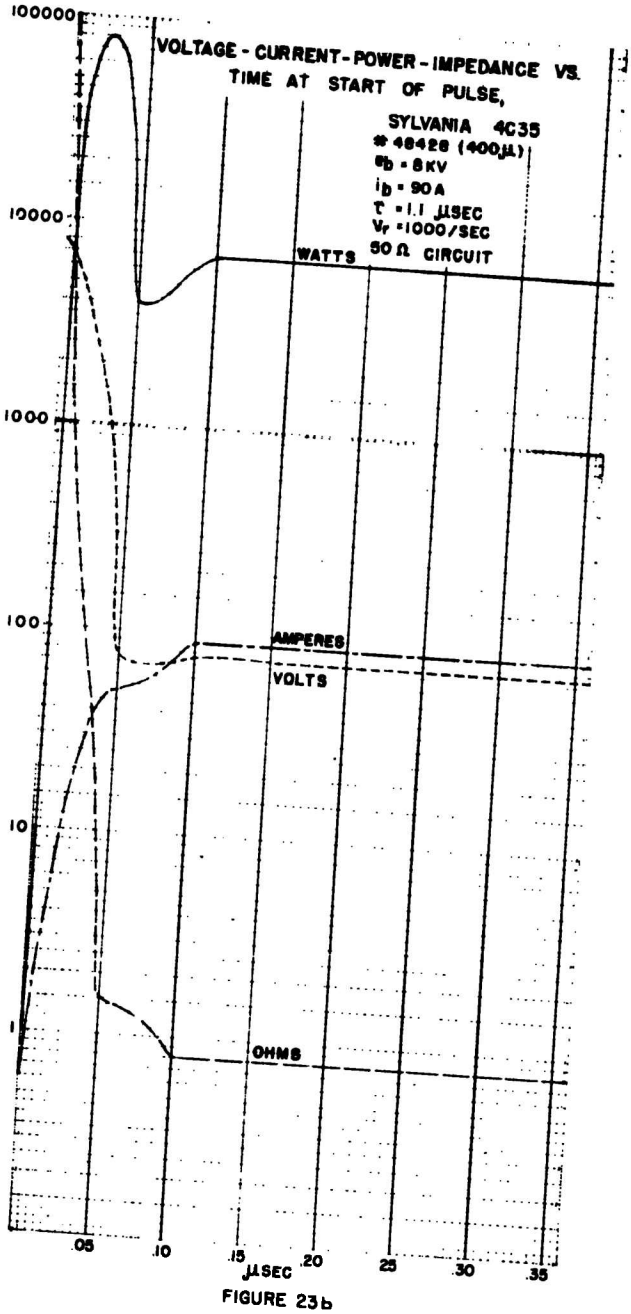


FIGURE 23b

REPORT 953-26b

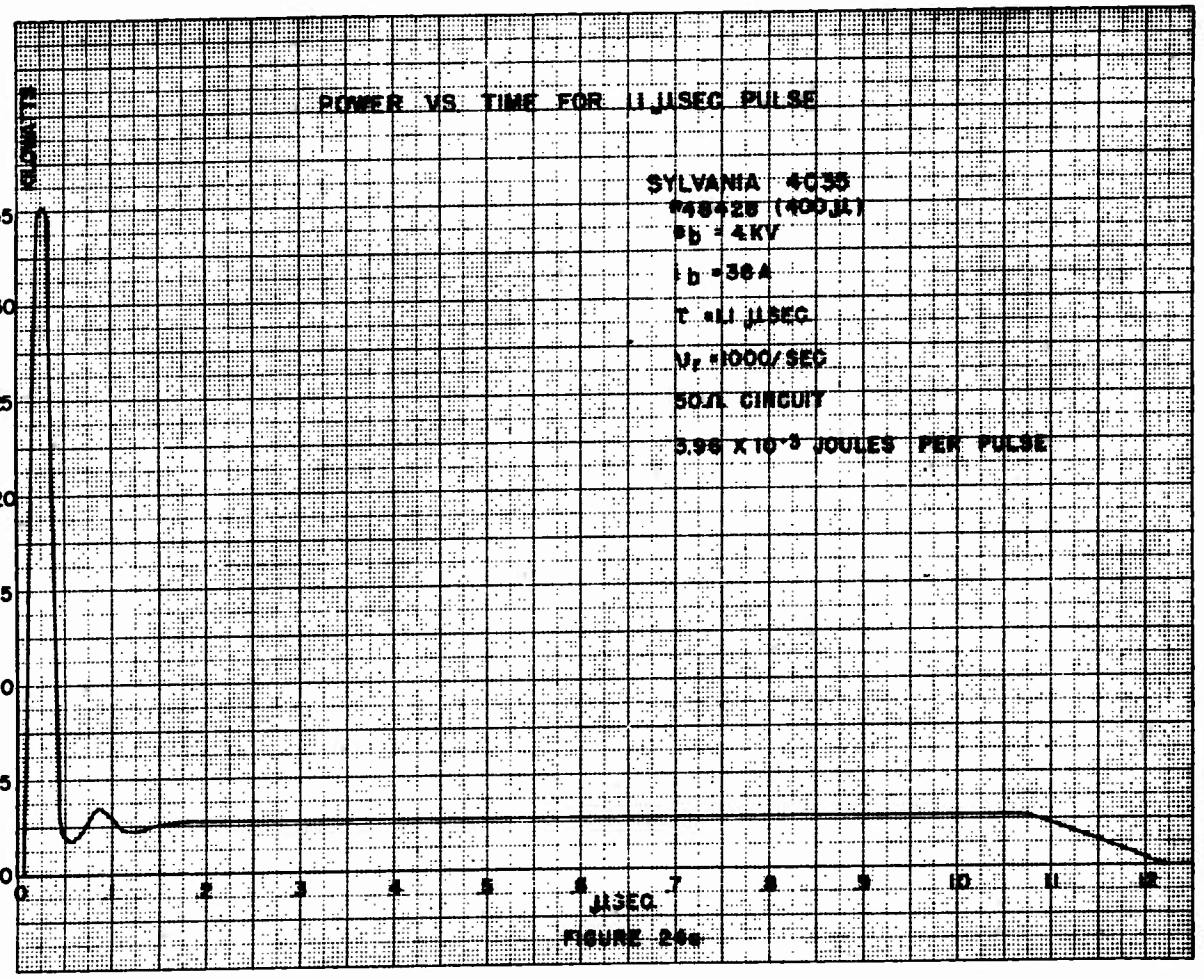


FIGURE 26a

REPORT 953-27a

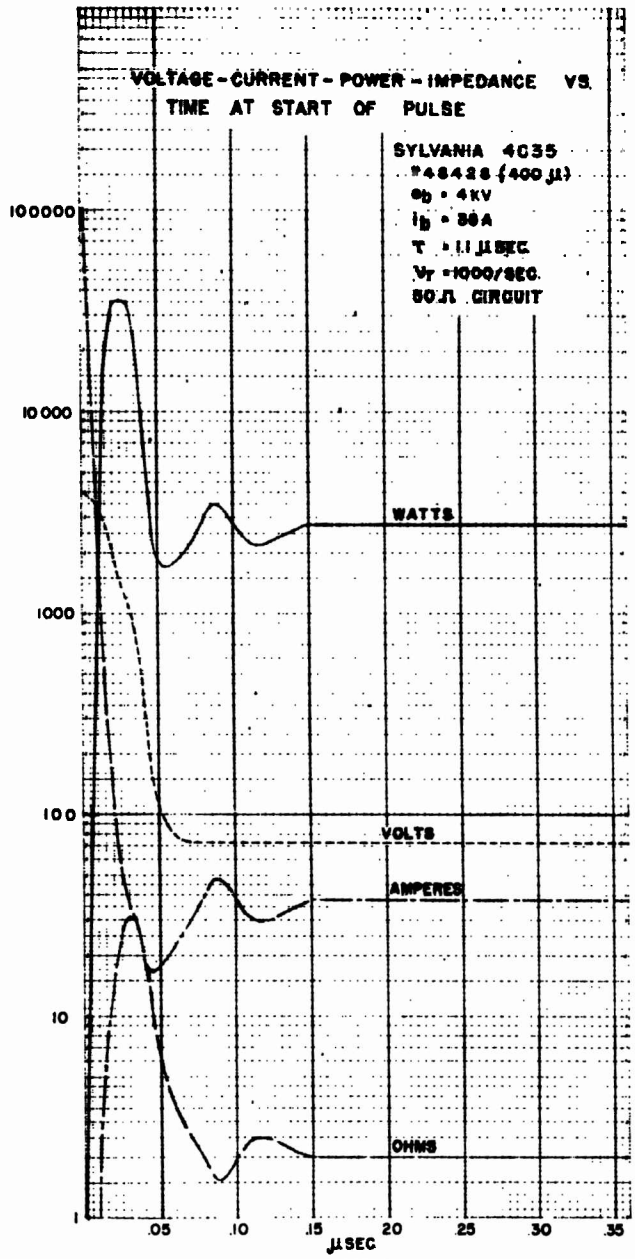


FIGURE 24b

REPORT 953-27b

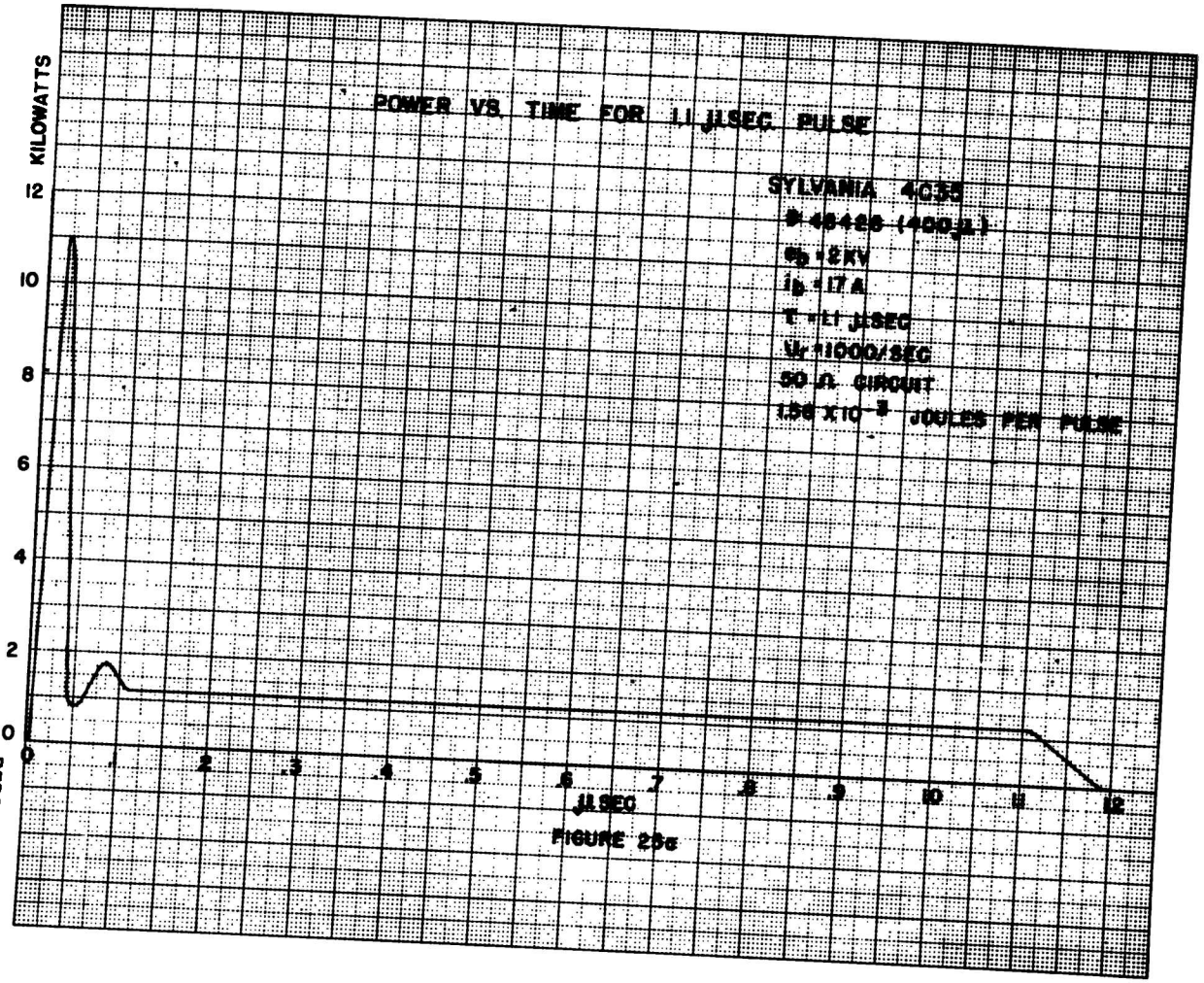


FIGURE 28a

REPORT 953-28a

VOLTAGE - CURRENT - POWER - IMPEDANCE VS TIME
AT START OF PULSE

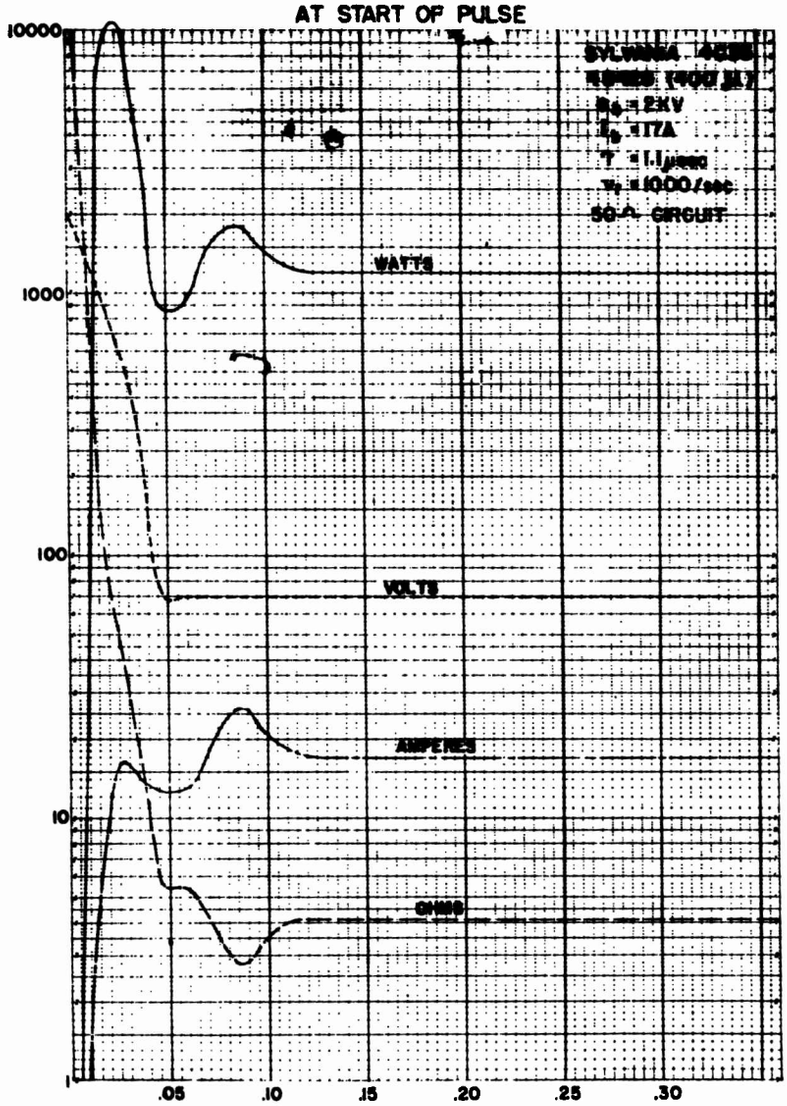
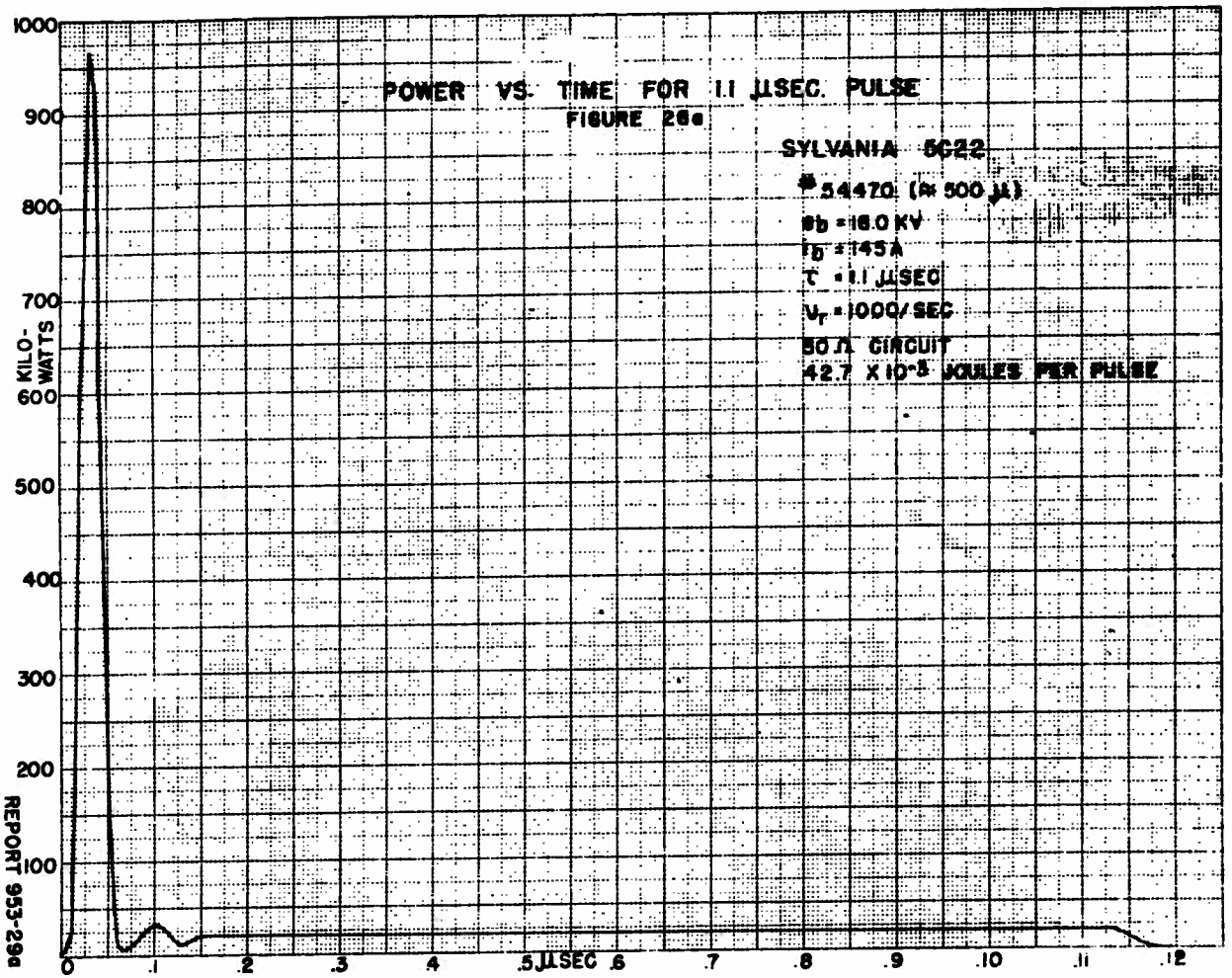


FIGURE 25b

REPORT 953-28b


POWER VS. TIME FOR 1.1 μSEC. PULSE
FIGURE 26a
SYLVANIA 5C22
#54470 (≈ 500 μ)
e_b = 16.0 KV
I_b = 145 A
τ = 1.1 μSEC
V_T = 1000/SEC
50 Ω CIRCUIT
42.7 X 10^{-3} JOULES PER PULSE
KILO-WATTS
1000
900
800
700
600
500
400
300
200
100
0
.1
.2
.3
.4
.5 μSEC
.6
.7
.8
.9
.10
.11
.12
REPORT 953-29a

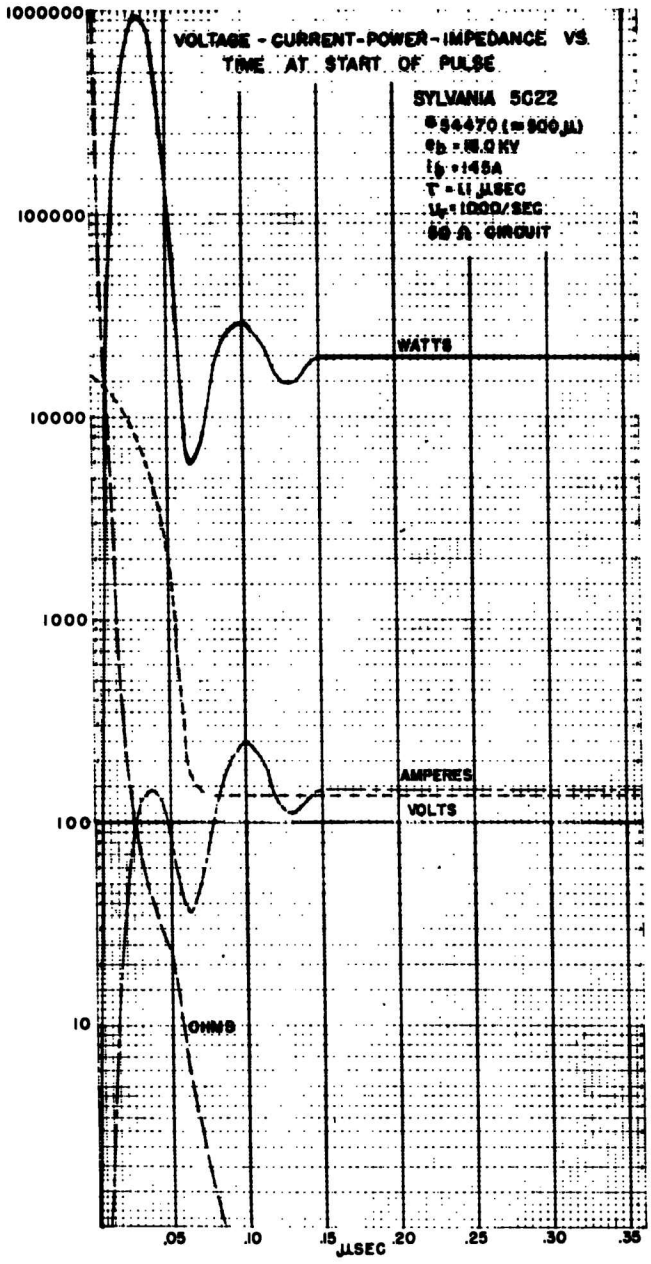


FIGURE 26b

REPORT 953-29b

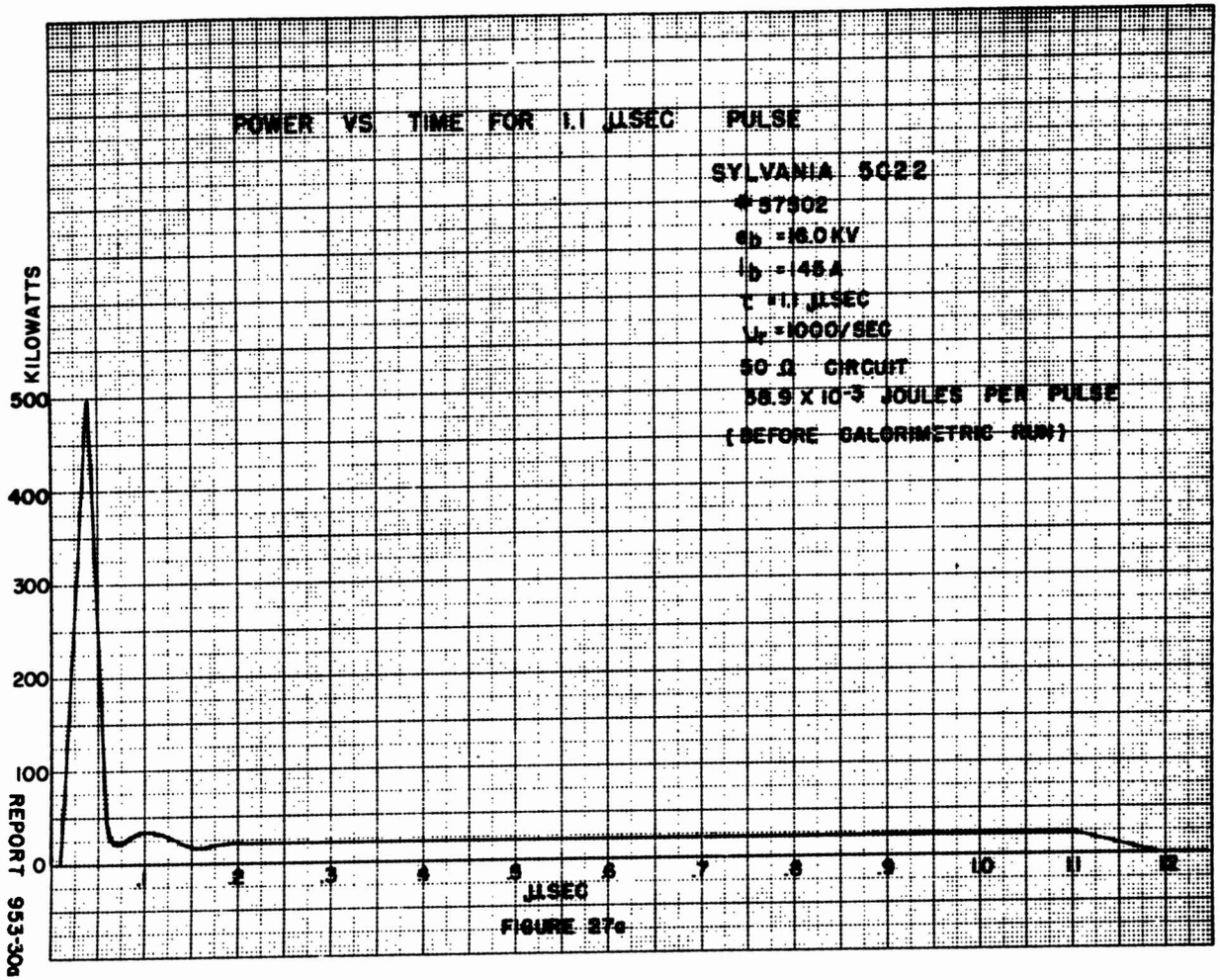

POWER VS TIME FOR 1.1 μSEC PULSE
SYLVANIA 5C22
#57302
e_b = 16.0 KV
I_b = 1.45 A
τ = 1.1 μSEC
f_p = 1000/SEC
50 Ω CIRCUIT
58.9 X 10^{-3} JOULES PER PULSE
(BEFORE CALORIMETRIC RUN)
KILOWATTS
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
μSEC

FIGURE 27e

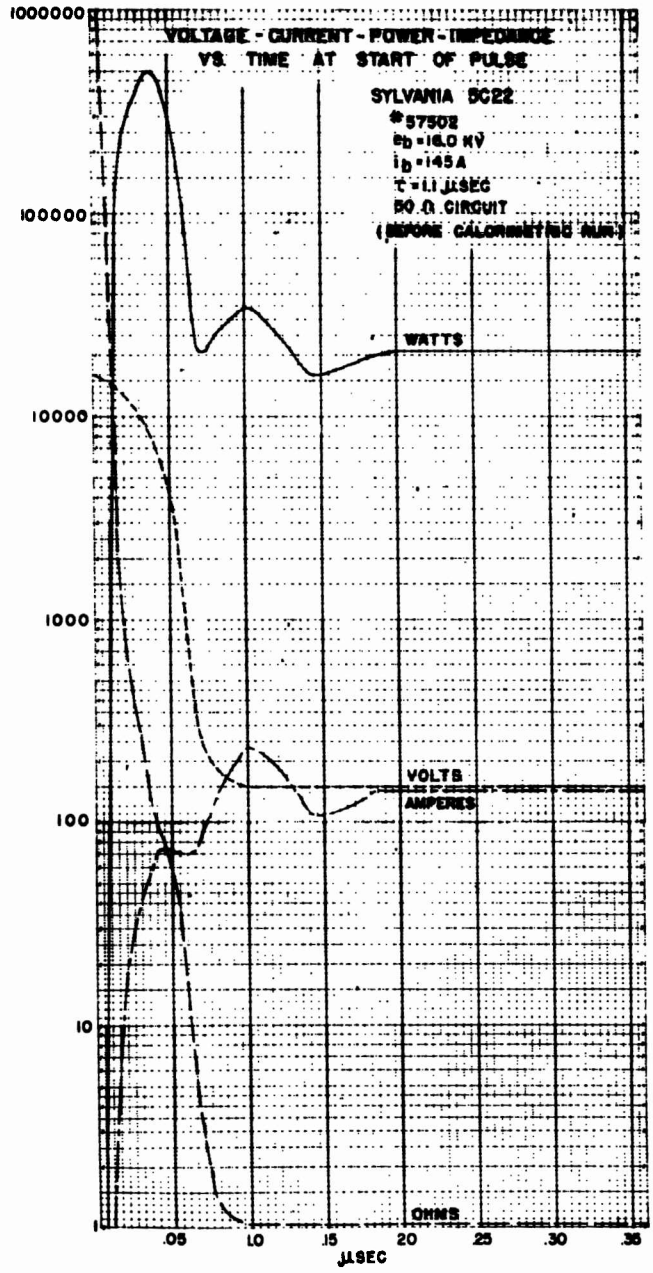


FIGURE 27b

REPORT 953-30b

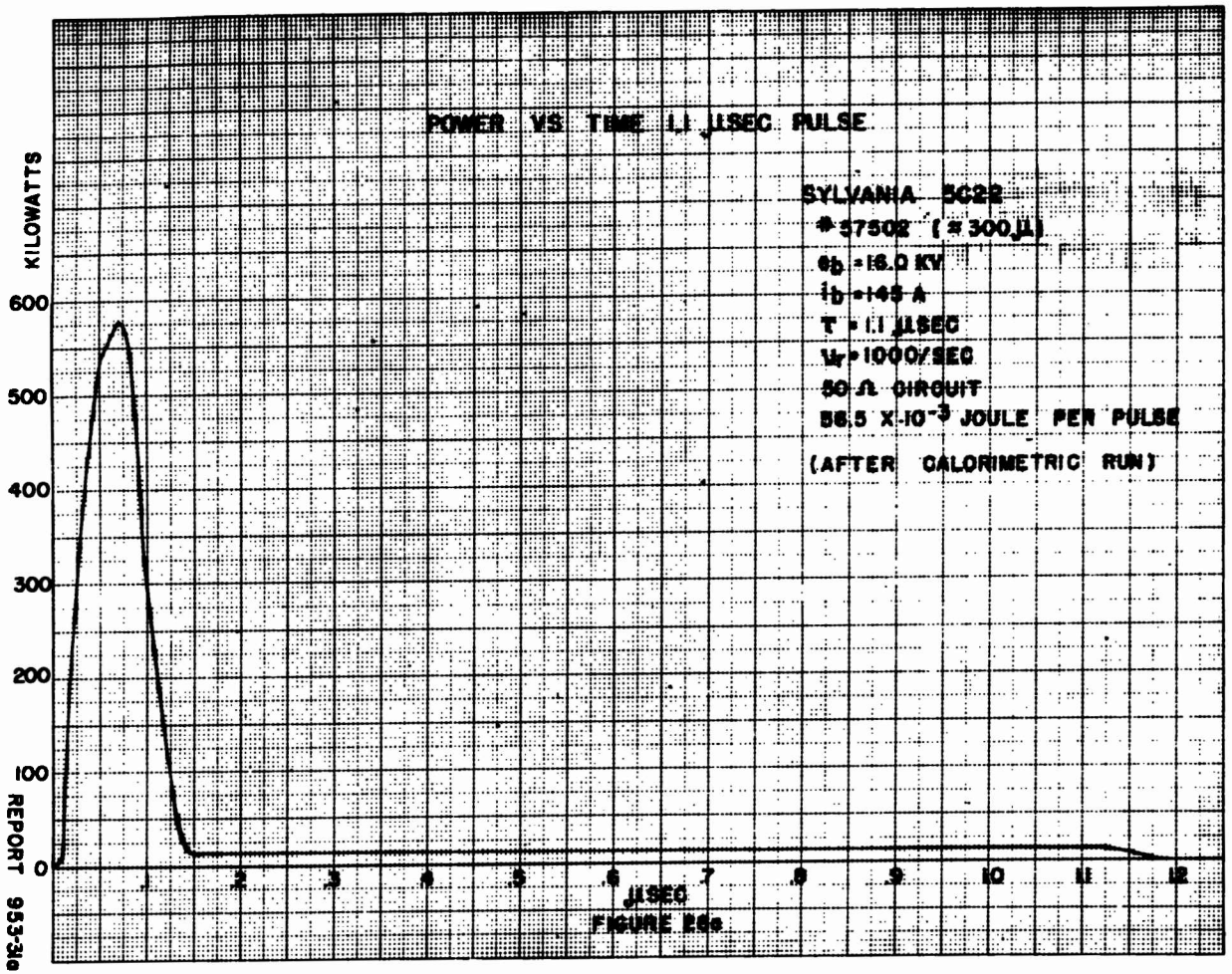

POWER VS TIME 1.1 μSEC PULSE
SYLVANIA 5C22
#57502 (# 300μ)
e_b = 16.0 KV
i_b = 145 A
T = 1.1 μSEC
ω_r = 1000/SEC
50 Ω CIRCUIT
86.5 X 10^{-3} JOULE PER PULSE
(AFTER CALORIMETRIC RUN)
KILOWATTS
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
μSEC

FIGURE 26a

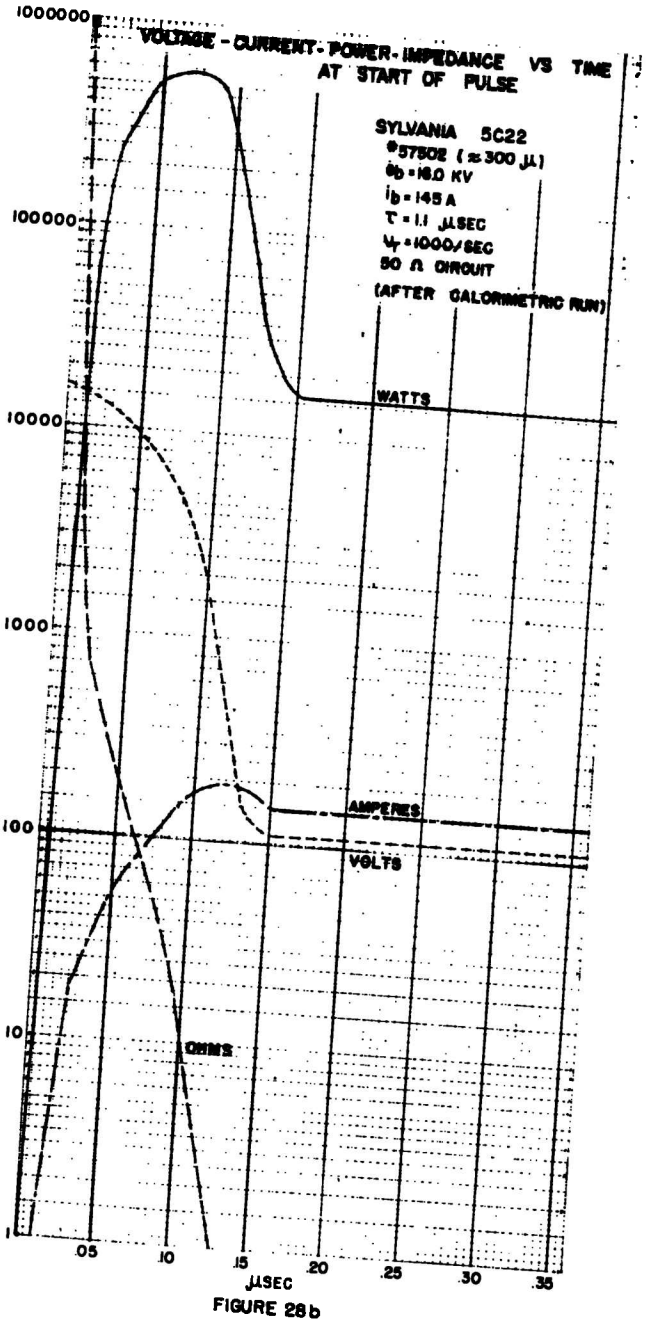

VOLTAGE - CURRENT - POWER - IMPEDANCE VS TIME
AT START OF PULSE
SYLVANIA 5C22
#57502 (≈ 300 μL)
e_b = 18.0 KV
i_b = 14.5 A
τ = 1.1 μSEC
$\frac{1}{T}$ = 1000/SEC
50 Ω CIRCUIT
(AFTER CALORIMETRIC RUN)
WATTS
AMPERES
VOLTS
OHMS
1000000
100000
10000
1000
100
10
1
.05
.10
.15
.20
.25
.30
.35
μSEC

FIGURE 28b

These graphs were plotted from the oscillograms in sections II and III. Figures 22 and 27 compare the [illegible] at 1 μsec pulse duration, and Figures 23, 24, and 25 show the variation in joules per pulse with operating power level for a 4035 in a 50 ohm circuit. Figures 22, 23, and 26 compare the 4035 and 5C22 under conditions of equal pulse length and repetition frequency at their respective [illegible] voltage and current ratings in a 50 ohm circuit.

In Figures 22a and 22b, for a 4035 operating at 1.1 μsec pulse duration, approximately 20-25% of the dissipated energy is used in establishing conduction. From Figures 22b and 27b, it is seen that the tube impedance reaches a very low value, about one ohm, in 2% to 3% μsec.

As the operating power level is reduced, Figures 23, 24, and 25, the power vs time curve keeps its same general characteristic. In Figure 25a, with an anode voltage of 2.0 kv, 20% of the energy is used in establishing conduction, and this is the same fraction as at 8.0 kv.

In Figure 26a, for a typical sample of the 5C22 at 16.0 kv, the energy dissipated in the tube per pulse for a 1.1 μsec pulse is 42.7×10^{-3} joules as compared to approximately 13×10^{-3} joules for a 4035 at 8.0 kv and the same pulse length. Also, for the 5C22, about 5% of the dissipated energy is lost in establishing conduction as compared to about 25% for the 4035.

Figures 27 and 28 show the effect of gas pressure on the distribution of dissipated energy during the pulse. This particular tube was faulty because in a few hours operation in a calorimeter, the gas pressure fell very rapidly and changed the characteristics of the tube. However, this case is a very interesting one and is a good illustration of the problem. In Figure 27, about 41% of the dissipated energy is used in establishing conduction, and the impedance is down to one ohm in about [illegible] μsec. In Figure 28, about 73.5% of the dissipated energy is lost in establishing conduction, and the impedance is down to about one ohm in 0.17 μsec.

B. Average Power Dissipation versus Pulse Repetition Frequency

In Figure 29 is plotted the variation in average power dissipation with pulse repetition frequency. The variation is approximately linear, and since the average power is a function of pulse repetition frequency,

$$\text{watts} = (\text{joules/pulse})\ (\text{pulses/second}),$$

the graph starts at the origin for zero pri.

C. Average Power Dissipation versus Pulse Duration

In Figure 30 is plotted the variation in average power dissipation with pulse duration. Theoretically, the intercept of these curves at zero pulse

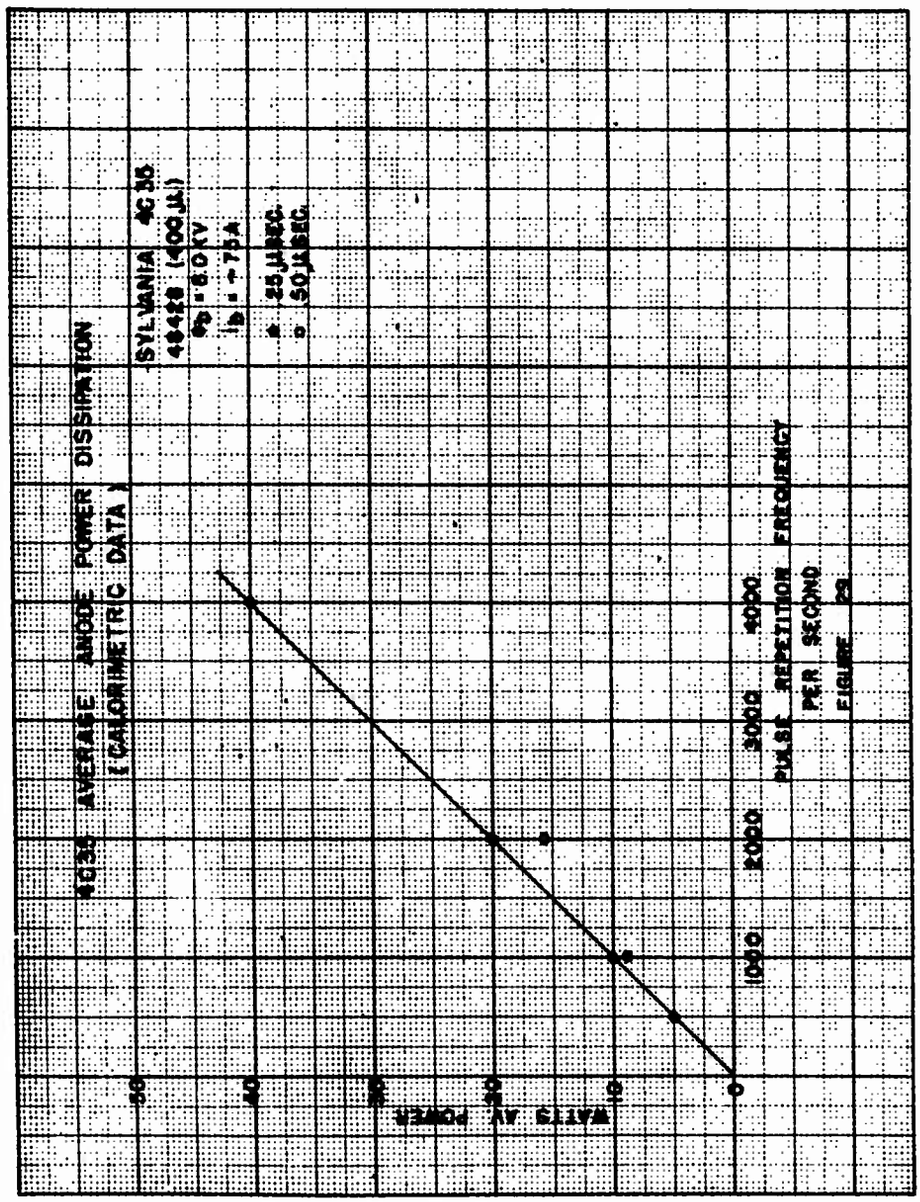

4635 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4C35
4642B (400 μs)
ep = 8.0 KV
Ib = 75A
25 μSEC.
50 μSEC.
WATTS AV POWER
50
40
30
20
10
0
1000
2000
3000
4000
PULSE REPETITION FREQUENCY
PER SECOND

FIGURE 29

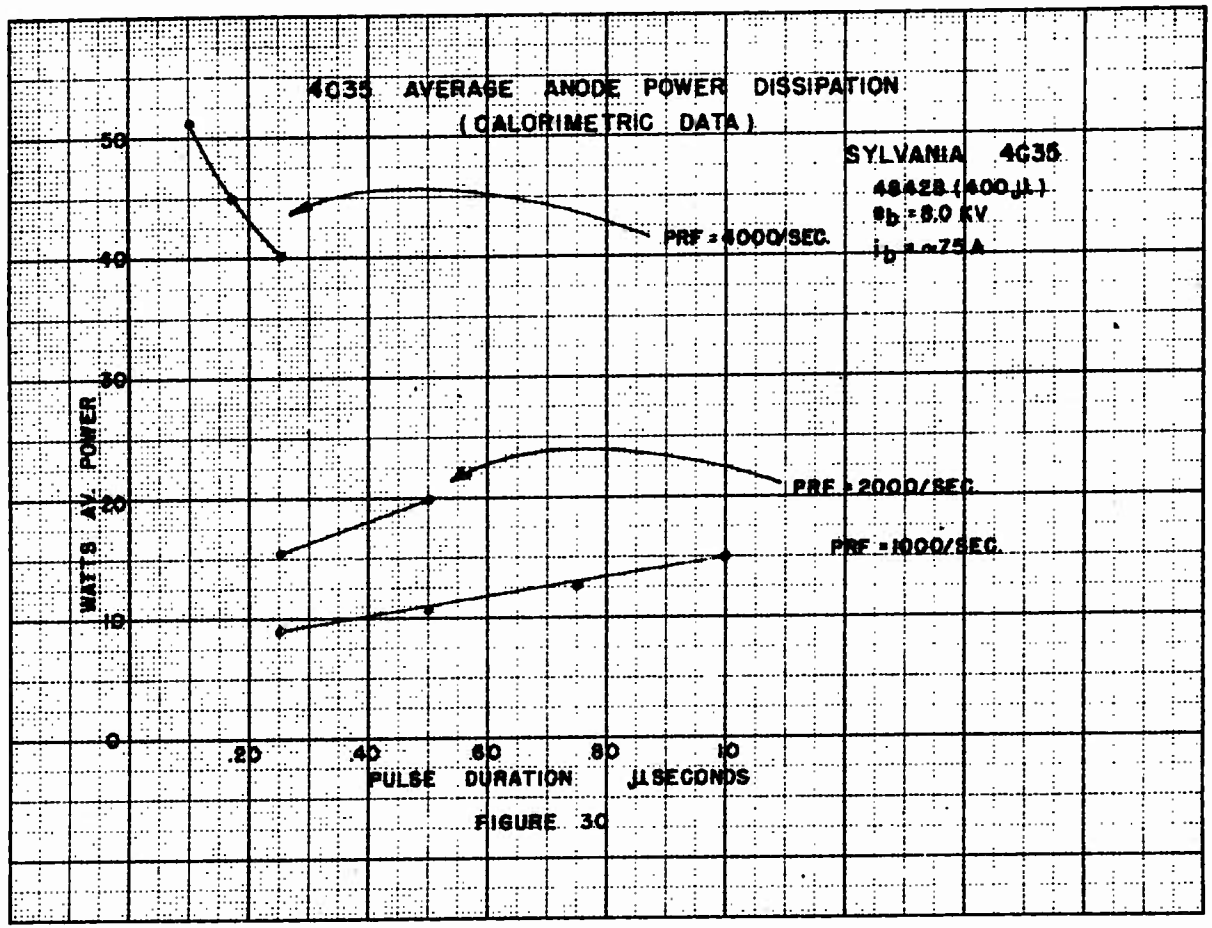


FIGURE 30

REPORT 953-34

duration divided by the pulse repetition frequency should be equal to the energy dissipated in establishing conduction. However, this energy depends on the rate of rise of current and it has been already shown in Figures 3-8 that with the conventional Type B pulse forming networks, it is difficult to keep $\frac{dib}{dt}$ constant for different pulse lengths. This practical difficulty probably explains why the curve for 60 cps prf slopes up instead of down with decreasing pulse length. It is probable that at pulse lengths less than 0.25 usec, the increase in $\frac{dib}{dt}$ more than compensated for the decrease in pulse length. In any event, the tube becomes less efficient at short pulses with conventional pulse forming networks.

D. Average Power Dissipation versus Power Level

In Figure 31 is shown the variation in average power dissipation when the operating power level is reduced at constant circuit impedance. In Figure 32, the power was reduced by increasing the circuit impedance so that the anode voltage was kept constant while the peak current was varied. In Figure 33, the anode voltage was varied while the current remained approximately constant. The data of Figures 32 and 33 were taken by connecting pulse forming networks in series and parallel. These data show that if it is necessary to reduce average power dissipation in a thyratron by reducing the operating power level, it is more effective to reduce both current and voltage than just one or the other.

E. Average Power Dissipation as a Function of Pulse Repetition Frequency for Constant Duty

Figures 34, 35, 36, and 37 present data on four tubes. Since previous data have shown that $\frac{dib}{dt}$ tends to increase with shorter pulses with conventional pulse forming networks, the curves of average dissipation versus prf for constant duty should not be linear. The linearity of the curves in Figures 34 and 35 is probably coincidence, and the non-linearity of Figures 36 and 37 is more correct. Figure 38 is a composite plot of Figures 34-37, and it is evident here that the average power dissipation increases with decreasing gas pressure. This may be due to the increase in energy dissipated in establishing conduction as shown in Figures 27 and 28. Figure 39 is a plot for a 5C22 thyratron. The effect of series anode inductance on dissipation can be seen here. It was shown in Figure 12 that series inductance reduced $\frac{dib}{dt}$. By limiting $\frac{dib}{dt}$, the energy dissipated during the start of conduction is reduced, and the average anode power dissipation is lowered. The reduction

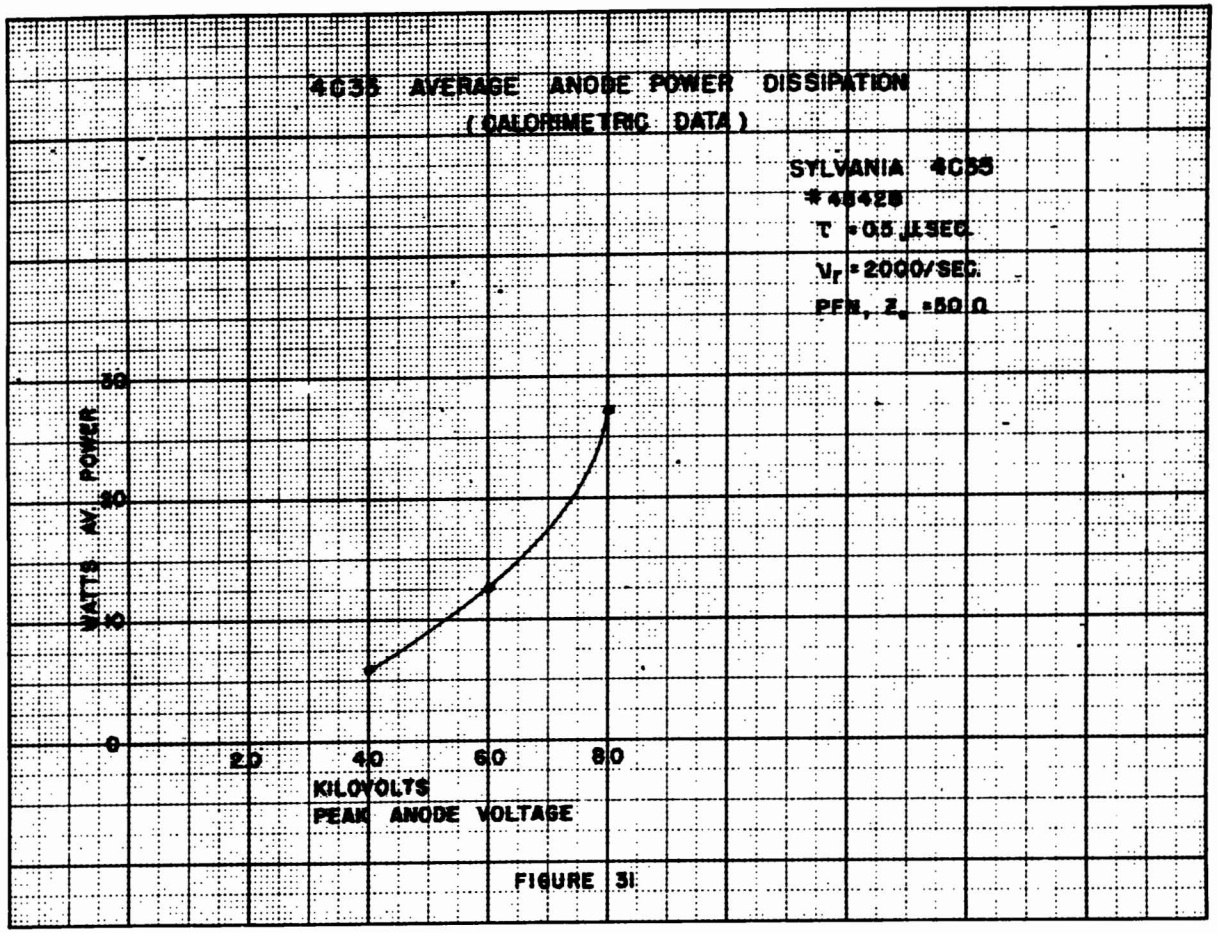

4C35 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4C35
#48428
τ = 0.5 μSEC.
V_f = 2000/SEC.
PFN, Z_o = 50 Ω
WATTS AV. POWER
30
20
10
0
20
40
60
80
KILOVOLTS
PEAK ANODE VOLTAGE

FIGURE 31

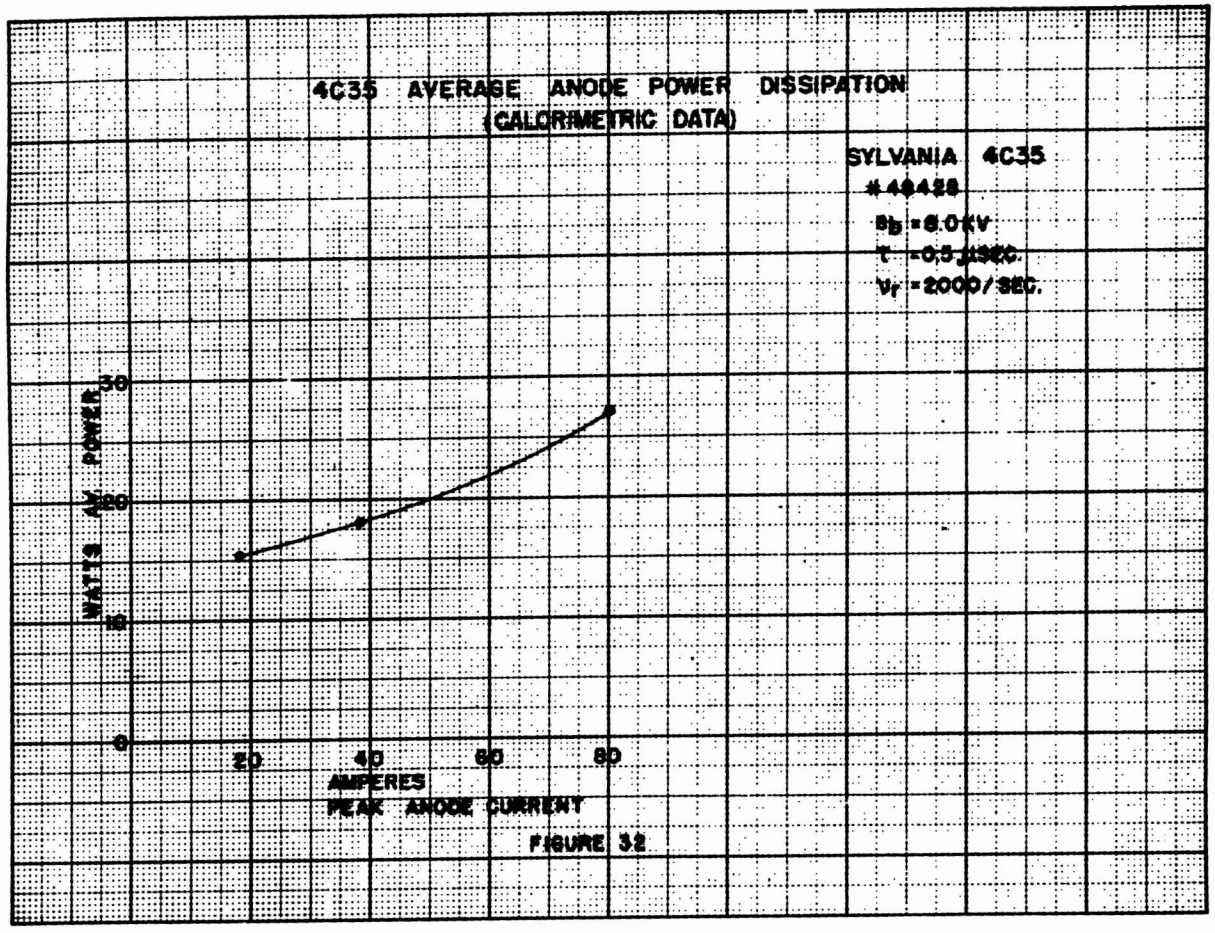

4C35 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4C35
#48428
e_b = 8.0 KV
t = 0.5 μSEC.
ν_f = 2000/SEC.
WATTS AV POWER
30
20
10
0
20
40
60
80
AMPERES
PEAK ANODE CURRENT

FIGURE 32

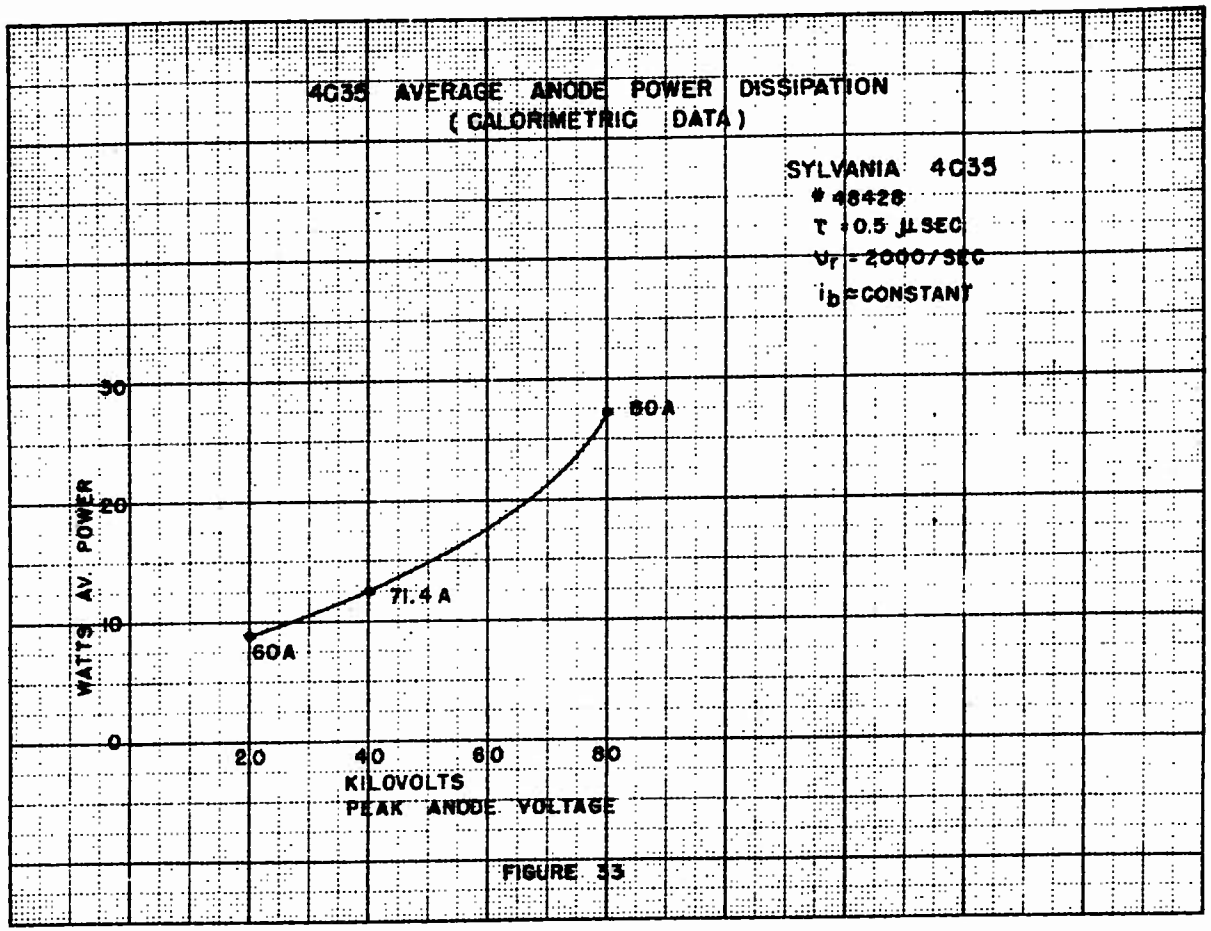

4C35 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4C35
48428
τ = 0.5 μSEC
ν_f = 2000/SEC
i_b = CONSTANT
WATTS AV. POWER
30
20
10
0
60A
71.4 A
80A
20
40
60
80
KILOVOLTS
PEAK ANODE VOLTAGE

FIGURE 33

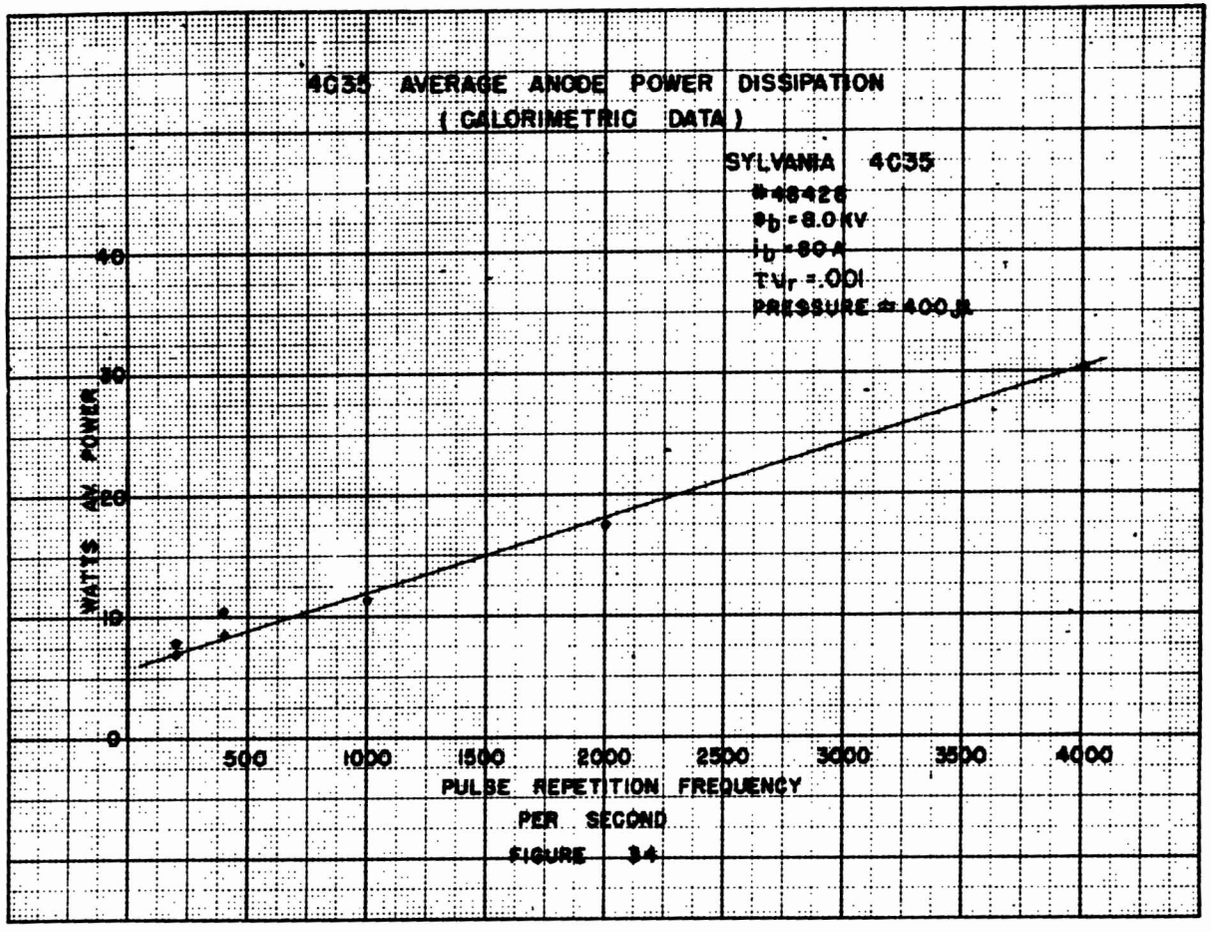

4C35 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4C35
#48426
e_b = 8.0 KV
i_b = 80 A
τv_r = .001
PRESSURE = 400 μ
WATTS AV POWER
40
30
20
10
0
500
1000
1500
2000
2500
3000
3500
4000
PULSE REPETITION FREQUENCY
PER SECOND

FIGURE 34

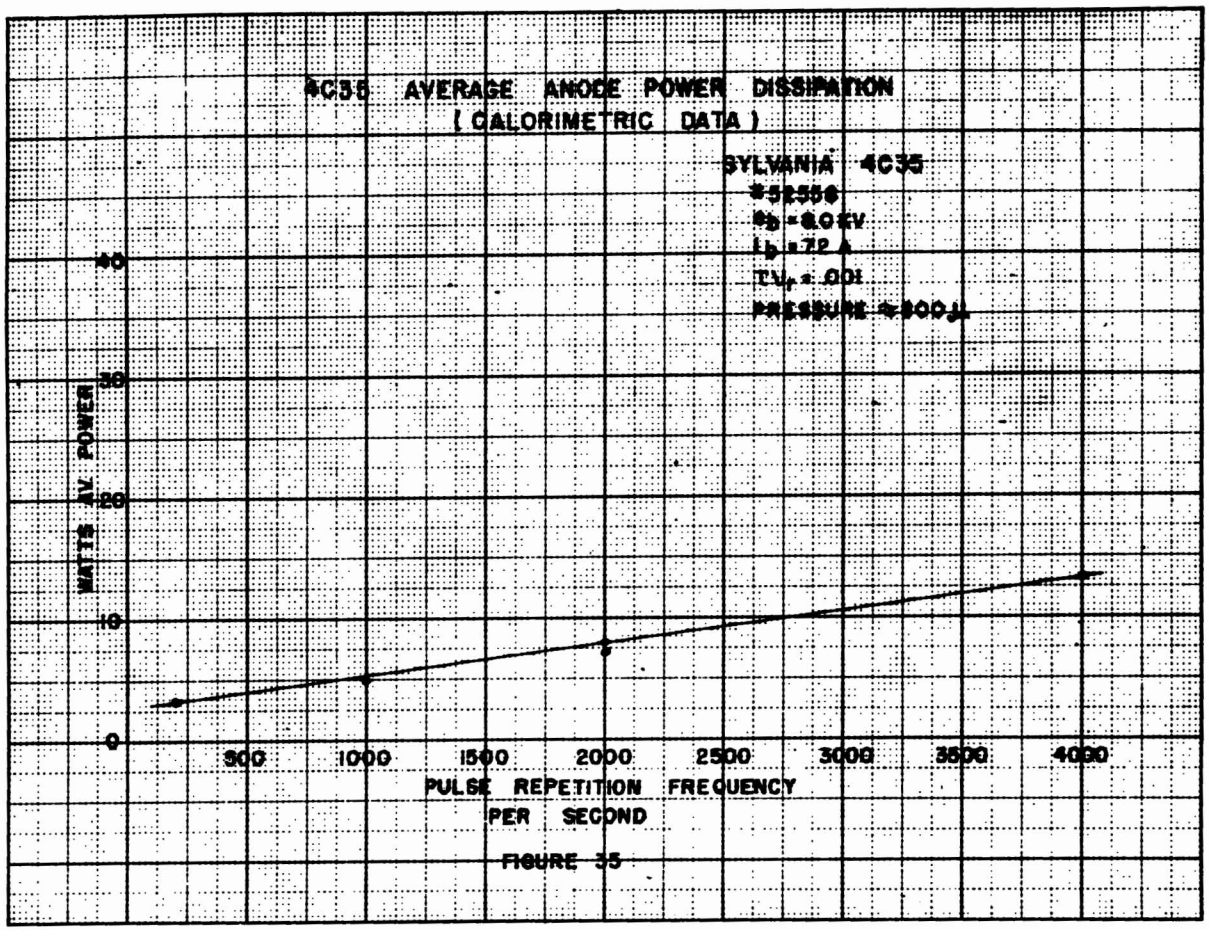

4C35 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4C35
#32356
E_b = 8.0 KV
I_b = 72 A
TV_f = .001
PRESSURE = 300 μ
WATTS AV POWER
40
30
20
10
0
500
1000
1500
2000
2500
3000
3500
4000
PULSE REPETITION FREQUENCY
PER SECOND

FIGURE 35

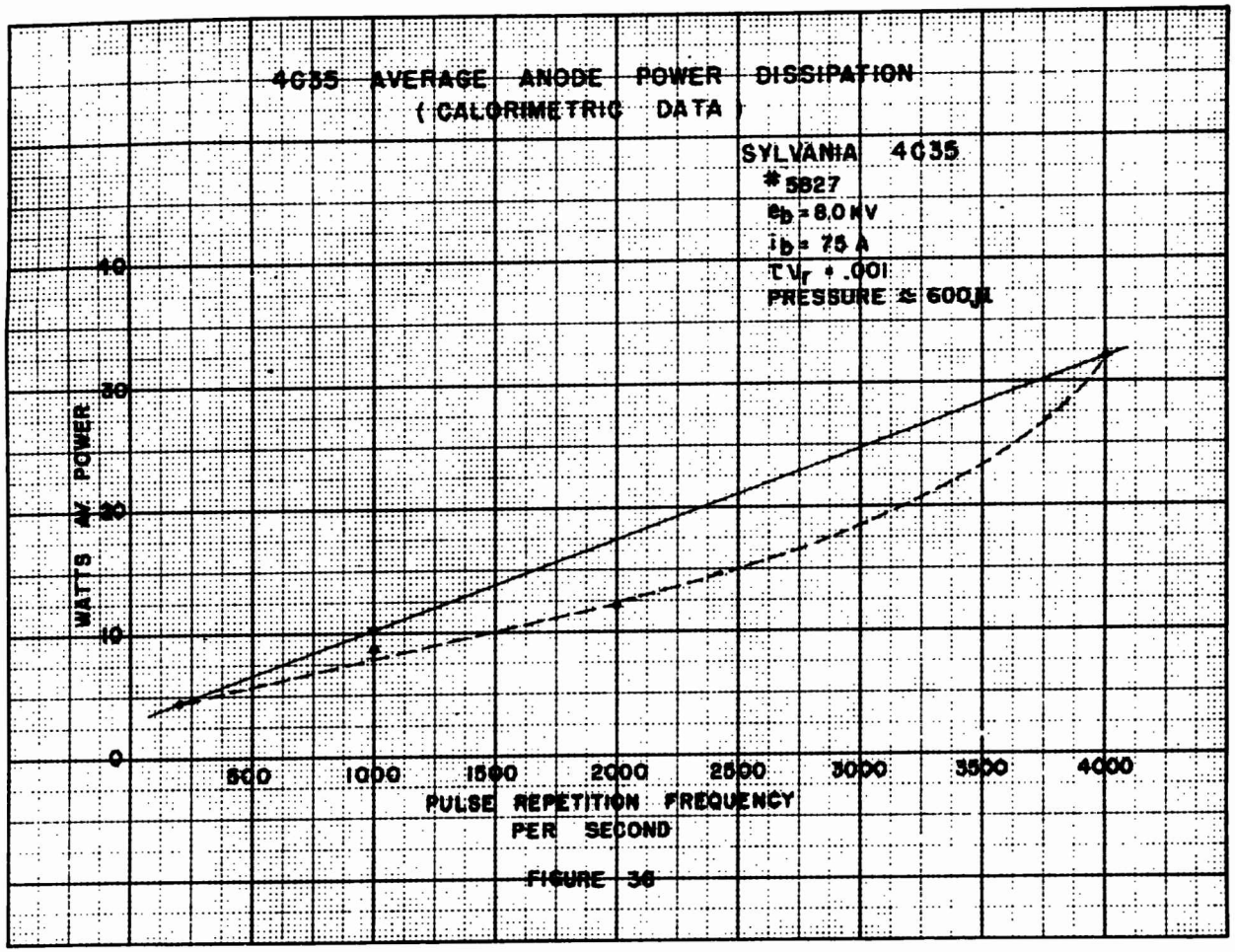

4C35 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4C35
#5827
e_b = 8.0 KV
i_b = 75 A
τV_f = .001
PRESSURE ≤ 600μ
WATTS AV. POWER
40
30
20
10
0
500
1000
1500
2000
2500
3000
3500
4000
PULSE REPETITION FREQUENCY
PER SECOND

FIGURE 36

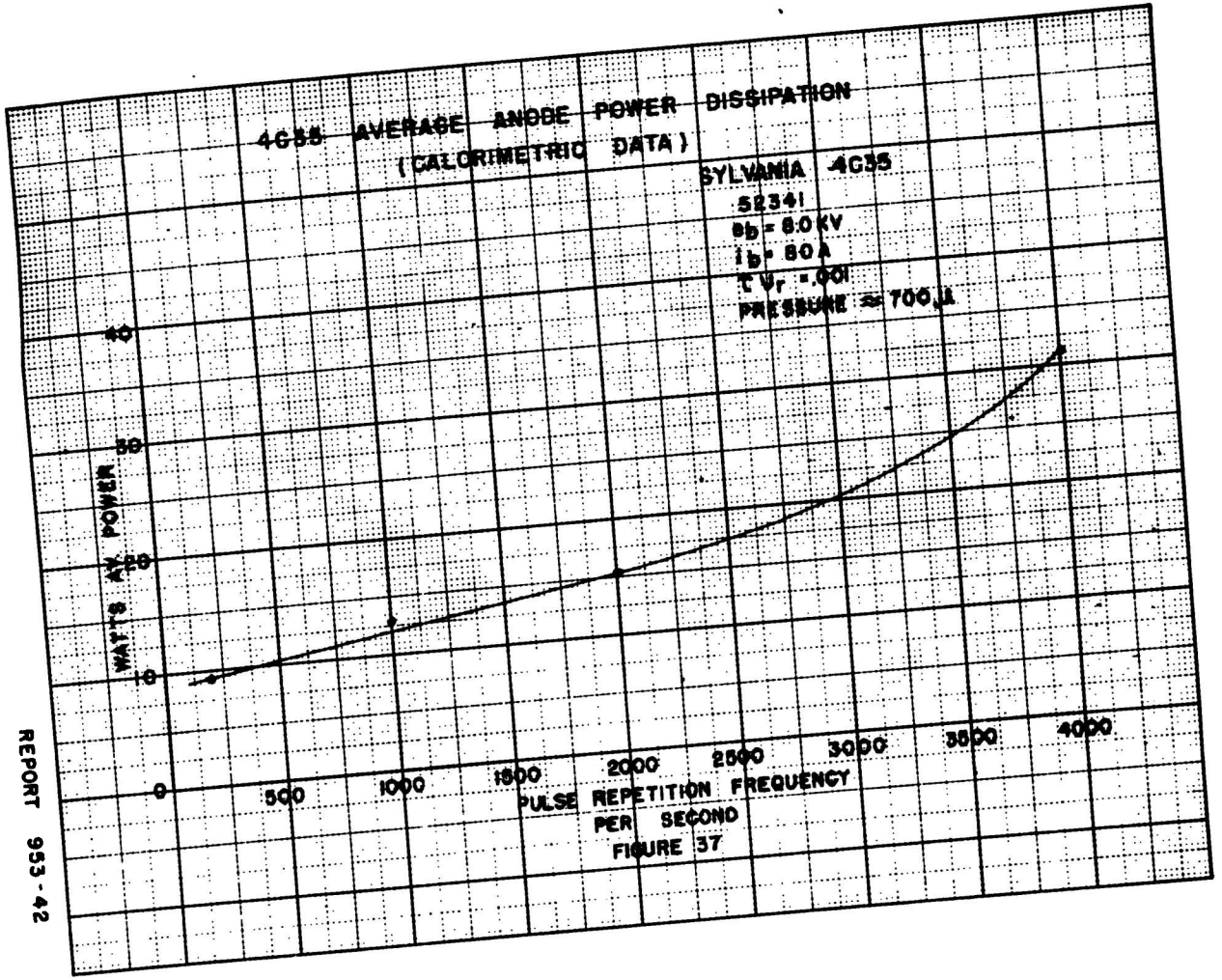

4G35 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4G35
5234!
eb = 8.0 KV
ib = 80 A
τ Vr = .001
PRESSURE ≈ 700 μ
WATTS AV POWER
40
30
20
10
0
500
1000
1500
2000
2500
3000
3500
4000
PULSE REPETITION FREQUENCY
PER SECOND

FIGURE 37

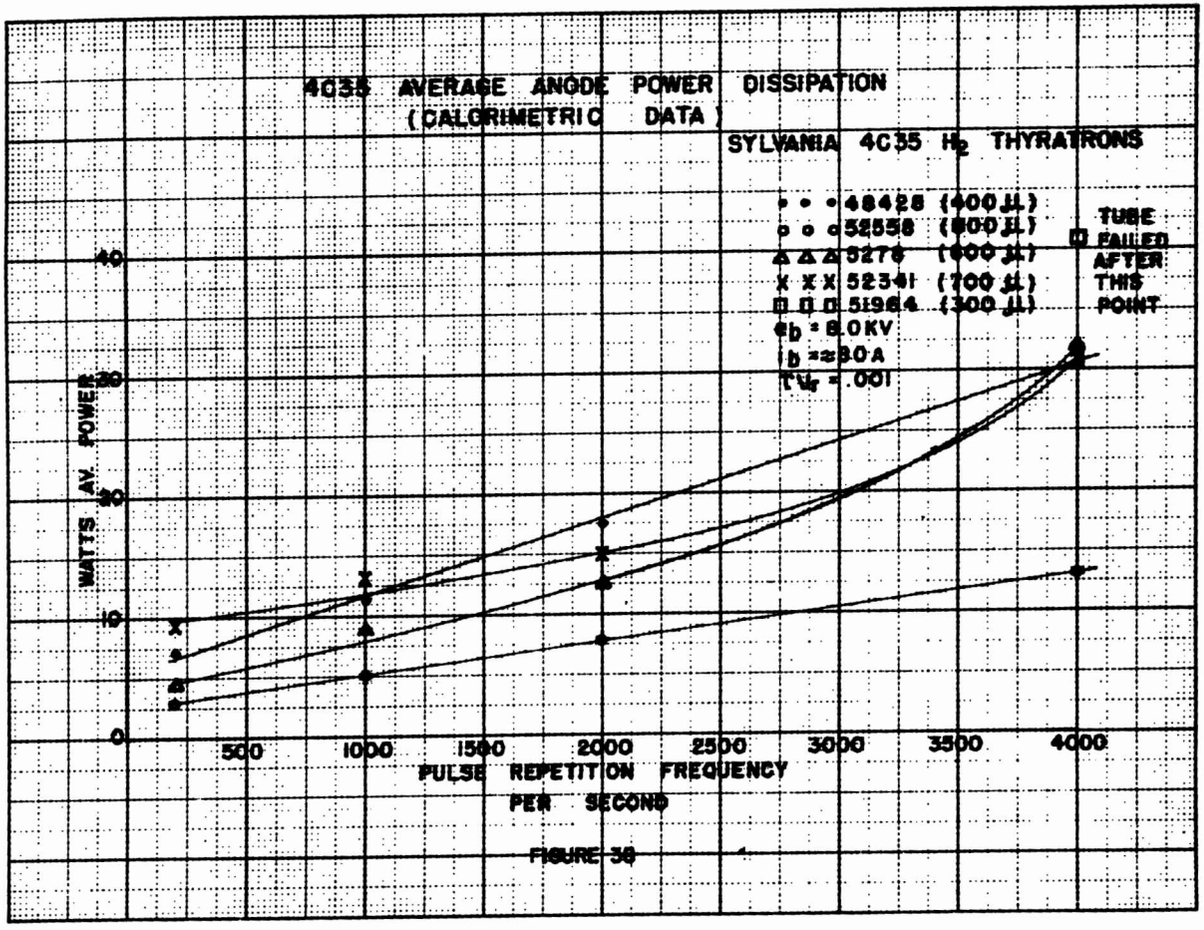

4C35 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 4C35 H2 THYRATRONS
• • • 48428 (400 µL)
o o o 52558 (600 µL)
△ △ △ 5276 (600 µL)
x x x 52541 (700 µL)
□ □ □ 51964 (300 µL)
TUBE FAILED AFTER THIS POINT
eb = 8.0 KV
ib = 30 A
τ/T = .001
WATTS AV. POWER
0
10
20
30
40
500
1000
1500
2000
2500
3000
3500
4000
PULSE REPETITION FREQUENCY
PER SECOND

FIGURE 38

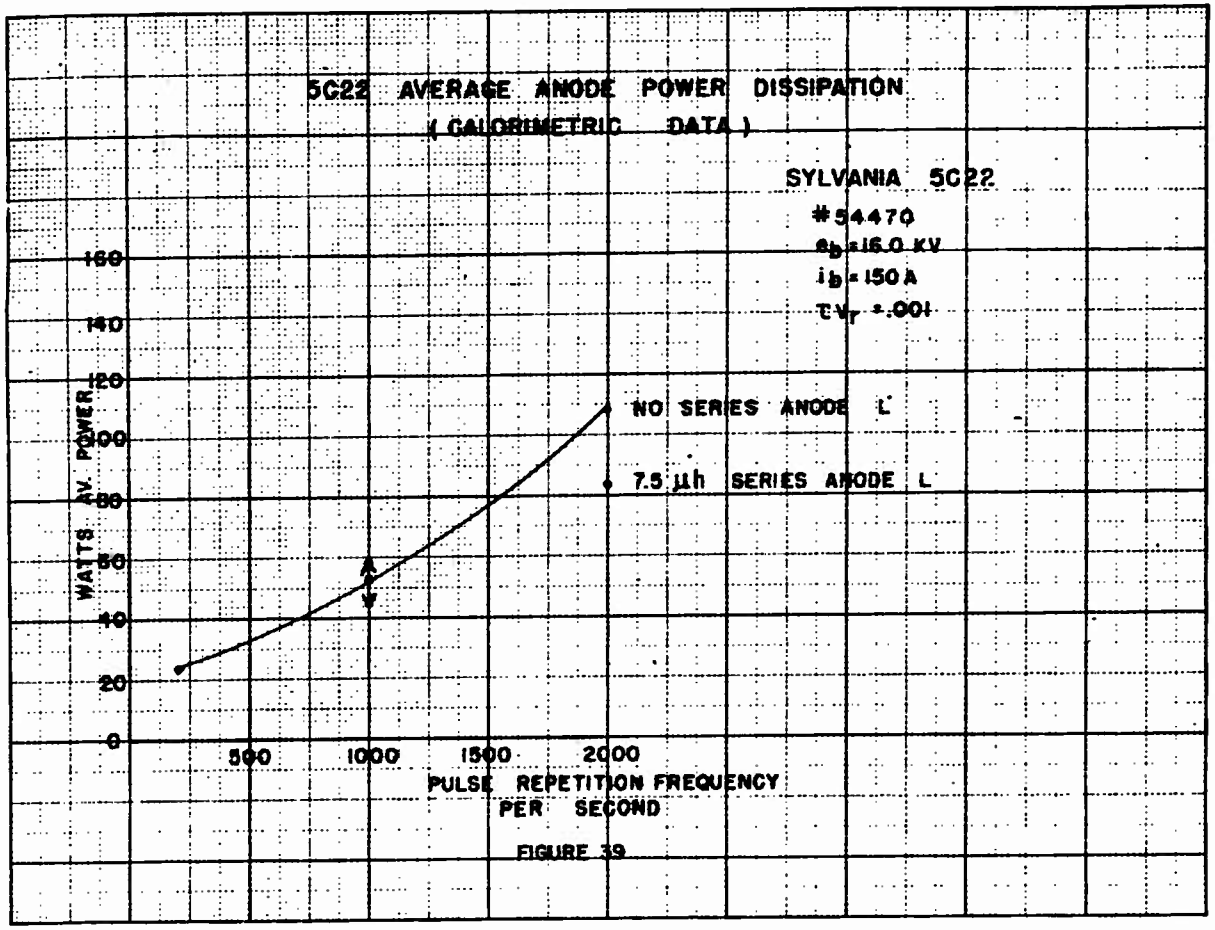

5C22 AVERAGE ANODE POWER DISSIPATION
(CALORIMETRIC DATA)
SYLVANIA 5C22
#54470
e_b = 16.0 KV
i_b = 150 A
τV_T = .001
NO SERIES ANODE L
7.5 µh SERIES ANODE L
WATTS AV. POWER
160
140
120
100
80
60
40
20
0
500
1000
1500
2000
PULSE REPETITION FREQUENCY
PER SECOND

FIGURE 39

of average power dissipation by the use of [illegible] inductance, and the increase of average power dissipation by the use of [illegible] capacity across the thyratron have been verified by life tests.

F. Comparison of [illegible] data and V-I data for 1 μsec pulse, 1000/sec, and a 5[illegible] circuit.

Tube	[illegible]	[illegible]	V-I
52*41	[illegible]	[illegible] watts	16.9 watts
4842*	[illegible]	[illegible]	9.8
5*27	[illegible]	[illegible]	11.0
54470	[illegible]	[illegible]	42.7
57911	[illegible]	[illegible]	-
57765	[illegible]	[illegible]	-

*These data were the first taken on this tube. All the other data were taken after this tube had been operated considerably, and the reason for the increase in dissipation in all the other curves is probably due to fluctuations in gas pressure.

To a fair approximation, the 5C22 must dissipate approximately four times the energy that the [illegible] dissipates when the two tubes are operated at their respective maximum ratings, and the same pulse duration and repetition frequency.

The data presented in this report indicate that the energy dissipated in the hydrogen thyratron depends on the following:

1. e_b -- anode voltage at the start of conduction.
2. i_b -- peak anode current.
3. pulse duration.
4. gas pressure - controls $\frac{de_b}{dt}$ and to some extent $\frac{di_b}{dt}$.
5. cathode emission -- controls tube drop.
6. $\frac{di_b}{dt}$

With this number of possible variables affecting dissipation, particularly gas pressure and cathode emission, it is almost impossible to duplicate data from one tube to another with any degree of accuracy.

The writer wishes to acknowledge the assistance of John T. Downing, Leo Shore, and Miss Muriel Carter in obtaining the data on which this report is based.

Stanley J. Krulikoski, Jr.
November 27, 1945

SB

953.46

RFFL - C
485
A.T.I.
13860

AD-B815 791

Krulikoski, S.

AUTHOR(S)

DIVISION: Electronics (3)
SECTION: Electronic Tubes (8)
CROSS REFERENCES: Thyratrons (94180); Tubes, Electronic (95220)

ATI- 13860
ORIG. AGENCY NUMBER
R-953
REVISION

U

AMER. TITLE: Hydrogen thyratrons in pulse generator circuits

FORG'N. TITLE:

ORIGINATING AGENCY: Massachusetts Inst. of Technology, Radiation Lab., Cambridge

TRANSLATION:

COUNTRY	LANGUAGE	FORG'N CLASS	U. S. CLASS.	DATE	PAGES	ILLUS.	FEATURES
U.S.	Eng.		Unclass.	Mar '46	55	46	graphs

ABSTRACT

Data are presented on the operating characteristics of hydrogen thyratrons in line-type pulse generator circuits. The rate of fall of anode voltage, rate of rise of anode current, and tube drop are presented. In addition to the operating anode voltage and current, the most important parameter governing tube dissipation is gas pressure. This is demonstrated both calorimetrically and by V-I plot. Because of the great number of possible variables that govern tube dissipation, most of them uncontrollable, it is impossible to reproduce data with any degree of accuracy.