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TECHNICAL INFORMATION SERIES

Title Page

AUTHOR	SUBJECT CLASSIFICATION	NO.
H. L. McLeland	Electron Tubes, Cathode-Ray	54E652
		DATE 2/22/54

TITLE

Pulse Aging of Oxide-Coated Cathodes

ABSTRACT

The method of aging oxide-coated cathodes by application of voltage pulses between cathode and first grid is described. Aging parameters were investigated, initial test and life test data were taken, and statistical analyses of variance were performed to obtain significance from the results. Need for further development is discussed.

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CONCLUSIONS

Dependable aging of oxide-coated cathodes in cathode ray tubes in a relatively short length of time is possible. The optimum total aging time is chosen as 3.8 minutes, compared to normal d.c. aging time of around 45 minutes. The values of the aging parameters - pulse amplitude, pulse width, repetition frequency, and cathode temperature - are not critical. Life test results of pulse aged tubes compare very favorably with those of normally aged tubes.

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For list of contents—drawings, photos, etc. and for distribution see next page (RTD-1011).

INFORMATION PREPARED FOR Cathode-Ray Tube Sub Department

TESTS MADE BY R. H. Rausch, R. Corrodi, H. L. McLeland

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DIVISIONS Electronics LOCATION Electronics Park, Syracuse, New York

FN-610-1F-E (2-52)

GENERAL ELECTRIC COMPANY
TECHNICAL INFORMATION SERIES
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NO. PAGES TEXT 28

NO. CHARTS 2

DRAWING NOS.

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REFERENCES See Bibliography

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PREFACE

This investigation was initially assumed by R. H. Rausch who designed and constructed the pulse generator and activation chassis, made the necessary theoretical calculations to determine the range of voltages required, and built and aged preliminary tubes to establish the limits of the aging parameters.

The investigation was next assumed by R. Corrodi who, with the assistance of F. Caplan, designed Latin Square experiments to determine by analyses of variance the optimum values of the aging parameters. As a result of these experiments, the optimum aging schedule was selected.

The author next undertook the analysis of life test data, re-design of the pulse generator (with the assistance of R. Olsson), and a production run of pulse aging on the factory floor at the Buffalo Tube Plant. Statistical analysis of the data was accomplished by F. Caplan and the investigation was drawn to a conclusion.

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I. INTRODUCTION

A. Sketch of the Aging Process

The cathode in a cathode-ray tube is of nickel metal (with controlled amounts of impurities), indirectly heated, unipotential, and coated on the circular end surface with a triple carbonate mix of Barium, Strontium and Calcium carbonates. During the exhaust of the tube the cathode is heated to a temperature which is high enough to break the carbonates down to their respective oxides, and then, at a sufficiently low pressure, the stem is sealed off. This treatment is known as activation of the cathode.

The oxide-coated cathode does not show any appreciable emission until a portion of the oxides is broken down to provide free alkaline earth metals. The decomposition may occur in four ways: (1) thermal, (2) electrolytic reduction, (3) chemical reduction, (4) ion bombardment.

In aging a cathode by the pulse method all four of the above processes occur. The cathode is heated to a temperature which is high enough for thermal decomposition; a voltage pulse is applied between cathode and first grid causing current to flow, thereby permitting electrolytical decomposition; positive ions are created by the electron beam current, producing ion bombardment of the cathode; and chemical reduction occurs at the nickel-oxide interface due to the presence of the minute quantities of reducing impurities in the nickel.

It has been shown by Becker[1] that an oxide-coated cathode, heated to a high temperature and subjected to a potential field which is strong enough to draw a temperature-limited current, will release a quantity of oxygen. He has also found that a cathode may be poisoned by too great an accumulation of oxygen at its surface. The aging of a cathode by the application of a strong potential field between cathode and first grid for a short interval of time followed by a relatively long rest interval was designed to age a cathode in the shortest possible time while, at the same time, minimizing the possibilities of oxygen poisoning. The cathode temperature is maintained at a high enough value to promote rapid diffusion of the oxygen out of the grid-cathode volume before another pulse is applied.

B. Need for the Investigation

Aging in the factory is presently accomplished by application of low d.c. voltages for an interval of around forty-five (45) minutes while the tubes are being transported by a conveyor system. If methods were to be adopted by the factory whereby its exhaust capacity could be increased, then aging conveyor space would be at a premium and, possibly, additional conveyor lines would need to be built. If a method of aging could be devised whereby the schedule could be made very short, without detriment to the quality of the tube, then the capacity of the aging conveyor line could also be increased.

C. Objectives

1. A determination of the minimum time necessary for proper aging of cathode-ray tube cathodes when pulse techniques are used.

C. Objectives (Cont.)

2. A determination of the effects of the pulse aging parameters, such as pulse width, pulse repetition frequency, and pulse amplitude, on degree of aging and total aging time.

3. A determination of cathode life when pulse aging is used as compared to cathode life when conventional aging schedules are used.

II. Equipment (See Figure 1)

A. Trigger Generator - A variable frequency micropulser built by Kay Electric Company

This pulser delivers to the pulse-output first a synchronizing pulse for the oscilloscope, then, after a predetermined delay interval, a positive firing pulse for the thyratron pulser. However, if it is desired to spread the pulse to investigate its shape, then the oscilloscope should be triggered internally, since the minimum delay between trigger pulse and firing pulse of the Kay micropulser is ten microseconds.

B. Thyratron Generator (See Figure 2)

This was designed so that the pulse voltage amplitude may be varied continuously from fifty (50) volts to two hundred (200) volts, the pulse width may have values of $\frac{1}{4}$, 1, and 2 microseconds, and the generator will operate at pulse repetition frequencies up to 5,000 pulses per second. The pulse output is negative, so the first grid must be grounded while the negative pulse is applied to the cathode.

In the output of the pulse generator is a twenty (20) ohm resistor to measure the current in the tube circuit. A switch is provided to give on the input of the oscilloscope either the pulse voltage or the voltage drop across the twenty (20) ohm resistor.

C. Filament Voltage Supplies, Timer Relays, and Pulse Switch

Two filament a.c. voltage supplies are mounted in a cabinet and connected, through timer relays, to the output tube socket in such a way that, at the push of a starting button, any desired voltage may be applied to the filament for a previously set interval; as the relay removes that voltage from the filament, the second filament supply applies any desired preset voltage and, at the same time, the pulse generator is switched into the circuit for the remainder of the aging cycle.

D. Oscilloscope

In order to view the shape of the pulse, and measure its width and amplitude, a scope with satisfactory bandwidth and calibrated amplifier is needed. In these experiments the Tektronix Type 514D was used.

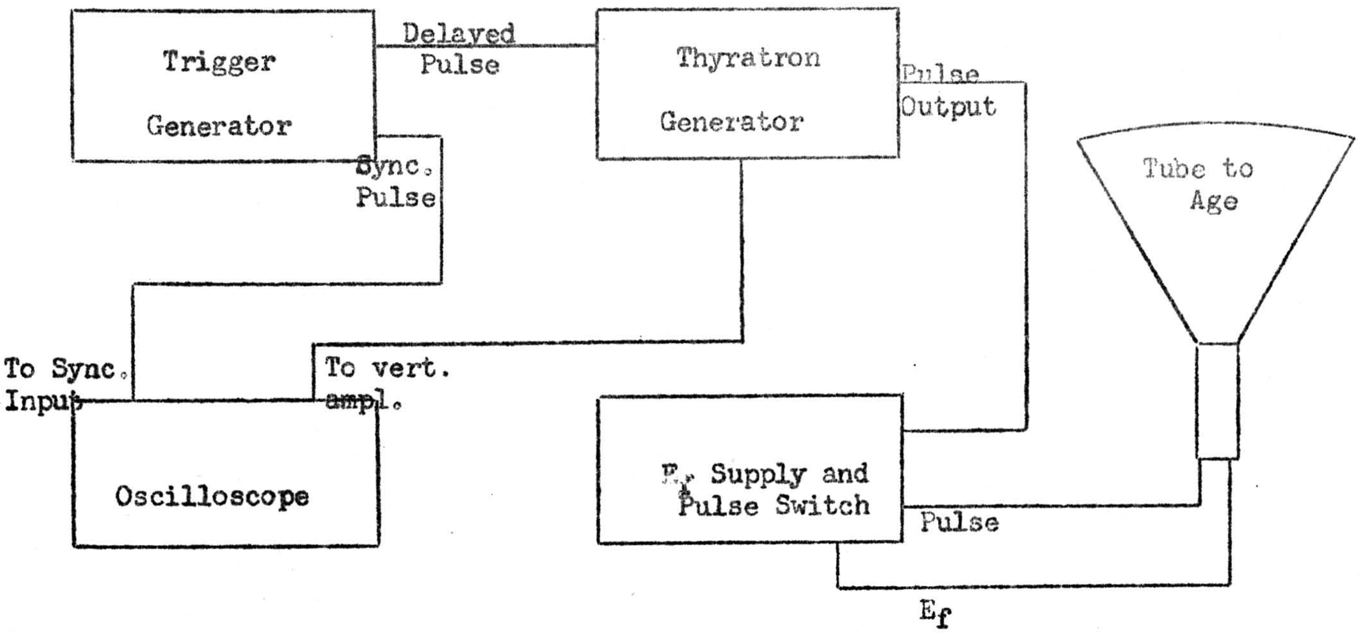

Figure 1

III Preliminary Investigation

A. Theoretical

Preliminary considerations have been based on G. E. TIS #52E603, dated January 15, 1952, by J. A. Murphy. He found that pulse aging of receiving tube cathodes, with which he worked, is dependent upon cathode temperature, pulse width, pulse repetition frequency, and pulse voltage. He also found that aging could be accomplished in very short lengths of time through the use of pulse methods. On the basis of Murphy's report, these same variables were chosen for investigation in the present work.

Theoretical calculations of temperature-limited emission current for several different temperatures were attempted on the basis of the design dimensions of the 10FP4 cathode-ray gun, but these calculations were found not to agree with experiment.

B. Experimental

One preliminary tube was built in the laboratory, aged by the normal d.c. aging schedule, and a volt-ampere characteristic run to determine the minimum voltage required to produce temperature-limited emission current. At the time this was run, the highest voltage available for filament power was 7.2 volts, so this was used. Figure 3 shows the curve obtained by pulsing grids #1 and #2 with short positive pulses, with respect to cathode. Curiously, the slope in the space-charge-limited region is 1.16 instead of the expected 1.5. The saturation voltage was around 30 volts.

Two more tubes were built for further preliminary tests. One was aged according to a conventional aging schedule and its zero bias emission and grid #1 voltage cut-off values taken. The other gun was pulse aged and the same characteristics were measured. Details of the pulse aging experiment

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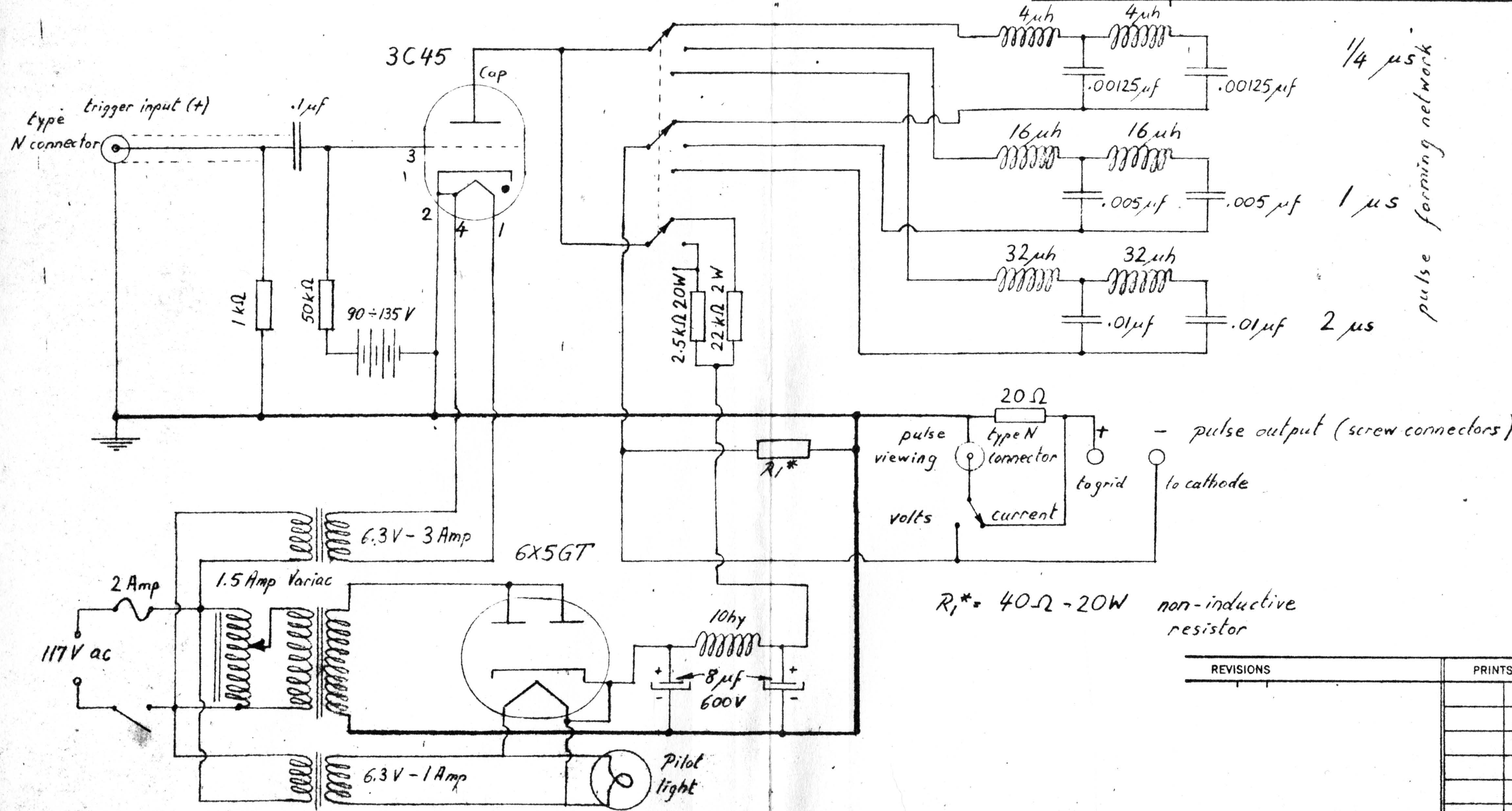

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Volt-Ampere Characteristic of 10FP4 Electron Gun

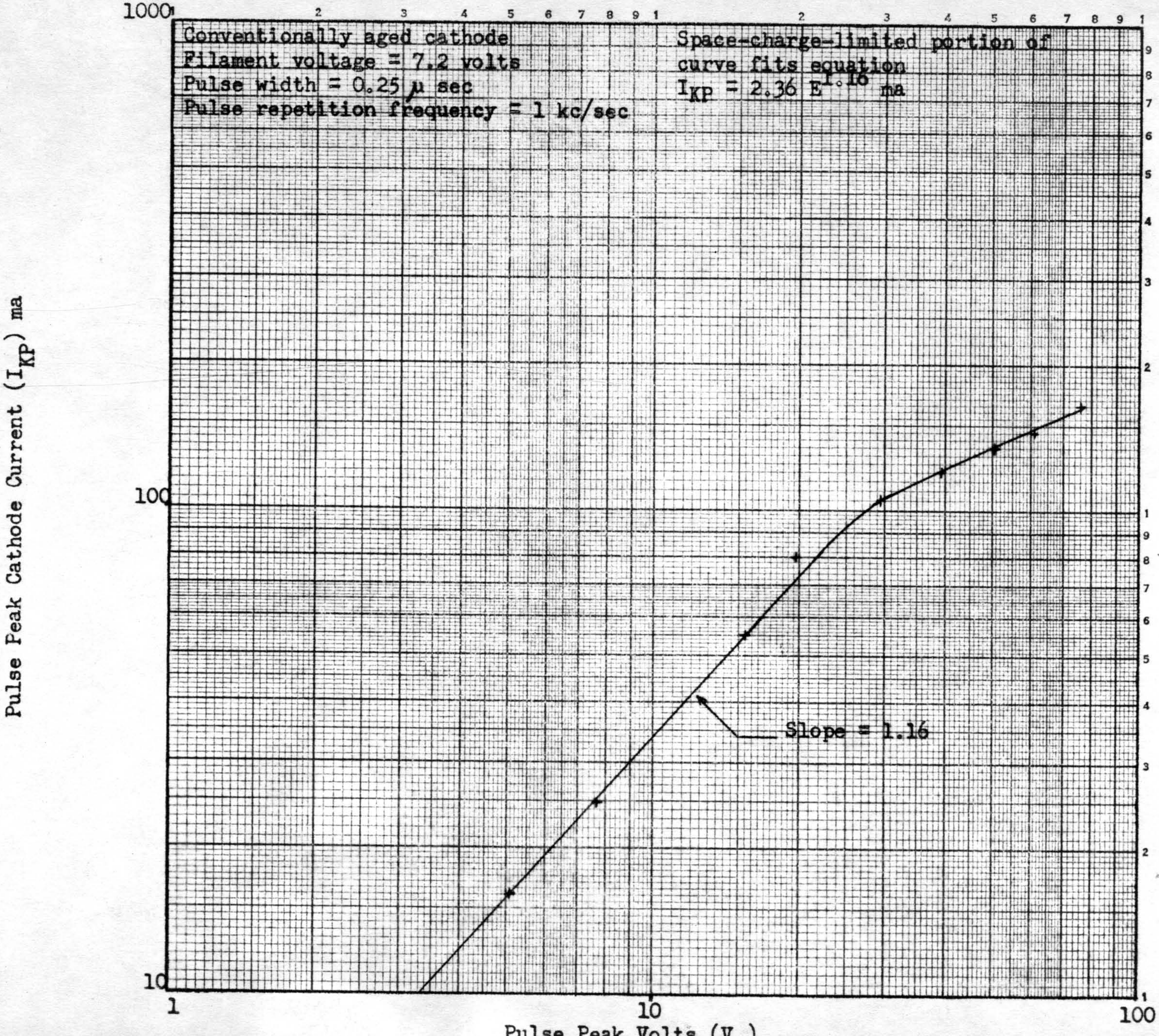

Figure 3

are given below:

The pulse aging parameters first applied were:

Filament voltage, E_f = 6.3 volts
Pulse peak voltage, V_p = 76.5 volts
Pulse width, T_p = 0.25 microsecond
Pulse repetition frequency, prf = 1 kilocycle/second

The peak pulse cathode current measured was:

$$I_{KP} = 60 \text{ ma}$$

Next, the parameters were changed to:

E_f = 8.5 volts
V_p = 76.5 volts
T_p = 0.25 microsecond
prf = 5 kilocycles/second

Within 15 to 30 seconds I_{KP} = 425 ma and did not change during two minutes of pulsing.

Next, the tube was pulsed under the original conditions again:

E_f = 6.3 volts
V_p = 76.5 volts
T_p = 0.25 microsecond
prf = 1 kilocycle/second

The pulse current was measured again and found to be 220 ma. It is significant to note that I_{KP} did not reduce to its original value of 60 ma. This indicates that the second period of pulsing did age the cathode to a greater extent than the first.

Zero bias emission was next measured on a test set, with E_f = 6.3 volts, E_{c1} = 0, E_{c2} = 200 volts, and I_K was found to be 1.4 ma.

This same tube was next aged by the conventional aging schedule given below:

For two minutes:

E_f = 10 volts
E_{c1} = 5 volts
E_{c2} = 0 volts

For the next 45 minutes:

E_f = 8 volts
E_{c1} = 5 volts
E_{c2} = 150 volts

Zero bias emission measurements were then found to be E_f = 6.3 volts, E_{c1} = 0, E_{c2} = 200 volts, I_k = 1.6 ma, and Grid #1 cut-off voltage, E_{co} = -45 volts. The d.c. aging improved the zero bias emission slightly, indicating that the activity obtained by pulse aging was not the optimum, but the difference was slight enough to indicate that the cathode was aged to a great extent by the pulse method alone.

Since Dr. Hillary Moss[3] gives $I_o = kE_{co}^{3/2}$, where I_o is the zero bias emission and E_{co} is the grid #1 cut-off voltage, the ratio $I_o/E_{co}^{3/2}$ should be a constant for guns with cathodes that are sufficiently aged. This ratio should, therefore, be a dependable means of comparison between cathodes, since it eliminates the effects of gun geometry. The value of the ratio, $I_o/E_{co}^{3/2}$, of the pulse aged tube compared favorably with that of the conventionally aged tube.

A conventional aging schedule which has been used in the Syracuse Tube Plant is given below:

For 2 minutes:

$$E_f = 12 \text{ volts}$$
$$E_{c1} = 0$$
$$E_{c2} = 0$$

For the next 40 minutes:

$$E_f = 8.5 \text{ volts}$$
$$E_{c1} = 3.5 \text{ volts}$$
$$E_{c2} = 0$$

The pulse aging was accomplished with the equipment illustrated by the block diagram in Figure 1. The complete procedure for pulse aging a tube is as follows:

1. Turn on both filament supplies, micropulser, pulse generator and oscilloscope.
2. To adjust micropulser: set frequency to desired value; set output switch for positive pulse; adjust pulse amplitude and pulse width to values such that pulse generator is driven in a stable manner.
3. To adjust pulse generator: set selector switch to desired value of pulse width; adjust pulse peak voltage amplitude by rheostat to desired unloaded voltage; turn analyzer switch to read output volts and allow to warm up for two minutes.
4. Connect oscilloscope to circuit; calibrate the scope face in volts; set trigger selector to internal negative; set sweep range to 10 microseconds.
5. Apply desired filament voltage for desired length of time (12 volts for 2 minutes in these experiments) for the preheating period. Next, apply desired filament voltage and pulse voltage simultaneously. The pulse peak voltage will now drop to a lower value, since the tube becomes part of the load, but all values in these experiments refer to the unloaded voltage.
6. The analyzer switch may now be turned to allow the scope to read the voltage drop across the 20 ohm resistor in series with the tube. This permits calculation of pulse peak cathode current.
7. The pulse is actually negative with respect to ground, so, actually, grid #1 (tied together with grid #2 and anode) is at ground level while the cathode is pulsed negatively.

Since the filament voltage is related to the temperature which a cathode will attain, it was decided to use this as a variable instead of cathode temperature, due to the fact that in the usual cathode-ray tube it is impossible to view the cathode with an optical pyrometer.

IV. Determination of Pulse Aging Parameters

A. Initial Experiments and Results

Preliminary tests on normal and low emission tubes showed the ranges of filament voltage, pulse repetition frequency, pulse voltage and pulse width to be used. All tubes aged in the following three series of tests were regular 12-inch production types (12KP4A's and 12LP4A's) from the Buffalo Tube Plant. In order to derive the maximum amount of information from a given laboratory procedure, a statistical analysis of variance should be performed. The laboratory procedure described below was designed to collect data which can be used for an analysis of variance.

1. First Series of Tubes Pulse Aged

Eighty-one tubes were aged in the series, the parameters being filament voltage, pulse width, and pulse repetition frequency. The pulse peak voltage and aging time were constants for all tubes. Three replications were considered sufficient. In order to insure the success of the experiment, the tubes were numbered and aged in a random fashion. Immediately before pulsing each tube, preheating was accomplished by applying $E_f = 12$ volts for 2 minutes. Then the pulsing schedule shown in Table I was applied.

$V_p = 80$ volts
Pulsing Time = 2.5 minutes

E_f	8V									10.5V									13V								
prf	1Kc			3Kc			5Kc			1Kc			3Kc			5Kc			1Kc			3Kc			5Kc		
T_p	$\frac{1}{4}$	1	2	$\frac{1}{4}$	1	2	$\frac{1}{4}$	1	2	$\frac{1}{4}$	1	2	$\frac{1}{4}$	1	2	$\frac{1}{4}$	1	2	$\frac{1}{4}$	1	2	$\frac{1}{4}$	1	2	$\frac{1}{4}$	1	2
No. of Tube	19	7	13	32	1	29	10	43	2	4	17	47	16	9	6	3	63	46	11	42	21	12	52	20	22	53	5
	40	55	35	64	15	38	14	45	39	23	26	74	28	41	27	44	24	56	18	49	36	34	68	25	30	59	8
	72	60	73	79	70	65	66	69	76	58	31	80	33	54	77	48	81	67	51	78	62	57	61	75	50	71	37

Table I: Schedule of Tube Aging

Instead of using the ratio $I_o/E_{co}^{3/2}$ as a criterion for comparison among tubes, it was decided to use the regular factory method of correcting the zero bias cathode emission current to the value it would have if the grid #1 voltage cut-off were -50 volts. This corrected emission current will be called, for the remainder of this report, 50-volt emission.

Values of emission current and grid #1 cut-off were taken both before and after aging, and records of the cathode images were taken to see if pulse aging would tend to damage the cathode surface.

Table II gives the 50-volt emission values for the first series of tubes.

E_f	8V								
prf	1Kc			3Kc			5Kc		
T_p	¼	1	2	¼	1	2	¼	1	2
	1080 1100 1070	1190 1090 1130	1130 1020 1050	1060 1150 900	1080 1120 1060	1270 1110 490	890 1090 1180	1050 840 1140	980 1140 340
Average	1083	1137	1067	1037	1087	990	1053	1010	820
Average peak pulse current	15.6 amp/cm^2								

E_f	10.5V								
prf	1Kc			3Kc			5Kc		
T_p	¼	1	2	¼	1	2	¼	1	2
	1160 1130 1130	1120 1160 1100	1090 1170 1140	1210 1130 1190	1010 1060 1130	1170 1080 1160	1150 1130 1150	1120 1040 890	1130 1130 750
Average	1140	1127	1133	1177	1067	1137	1143	1017	1003
Average peak pulse current	19.2 amp/cm^2								

E_f	13V								
prf	1Kc			3Kc			5Kc		
T_p	¼	1	2	¼	1	2	¼	1	2
	1120 1090 1070	1130 1110 1130	1160 1140 1140	1140 1110 1080	1180 1140 1040	1160 1120 1050	1140 1100 980	1120 1070 1140	1140 1110 1130
Average	1093	1123	1147	1110	1120	1110	1073	1110	1127
Average peak pulse current	21.3 amp/cm^2								

Table II

The three series of tests were designed as "full factorial experiments", and the method of evaluation was the analysis of variance, ending in its last step in a variance ratio test ("f" test). All statistical data obtained in this investigation has been analyzed by F. Caplan of Process Quality Control

An evaluation of the measurements obtained from the first series of tubes showed that a significant correlation exists only for the filament voltage. The choice is between E_f = 10.5 volts and E_f = 13 volts, with the optimum value nearer to E_f = 10.5 volts.

2. Second series of Tubes Pulse Aged

For the second series of 60 tubes to be pulse aged the filament voltage used during pulsing was chosen to be constant at 11 volts, and the length of pulsing time was used as a parameter. Since no significant correlation existed for pulse repetition frequency or pulse width, and to allow more replications, the extremes only of these parameters were used. Five replications were accomplished. Table III gives the 50-volt emission values for these tubes after aging.

V_p = 80 volts E_f = 11 volts												
Time	1				2.5				5			
prf	1		5		1		5		1		5	
T_p	$\frac{1}{4}$	2	$\frac{1}{4}$	2	$\frac{1}{4}$	2	$\frac{1}{4}$	2	$\frac{1}{4}$	2	$\frac{1}{4}$	2
	1160	1150	1130	1130	1160	1160	1100	1120	1150	1160	1170	1130
	1100	1130	1170	1150	1090	1140	1080	1110	1090	1160	1130	1140
	1130	1150	1120	1100	1140	1090	1100	1120	1080	1120	1140	1150
	1150	1130	1140	1150	1100	1100	1160	1190	1120	1130	1130	1150
	1110	1170	*1660	1180	1150	1100	1160	1130	1110	1400	1110	1150
Average	1130	1146	1244	1142	1128	1118	1120	1134	1110	1194	1136	1144
Average Peak Current - 14.9 amp/cm^2												

All tubes preheated for two minutes at E_f = 12 volts before pulsing.

*This value was measured on one extraordinary tube with a low cut-off (-42 volts).

Table III

The evaluation of these results showed that all tubes were very good and no significant correlation existed. The only positive result was that a tube seemed to be aged after one minute of pulsing time, because there was no significant difference in 50-volt emissions.

3. Third Series of Tubes Pulse Aged

Seventy-two tubes were pulse aged in this series. This permitted six replications, with this aging schedule design. This time the filament voltage was held constant at 11 volts and the pulsing time for each tube was one minute. Table IV gives the 50-volt emission values for these tubes after aging.

E_f = 11 volts Pulsing Time = 1 minute												
Peak V	50				80				130			
prf	1		5		1		5		1		5	
T_p	1	2	1	2	1	2	1	2	1	2	1	2
	740	1130	980	1120	1080	900	1080	1130	1060	780	810	490
	1070	1090	900	1060	1120	850	1250	1130	1070	1060	880	590
	480	630	760	1130	1130	1020	1100	720	1120	870	790	1090
	1220	880	830	1090	1170	1110	1130	1090	490	880	1090	1000
	1100	1120	1060	1140	1100	1100	1150	1080	240	1090	1130	460
	1060	1150	940	1110	650	1120	1130	1150	1120	1150	1140	890
Average	945	1000	911	1108	1041	1017	1140	1050	850	972	973	753
Pulse peak current	13.6 amp/cm^2				22.1 amp/cm^2				34.5 amp/cm^2			

(Third Series of Tubes Pulse Aged - Cont.)

All tubes preheated for 2 minutes at $E_f = 12$ volts before pulsing.

Table IV

Evaluation of these results indicated a significant correlation between the pulse peak voltages. The choice is between 50 volts peak and 80 volts peak, nearer to 80 volts peak. The 130 volt peak value gave extremely poor results. There is no significant correlation between pulse widths or pulse repetition frequencies or evidence of their interaction.

4. Next, it was decided to run a "t" test by comparing the average emission of the best pulse aging schedule with the average emission of the same number of conventionally aged tubes. Six tubes were aged by the conventional d.c. schedule and their 50-volt emission values averaged. See Table V.

D.C. AGED TUBES

Tube #	Before Aging I_k (μa)	Before Aging Grid #1 Cut-off (volts)	Before Aging 50V I_k (μa)	After Aging I_k (μa)	After Aging Grid #1 Cut-off (volts)	After Aging 50V I_k (μa)
I	1270	-57.5	1030	1280	-58	1030
II	390	-55	340	1240	-54	1110
III	730	-53	670	1250	-54	1120
IV	1600	-63	1130	1600	-62.5	1140
V	450	-50.5	440	1100	-50.5	1080
VI	1350	-61	1000	1500	-60	1140
						Average 1103

Table V

Although the best pulse aging schedule (80 volts peak, 5 kilocycles/second, 1 microsecond pulse width, pulse time of one minute) produced an evidently higher average emission than the conventionally aged tubes, a "t" test showed no significant correlation. To get a significant relation, it would be necessary to run at least 20 tubes on the same schedule.

The following schedule was derived from the best results of these series of experiments and was used in aging a part of the production tubes in the Buffalo Tube Plant and in the Syracuse Tube Plant.

Preheat for 2 minutes at $E_f = 12$ volts
Pulse for 1.8 minutes at:
$E_f = 11$ volts
$V_p = 75$ volts peak
prf = 3 kilocycles/second
$T_p = 1$ microsecond

The results of the production runs were satisfactory except in one respect. It was reported that the percentage of initial rejects of tubes for high gas pressure was objectionably greater for tubes pulse aged at the Buffalo Tube Plant than for conventionally aged tubes. This problem was investigated and the results are presented later in this report.

B. Life Test Results

Because a sufficient number of life test positions were not available at the Syracuse Tube Plant at the time of these tests, part of the tubes were sent to the Chemical Products Works, Lamp Department, Cleveland, Ohio, for life testing. Because of a misunderstanding, the only reading taken on these tubes was at the end of 1515 hours. Variations during life of these nine tubes are not known, but the final emission and the percentage of the initial emission at the end of life are calculated. Five pulse aged and one conventionally aged tube were put on life test at the Syracuse Tube Plant, and three pulse aged tubes were life tested at the Buffalo Tube Plant. The 21-inch tubes, listed by tube type only, were pulse aged and life tested at the Buffalo Tube Plant.

LIFE TEST DATA FROM CHEMICAL PRODUCTS WORKS

TUBE #		0 Hours	1515 Hours
7B	50V I_k (μa)	1080	975
	Cut-off (volts)	-58	-50
	* % 50V I_{ko}	100%	90.2%
46A	50V I_k (μa)	1180	884
	Cut-off (volts)	-50	-47
	% 50V I_{ko}	100%	75%
63B	50V I_k (μa)	1090	1250
	Cut-off (volts)	-52	-50
	% 50V I_{ko}	100%	115%
10B	50V I_k (μa)	870	1090
	Cut-off (volts)	-57	-54
	% 50V I_{ko}	100%	125%
7	50V I_k (μa)	1120	1180
	Cut-off (volts)	-56	-52
	% 50V I_{ko}	100%	105%
19B	50V I_k (μa)	1080	910
	Cut-off (volts)	-58	-55
	% 50V I_{ko}	100%	84.3%
31	50V I_k (μa)	1030	825
	Cut-off (volts)	-60	-51
	% 50V I_{ko}	100%	80%
15B	50V I_k (μa)	840	780
	Cut-off (volts)	-54.5	-52
	% 50V I_{ko}	100%	93%
32B	50V I_k (μa)	1120	1020
	Cut-off (volts)	-55	-52
	%50V I_{ko}	100%	91%

* I_{ko} represents initial value of I_k (cathode current) at zero hours.

TUBE # OR TYPE		0 hrs.	47 hrs.	210 hrs.	535 hrs.	1021 hrs.	2021 hrs.	2605 hrs.
46	50V I_k (μa)	1200	1200	1110	1070	885	890	910
	Cut-off (volts)	-54	-54	-54	-54	-54	-54	-55
	% 50V I_{ko}	100%	100%	92.5%	89.3%	73.8%	74.0%	76.0%
4	50V I_k (μa)	1240	1220	1190	1090	1010	915	830
	Cut-off (volts)	-58	-60	-59	-57	-57	-54	-54
	% 50V I_{ko}	100%	98.5%	96.0%	88.0%	81.5%	73.8%	66.8%
16	50V I_k (μa)	1250	1230	1210	1180			
	Cut-off (volts)	-54	-52	-51	-52			
	% 50V I_{ko}	100%	98.0%	96.8%	94.5%			

TUBE # OR TYPE		0 hrs.	50 hrs.	192 hrs.	250 hrs.	500 hrs.	503 hrs.	512 hrs.
21ZP4A	50V I_k (μa)	1359	1368	1379	1300	870		
	Cut-off (volts)	-52	-51	-51	-54	-55		
	% 50V I_{ko}	100%	100.6%	101.5%	95.6%	64.2%		
21ZP4A	50V I_k (μa)	1408	1299	1339	1308	1260		
	Cut-off (volts)	-47	-49	-49	-49	-50		
	% 50V I_{ko}	100%	92.3%	95.0%	92.8%	89.6%		
21ZP4B	50V I_k (μa)	1260						1010
	% 50V I_{ko}	100%						80.0%
21ZP4B	50V I_k (μa)	1160					930	
	% 50V I_{ko}	100%					80.0%	

LIFE TEST DATA FROM BUFFALO TUBE PLANT

Tube #		0 hrs.	65 hrs.	207 hrs.	349 hrs.	514 hrs.	755 hrs. *	1018 hrs.	1281 hrs.
27B	50V I_k (μa)	1410	1360	1340	1280	1325	930	1170	1150
	Cut-off (volts)	-52	-54	-52	-53	-53	-51	-51	-50
	% 50V I_{ko}	100%	96.5%	95.0%	90.8%	94.0%	66%	83.0%	81.5%
35	50V I_k (μa)	1330	1420	1320	1330	1110	800	1120	1050
	Cut-off (volts)	-48	-47	-45.5	-46	-45.5	-45.5	-43	-45
	% 50V I_{ko}	100%	107.0%	99.3%	100%	83.5%	60.0%	84.2%	79%
53B	50V I_k (μa)	1415	1380	1345	1670	1320	910	1190	1020
	Cut-off (volts)	-51	-50.5	-53.5	-52	-52	-52	-51	-53
	% 50V I_{ko}	100%	97.5%	95%	118%	93.3%	64.4%	84.0%	72.0%

Tube #		0 hrs.	96 hrs.	187 hrs.	371 hrs.	532 hrs.	843 hrs.	884 hrs.
41B	50V I_k (μa)	1360	1550	1450	900	1070	1240	1300
	Cut-off (volts)	-48	-46.5	-47.5	-46	-45	-46	-46
	% 50V I_{ko}	100%	114%	107%	66.1%	78.6%	91.1%	95.5%
31B	50V I_k (μa)	1410	1675	1610	940	1300	1325	1170
	Cut-off (volts)	-49	-50	- 52	-50	-48	-50	-54
	% 50V I_{ko}	100%	119%	114%	66.8%	92.3%	94.0%	83.0%
VIB	50V I_k (μa)	1410	1420	1400	1140	1060	970	1140
	Cut-off (volts)	-55	-56	-58	-56	-56	-55	-54.5
	% 50V I_{ko}	100%	101%	99.4%	80.9%	75.3%	68.8%	81.0%

* Since all readings in this column deviate considerably from the normal trend, it would seem likely that an error was introduced due either to an inexperienced operator or test equipment which was defective at that time. (These three tubes were read at the same time by the same operator on one piece of test equipment.)

LIFE TEST DATA FROM SYRACUSE TUBE PLANT

COMBINED LIFE TEST DATA

Average Values of 50 Volt I_k at Intervals During Life Test

	0 hrs.	50 hrs.	200 hrs.	250 hrs.	500 hrs.	1000 hrs.	1515 hrs.	2605 h
Avg. 50V I_k (μa)	1146	1263	1245	1105	1059	947	990	870
% 50V I_{ko}	100%	110%	108.6%	96.4%	92.4%	82.6%	86.5%	76.0

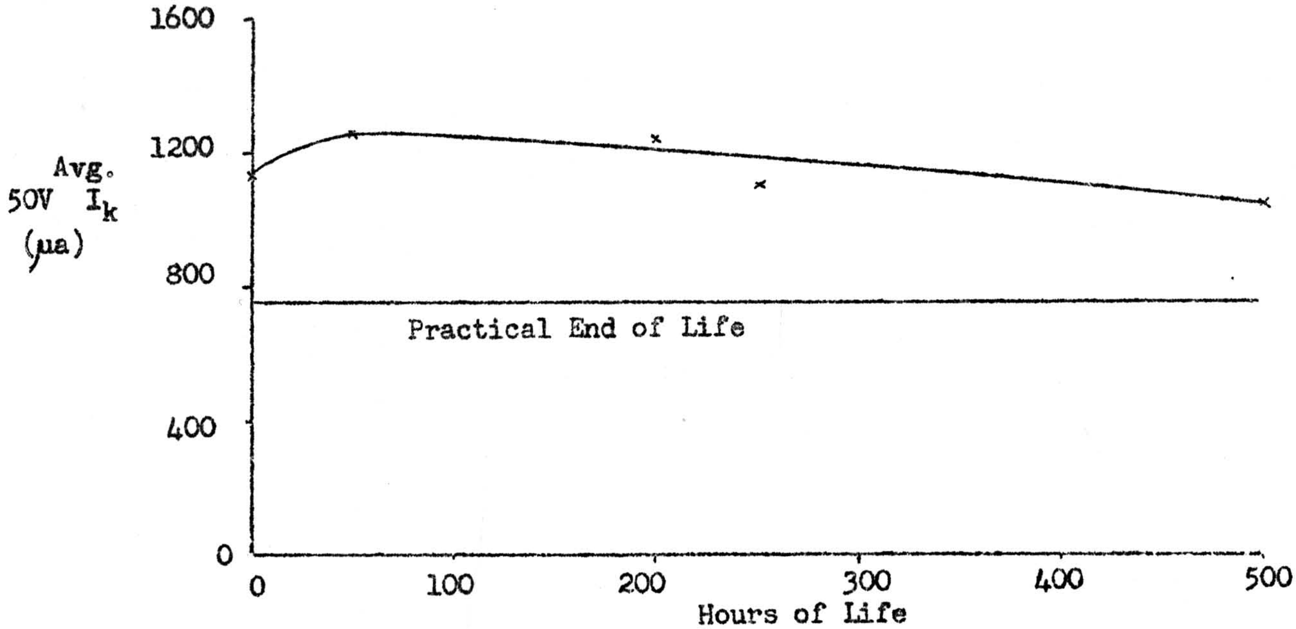

Figure #5

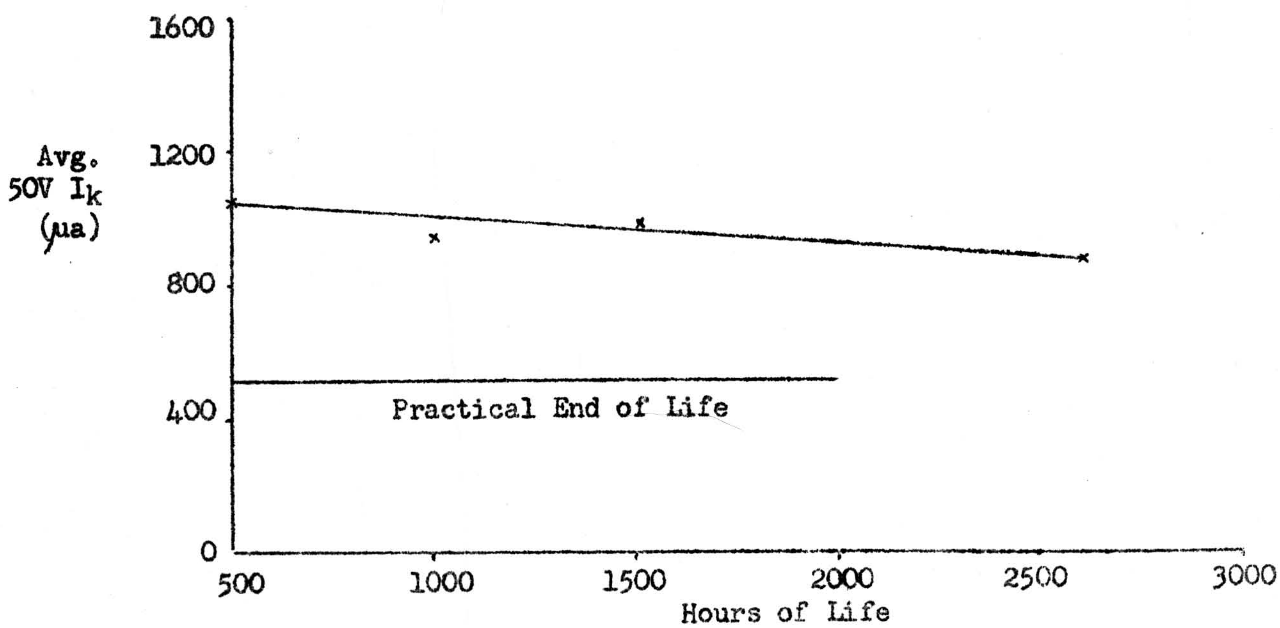

Figure #5a

For a means of comparison Figure 6 is a graph of average 50-volt emission versus hours on life test for 63 conventionally aged tubes (type 21EP4B) over the period October, 1952 to June, 1953.

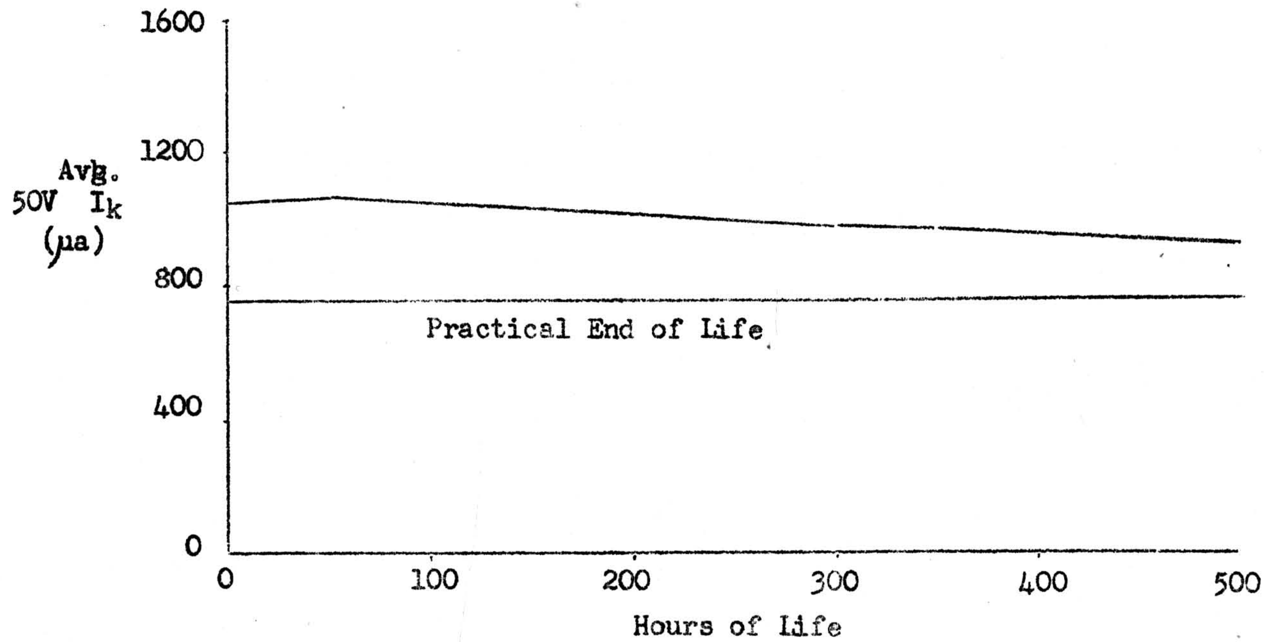

Figure #6

According to Standing Instructions No. 13701 T2-73, of the Syracuse Tube Plant, dated November 10, 1953, concerning the practical end of life for a tube on life test --

"End of Life (500 hours)

When the 50-volt emission level falls below 80% of the original level or below 750 microamperes, whichever comes after the longest period of activation."

"Extended Life (2,000 hours)

When 50-volt emission level falls below 55% of the original level or below 515 microamperes, whichever comes last."

It appears that pulse aged tubes compare very favorably with all of these criteria.

V. Redesign of Pulse Delay Line

When the author assumed the investigation, the pulse equipment was returned to the Syracuse Tube Plant and checked completely. The pulse shape was examined and found not to have any constant or average peak value. For instance, the rounded peak of the one microsecond pulse occupied an interval of between 0.2 and 0.3 microsecond, while the rest of the time was occupied by the rise and the decay of the pulse. Since the value of the pulse amplitude does not appear to be critical in these experiments, the deviation of the pulse shape from a true rectangular form should not be construed to vitiate the experimental results. However, in order to run additional experiments with a pulse shape as close to a true rectangular shape as possible, the delay line of the pulse generator was redesigned and rebuilt. This was necessary in order that the factory, at any future time, may reproduce the conditions and variables of the experiments and have assurance of obtaining similar results, as long as the equipment is of optimum design. For example, if the factory would attempt to pulse tubes with a peak voltage that remained constant for the full microsecond (a rectangular pulse) it would age tubes to a much greater extent than was indicated by these experiments.

Calculations of the delay line constants, as outlined by Elmore and Sands[4], provide the following: Since the pulse rise time is given by

$$T_R \approx 1.1\, n^{1/3} \sqrt{L\,C}$$

(where n is the effective number of sections), low values of C and R were chosen. The values used are: $C = 625\,(10)^{-12}$ farad and $L = 2\,(10)^{-6}$ henry. The total delay time is given by

$$T_D = n\sqrt{LC}$$

A delay time of one microsecond is required, so the number of sections needed is

$$n = \frac{T_D}{\sqrt{LC}} = \frac{10^{-6}}{\sqrt{2(10)^{-6}\,(625)\,(10)^{-12}}} = 28.3$$

Since the delay line is open at the end, the voltage wave is reflected with a 180° change of phase back to the input end. Thus, the length of the pulse is the time required for the voltage wave to travel to the open end and back. A delay line of this type, therefore, requires only fourteen physical sections.

The rise time is then approximately -

$$T_R \approx 1.1\,(28)^{1/3}\sqrt{2(10)^{-6}(625)\,(10)^{-12}} = 0.12\,\mu\ \text{sec.}$$

This is satisfactory.

The characteristic impedance is given by -

$$Z_c = \sqrt{\frac{L}{C}} = \sqrt{\frac{2(10)^{-6}}{625(10)^{-12}}} = 56.6 \text{ ohms}$$

The capacitances and inductances were carefully mounted to avoid excessive stray capacitances, and the load resistor, R_1, of Figure 2 was replaced by one of 50 ohm value.

Measurement of the pulse produced by the new delay line, while loaded with a cathode-ray tube, showed the pulse to be of one microsecond width, with peak value constant for about 0.8 microsecond.

VI The Gas Problem

A. After the optimum parameters for pulse aging had been determined, the Buffalo Tube Plant pulse aged several hundred tubes on the factory floor. Upon analysis of the results a report was issued which stated that high gas pressure at initial test was a serious obstacle to pulse aging; that the average gas pressure at initial test was about twice that for regularly aged tubes; that rejects for gas at initial test on pulse aged tubes were about 8 per cent higher than for regularly aged tubes; and that pulse aging, as set up at that time, was not suitable for factory production. It was thought that oxygen was liberated from the oxide coating on the cathode at a faster rate than the getter material could remove it by sorption. It was known that the gas cleared up of its own accord upon standing, but it was thought that the time necessary to hold the tubes before they tested within limits would be excessive.

Several methods for cleaning up the gas in a rapid manner were suggested, the most promising among them being the method of scanning the tube with zero bias emission for 15 seconds. The Syracuse Tube Plant applied this scanning method to both pulse aged and regularly aged tubes and in every case the gas pressure tested well within the limits immediately after scanning. The Buffalo Tube Plant, however, reported that after scanning their tubes increased in gas pressure. Their conclusion was that pulse aged gas rejects could not easily be recovered by scanning.

It was decided that the approach to this gas problem should be in terms of determining the actual length of time required for the gas pressure to drop to within limits after pulsing. If the interval were short enough to be tolerated in the factory schedule, then special auxiliary equipment, designed especially to clear up gas, could be avoided.

The author first pulse aged several tubes in the Design Engineering laboratory at Syracuse, using the new delay line, and found that all gas pressures were well within limits from immediately after aging. The equipment was then taken to the Buffalo Tube Plant and set up on the factory floor. Tubes were taken from regular production at random just ahead of the normal d.c. aging conveyor and were pulse aged using the optimum schedule of -

For two minutes:
    Filament hotshot of E_f = 12 volts

For the next 1.8 minutes:
    $E_f \approx$ 11 volts
    Pulse peak voltage (unloaded), V_p = 75 volts
    Pulse width = 1 microsecond
    Pulse repetition frequency = 3 kilocycles/second

Ninety-three (93) tubes were pulse aged and data was taken from seventy-eight (78) control tubes. The following procedure was used.

A strip of tape was placed on each tube on which all data pertinent to that tube was recorded. After pulse aging, the tube was held for ten minutes and then placed on the regular aging conveyor just three minutes ahead of the test operator; this allowsthe tube to preheat before testing. To assure an equal number of controls, also selected at random, a piece of data tape was also placed on a tube four or five positions behind each pulse aged tube. In order to eliminate some of the variables due to manufacturing equipment, and to permit all testing to be done in one set, only 21" tubes were chosen. In order to keep the testing as uniform as possible, all tubes tested in this experiment, both pulse aged and controls, were done on one test set. The data follows.

TUBES PULSE AGED AT B.T.P.

Peak Voltage (V_p) = 75 V (unloaded)
Pulse rep. freq. = 3 kc/sec.
Pulse width = 1 μ sec.
Hotshot at E_f = 12 volts for 2 min.
Pulse Time at E_f = 11 volts for 1.8 min.

Tube Type And No.	Al. or Black	Elec. or Mag.	Inline #	Peak Current I_p (ma)	Emission I_k (μa)	50V I_k Em. (μa)	Cut off (volts)	Gas Ratio Before Test	Gas Ratio After Test	Cath. Image
G023 21EP4B	Al.	Mag.	1	500	1350	1105	57	.08		ok
G377 21YP4	Black	Elec.	2	350	1000	1170	45	.16		ok
G040 21YP4	Black	Elec.	1	350	1100	1210	47	.04		ok
F315 21EP4B	Al.	Mag.	2	400	1200	1040	55	.32	.16	ok
F317 21YP4	Black	Elec.	2	400	1050	1150	47	.088		ok
F088 21FP4A	Black	Elec.	2	400	1300	1125	55	.16		ok
G344 21FP4A	Black	Elec.	2	400	1150	1150	50	.40	.12	ok
G385 21FP4A	Black	Elec.	2	350	1250	1110	54	.40	.16	ok
G001 21FP4A	Black	Elec.	1	400	1200	1200	50	.40	.20	ok
G017 21YP4	Black	Elec.	1	400	1250	1110	54	.34	.16	ok
H052 21YP4	Black	Elec.	1	350	1000	1175	45	.12		ok
H367 21YP4	Black	Elec.	2	450	1000	1175	45	.08		ok
H213 21YP4	Black	Elec.		400	1200	1200	50	.04		ok
K301 21EP4B	Al.	Mag.	2	350	950	950	50	.40	.16	ok
K311 21YP4	Black	Elec.	2	400	1700	1145	65	.40	.16	ok
K302 21YP4	Black	Elec.	2	550	1300	1125	55	.40	.16	ok
K002 21YP4	Black	Elec	1	350	1650	1110	65	.28	.08	ok
J061 21YP4	Black	Elec.	1	350	1100	1100	50	.32	.16	ok
J376 21YP4	Black	Elec.	2	350	1300	1125	55	.40	.32	ok
L350 21YP4	Black	Elec.	2	400	900	1055	45	.40	.12	ok
K329 21YP4	Black	Elec.	2	350	1200	1410	45	.18		ok
No # 21YP4	Black	Elec.		300	1000	1400	40	.40	.24	ok
M391 21YP4A	Al.	Elec.	2	300	1000	1175	45	.16		ok

Tube Type And No.	Al. or Black	Elec. or Mag.	Inline #	Peak Current I_p (ma)	Emission I_k (μa)	50V I_k Em. (μa)	Cut off (volts)	Gas Ratio Before Test	Gas Ratio After Test	Cath. Image	
E070 21FP4A	Black	Elec.	1	250	1250	1080	55	.20		ok	
L353 21YP4	Black	Elec.	2	350	1100	1290	45	.40	.16	ok	
K830 21ZP4B	Al.	Mag.		400	350	303	55	.40	.12	ok	Low Em.
	Reaged			350	500		55	.16		X	*
	Regular Aging				1200	1200	50	.12		ok	*
K336 21FP4A	Black	Elec.	2	300	1000	1175	45	.06		ok	
L358 21YP4	Black	Elec.	2	400	1200	910	60	.40	.20	ok	
P414 21FP4A	Black	Elec.	2	300	1725	1160	65	.40	.08	ok	
P331 21ZP4B	Al.	Mag.	2		1000	845	56	.40	.16	ok	
P330 21EP4B	Al.	Mag.	2	350	1250	995	58	.40	.14	ok	
P392 21YP4	Black	Elec.	2	300	1650	1255	60	.40	.16	ok	
N347 21YP4	Black	Elec.	2	350	1750	1010	72	.40	.20	ok	
P318 21ZP4B	Al.	Mag.	2	400 to 350	1250	970	59	.40	.184	ok	
No # 21FP4A	Black	Elec.		300	1525	860	73	.40	.16	ok	
Q364 21YP4	Black	Elec.	2	350	1250	1080	55	.40	.224	ok	
R376 21ZP4B	Al.	Mag.	2	400	1200	1035	55	.40	.08	ok	
P315 21YP4	Black	Elec.	2	300	1100	980	54	.40	.14	ok	
No # 21EP4B	Al.	Mag.		350	1300	960	61	.40	.152	ok	
L348 21YP4	Black	Elec.	2	600 to 1000	1700	760	85	.40	1.20	ok	**
L368 21EP4B	Al.	Mag.	2	400	1300	985	60	.28	.12	ok	
M398			2	350	1100	1290	45	.40	2.40	ok	Leaky tu
L097 21YP4	Black	Elec.	1	350	1000	1400	40	.24		ok	
L347 21YP4	Black	Elec.	2	350	1500	1500	50	.32	.08	ok	
N342 21YP4	Black	Elec.	2	350	1500	1370	53	.40	.08	ok	
N022 21YP4A	Al.	Elec.	1	400	1500	1140	60	.216	.096	ok	
No # 21YP4	Black	Elec.		350	1400	1250	54	.40	.12	ok	
M003 21YP4	Black	Elec.	1	400	1900	1220	67	.32	.16	ok	

** Evidently a leaky tube and should not be averaged in.
* Notice that regular aging saved the tube.

Tube Type And No.	Al. or Black	Elec. or Mag.	Inline #	Peak Current I_p (ma)	Emission I_k (μa)	50V I_k Em. (μa)	Cut off (volts)	Gas Ratio Before Test	Gas Ratio After Test	Cath. Image
N340 21FP4A	Black	Elec.	2	400	1850	1305	63	.12		ok
M009 21YP4	Black	Elec.	1	350	1250	1080	55	.32	.14	ok
No # 21FP4A	Black	Elec.		300	1525	1130	61	.40	.20	ok
P332 21YP4	Black	Elec.	2	350	1925	1325	64	.336	.16	ok
M314 21FP4A	Black	Elec.	2	300	1075	930	55	.24	.12	ok
N388 21YP4	Black	Elec.	2	350	1500	1105	61	.40	.12	ok
3371 21YP4	Black	Elec.	2	350	1050	1230	45	.40	.36	ok *
No # 21YP4	Black	Elec.		350	500	500	50	.20		ok **
	Reaged			350	725	705	51			
N394 21FP4A	Black	Elec.	2	350	1000	1030	49	.40	.08	ok
P395 21YP4	Black	Elec.	2	300	1500	1080	62	.40	.12	ok
T090 21FP4A	Black	Elec.	1	350	1950	1315	65	.40	.16	ok
P309 21ZP4B	Al.	Mag.	2	450	1500	1010	65	.40	.16	ok
N055 21YP4	Black	Elec.	1	350	1000	975	51	.40	.16	ok
Q035 21YP4	Black	Elec.	1	350	1750	1205	64	.40	.22	ok
N344 21FP4A	Black	Elec.	2	300	1500	1055	63	.40	.16	ok
R377 21EP4B	Al.	Mag.	2	400	1450	1045	62	.40	.16	ok
Q365 21FP4A	Black	Elec.	2	300	Low Emission					
R025 21YP4	Black	Elec.	1	350	1250	1080	55	.24	.168	ok
No # 21FP4A	Black	Elec.		250	900	665	61	.40	.16	ok ***

* 2 hrs. later G. R. = .40
** Low emission - reaging did not bring within limits.
*** Low emission

TUBES PULSE AGED AT B. T. P.

Peak Voltage (V_p) = 75 V (unloaded)
Pulse rep. freq. = 3 kc/sec.
Pulse width = 1 μ sec.
Hotshot at E_f = 12 V for 2 min.
Pulse time at E_f = 11 V for 1.8 min.

Tube Type And No.	Al. or Black	Elec. or Mag.	Inline #	Peak Current I_p (ma)	Emission I_k (μa)	50V I_k Em. (μa)	Cut off (volts)	Gas Ratio Before Test	Gas Ratio After Test	Cath. Image
F066 21YP4	Black	Elec.	1	300	1150	1150	50	.32	.08	ok
F065 21YP4	Black	Elec.	1	350	1000	1175	45	.40	.16	ok
F073 21EP4B	Al.	Mag.	1	400	300	300	50	.16		X *
F075 21ACP4A	Al.	Mag.	1	375	550	470	55	.28	.12	X *
Y069 21EP4B	Al.	Mag.	1	400	1100	950	55	.24		ok
F397 21YP4	Black	Elec.	2	375	1350	1170	55	.36	.12	ok
G026 21YP4	Black	Elec.	1	350	1100	1290	45	.22		ok
G007 21YP4	Black	Elec.	1	350	550	640	45	.24		X **
G008 21YP4	Black	Elec.	1	350	1250	950	60	.16		ok
G103 21YP4	Black	Elec.	1	300	1400	1065	60	.18		ok
G102 21YP4	Black	Elec.	1		650	565	55	.24		X **
G023 21FP4A	Black	Elec.	1	375	1500	1140	60	.40	.16	ok
G022 21YP4	Black	Elec.	1	350	1600	1215	60	.36	.16	ok
G024 21YP4	Black	Elec.	1	300	1500	1140	60	.32	.16	ok
H037 21YP4	Black	Elec.	1	350	950	825	55	.24		ok
F409 21FP4A	Black	Elec.	2	375	1650	1250	60	.40	.12	ok
H035 21YP4	Black	Elec.	1	300	1300	985	60	.36	.12	ok
F412 21ZP4B	Al.	Mag.	2	400	1000	1175	45	.40	.16	ok
G374 21YP4	Black	Elec.	2	375	1750	1180	65	.40	.16	ok
K002 21YP4	Black	Elec.	1	375	1600	1080	65	.40	.40	ok Gassy
G387 21YP4	Black	Elec.	2	400	2000	1210	70	.40	.16	ok

* Cathode damaged or poisoned - not especially by pulsing.
** Low emission - not especially from pulsing.

Tube Type And No.	Al. or Black	Elec. or Mag.	Inline #	Peak Current I_p (ma)	Emission I_k (μa)	50V I_k Em. (μa)	Cut off (volts)	Gas Ratio Before Test	Gas Ratio After Test	Cath. Image
F373 21ZP4B	Al.	Mag.	2	450	1500	1140	60	.40	.20	ok
F410 21YP4	Black	Elec.	2	350	1350	1020	60	.40	.20	ok
X365 21EP4B	Al.	Mag.	2	325	750	880	45	.40	.16	ok
K049 21YP4	Black	Elec.	1	400	1000	1175	45	.32	.16	ok
G386 21YP4	Black	Elec.	2	350	1500	1140	60	.40	.20	ok

In these data sheets the values of gas ratio are given instead of absolute pressure. It has been determined that conversion of gas ratio to absolute pressure in microns can be accomplished by dividing the value of gas ratio by a factor of 10.

CONTROL TUBES FOR PULSE AGING EXPERIMENT AT B. T. P.

Tube Type And No.	Al. or Black	Elec. or Mag.	Inline #	I_k (μa)	50V I_k (μa)	Cutoff (volts)	Gas Ratio Before Test	Gas Ratio After Test	Cath. Image
E399 21YP4	Black	Elec.	2	1700	1290	60	.16		
F093 21YP4	Black	Elec.	1	1000	1000	50	.16		
F332 21FP4A	Black	Elec.	2	950	1115	45	.36	.08	
F072 21YP4	Black	Elec.	1	1250	1180	55	.08		
D366 21YP4A	Al.	Elec.	2	1000	1400	40	.30	.12	
F309 21YP4	Black	Elec.	2	1200	1040	55	.40	.20	
H048 21YP4	Black	Elec.	1	1100	1100	50	.20		
G386 21YP4	Black	Elec.	2	1250	1250	50	.24	.12	
G387 21ZP4B	Al.	Mag.	2	1250	1080	55	.08		
G002 21YP4	Black	Elec.	1	1200	1200	50	.12		
J381 21ZP4B	Al.	Mag.	2	1300	985	60	.32	.12	
J020 21YP4	Black	Elec.	1	1750	1180	65	.08		
H301 21YP4	Black	Elec.	2	900	1055	45	.12		
H309 21YP4	Black	Elec.	2	1700	1150	65	.16		
J364 21YP4	Black	Elec.	2	900	1055	45	.32	.12	ok
J360 21YP4	Black	Elec.	2	1000	1000	50	.04		ok
J054 21YP4	Black	Elec.	1	1000	1000	50	.28	.08	ok
K326 21YP4	Black	Elec.	2	1100	1100	50	.20		ok
D398 21YP4A	Al.	Elec.	2	1050	1230	45	.12		ok
S415 21YP4	Black	Elec.	2	1100	950	55	.12		ok
H325 21YP4	Black	Elec.	2	800	690	55	.08		X
J366 21YP4	Black	Elec	2	1200	1200	50	.12		ok
K094 21YP4	Black	Elec.	1	1400	1400	50	.08		ok
L355 21YP4	Black	Elec.	2	1100	1100	50	.20		ok
L336 21EP4B	Al.	Mag.	2	1200	1200	50	.32	.08	ok
L663 21YP4	Black	Elec.	Rotary	2000	1210	70	.18		ok

Tube Type And No.	Al. or Black	Elec. or Mag.	Inline #	I_k (μa)	50V I_k (μa)	Cutoff (volts)	Gas Ratio Before Test	Gas Ratio After Test	Cath. Image	
L091 21YP4	Black	Elec.	1	1250	1080	55	.18		ok	
P312 21YP4	Black	Elec.	2	1000	1170	45	.16		ok	
L358 21YP4A	Al.	Elec.	2	1200	1100	53	.28	.08	ok	
L377 21YP4	Black	Elec.	2	1150	720	68	.40	.40	ok	Low emission Gassy
L345 21YP4	Black	Elec.	2	1525	1075	63	.08		ok	
N349 21FP4A	Black	Elec.	2	Low emission - no reading possible.						
N369 21FP4A	Black	Elec.	2	1075	880	57	.34	.16	ok	
No # 21YP4	Black	Elec.		1075	930	55	.24	.14	ok	
No # 21YP4	Black	Elec.		2000	1410	63	.40	.25	ok	
N051 21EP4B	Al.	Mag.	1	1300	940	62	.12		ok	
Q363 21YP4A	Al.	Elec.	2	1500	1295	55	.16	.08	ok	
P001 21YP4	Black	Elec.	1	1775	1200	65	.32	.14	ok	
N350 21YP4	Black	Elec.	2	1225	930	60	.30	.16	ok	
P301 21YP4	Black	Elec.	2	1000	920	53	.28	.12	ok	
M391 21YP4	Black	Elec.	2	2000	1110	74	.08		ok	
P403 21YP4	Black	Elec.	2	1725	1135	66	.36	.12	ok	
No # 21FP4A	Black	Elec.		1700	1145	65	.40	.15	ok	
P313 21YP4	Black	Elec.	2	1750	1180	65	.40	.16	ok	
P326 21EP4B	Al.	Mag.	2	1250	840	65	.32	.17	ok	
N349 21FP4A	Black	Elec.	2	775	750	51	.40	.16	ok	Low emission
Q337 21FP4A	Black	Elec.	2	1750	1205	64	.32	.16	ok	
P410 21YP4	Black	Elec.	2	1750	1125	67	.40	.40	ok	Gassy
Q369 21FP4A	Black	Elec.	2	1100	1040	52	.40	.17	ok	
R100 21YP4	Black	Elec.	1	1100	1005	53	.20	.12	ok	
R373 21YP4	Black	Elec.	2	1150	995	55	.40	.18	ok	*

* This tube was rejected for gas; I labeled it and it was tested again 2 minutes later and is within limits.

Tube Type And No.	Al. or Black	Elec. or Mag.	Inline #	I_k (μa)	50V I_k (μa)	Cutoff (volts)	Gas Ratio Before Test	Gas Ratio After Test	Cath. Image	
Q354 21YP4	Black	Elec.	2	2000	1130	73	.40	.18	ok	
N346 21YP4	Black	Elec.	2	1650	1060	67	.40	.16	ok	
F031 21YP4	Black	Elec.	1	1200	1200	50	.16		ok	
F398 21YP4	Black	Elec.	2	1250	1180	55	.40	.40	ok	Gassy
G098 21EP4B	Al.	Mag.	1	1150	990	55	.06		ok	
F070 21YP4	Black	Elec.	1	1350	1170	55	.20		ok	
G005 21YP4	Black	Elec.	1	1400	1065	60	.40	.40	ok	Gassy
G002 21YP4	Black	Elec.	1	1500	1140	60	.16		ok	
G011 21FP4A	Black	Elec.	1	1900	1145	70	.16		ok	
G021 21YP4	Black	Elec.	1	1650	1255	60	.36	.12	ok	
G025 21YP4	Black	Elec.	1	1500	1140	60	.16		ok	
G094 21EP4B	Al.	Mag.	1	650	760	45	.08		X	Low Emission
F060 21YP4	Black	Elec.	1	1000	1170	45	.12		ok	
H062 21YP4	Black	Elec.	1	1150	995	55	.16		ok	
P306 21YP4	Black	Elec.	2	1750	1180	65	.40	.40	ok	Gassy
F305 21YP4	Black	Elec.	2	2000	895	85	.40	.22	ok	Cutoff out of specs.
J085 21YP4	Black	Elec.	1	1700	1145	65	.16		ok	
F309 21YP4	Black	Elec.	2	1950	1315	65	.12		ok	
F365 21YP4	Black	Elec.	2	1650	1250	60	.20		ok	
F358 21ZP4B	Al.	Mag.	2	1200	910	60	.20		ok	
F337 21YP4	Black	Elec.	2	1500	1140	60	.40	.40	ok	Gassy
F361 21FP4A	Black	Elec.	2	1100	1100	50	.20		ok	
F340 21YP4	Black	Elec.	2	1500	1500	50	.40	.16	ok	
J019 21FP4A	Black	Elec.	1	1100	660	70	.18		ok	
Z358 21FP4A	Black	Elec.	2	1100	1290	45	.20		ok	
G385 21YP4	Black	Elec.	2	1000	1170	45	.24		ok	
F415 21YP4	Black	Elec.	2	1650	1250	60	.24		ok	

B. Analysis of Data

Statistical methods of analysis were employed by F. Caplan to obtain the following results and conclusions.

C. Results

1. Comparison of gas pressures between tubes pulse aged and control tubes:

Before testing, gas pressures of pulse aged tubes are significantly higher than those of control tubes. After testing, the indication is strong that gas pressures of pulse aged tubes are lower than those of control tubes.

2. Comparison between inline exhaust ovens:

According to the gas pressures read before testing, there is a significant difference between the tubes exhausted in Inline #1 and Inline #2 exhaust ovens, the Inline #2 producing tubes with higher gas pressures. According to the readings after testing, there is no significant difference between the tubes exhausted by either oven.

Since it was indicated that the two exhaust ovens varied significantly from each other, an analysis was run on tubes exhausted bv one oven only, the #2 oven. The results still showed significance indicating pulse aged tubes, before testing, have a higher gas pressure than control tubes. Thus, it appears that the difference in exhaust ovens did not affect the final results.

3. Comparison between pulse aged and controls of gas rejects:

Before testing, the number of pulse aged tubes with gas pressures higher than specification limits was significantly higher than for control tubes. After testing, there was no significant difference between the two.

4. Comparison of gas pressures between aluminized magnetic and black electrostatic tubes:

Analysis indicates no significant difference in initial emission between pulse aged and control tubes.

6. Correlation of peak pulse current with initial emission and with Grid #1 cut-off:

There is no correlation of peak pulse current with either of the above.

D. Remarks

Although at the start of testing, pulse aged tubes read significantly higher gas pressures, they compare very favorably with the control tubes at the end of normal testing. Since it is normal factory procedure to accept any tube found within limits at the end of testing, it seems that the criterion for judging pulse aged tubes should be the final gas check.

There seems to be no reason for continuing to read peak pulse current as there is no correlation between this and any other tube characteristic. However, this does not imply that information cannot be gained from the current wave shape in later investigations. It may turn out that some measurement, such as the slope of the leading edge of the "rectangular" wave, may prove significant as to cathode condition.

It should be noted that one tube, which was a low emission reject when aged and re-aged by the pulse method, was salvaged by aging it in the regular aging cycle.

VII Conclusions

A cathode-ray tube can be aged in an interval of 3.8 minutes by the pulse method, using the parameters found by this investigation to be optimum, and will be equal in quality to conventionally aged tubes in all respects. Although a slight increase in gas pressure may be expected immediately after aging, this diminishes in value within a period of thirteen (13) minutes such that at the end of the final test the gas pressure is within limits.

Neither the aging parameters nor aging time seem to be critical. Since factory equipment, even under close supervision, may be expected to vary to a certain extent, any process used in the factory should inherently possess a certain amount of latitude. The pulse aging process, then, is favorable for factory application.

VIII Facets for Future Investigation

At the start of the final series of tubes it was thought that a resting period between pulsing and testing would be needed to allow gas pressure to stabilize at a value within specification limits; therefore, that experiment was designed to arbitrarily allow a minimum of thirteen (13) minutes delay between pulsing and testing. Since the results are favorable, it might be desirable to determine the minimum delay time which may be needed between pulsing and testing.

The normal procedure in the factory, in the aging process, is to preheat the cathode to a high temperature and maintain it for two minutes to condition it for the application of the various d.c. voltages. In this investigation this preheating cycle was presumed to be necessary and the usual values optimum. If a shorter aging cycle were to be considered desirable, it might be fruitful to determine the minimum necessary preheating time and temperature, using the optimum pulse aging parameters.

Since the equipment used in this investigation was designed to allow variation of all the parameters, it is not directly adaptable to factory use. Factory equipment designed for one specific set of the parameters will require fewer components and a much smaller volume. The problems associated with the design of pulsing equipment for factory application are many. Among the most critical is the sensitivity of the pulse shape to any stray capacitances or inductances in the output circuit. Impedance matching between output load and the delay line is also essential, thereby lending discouragement to the possibility of aging several tubes in parallel with one delay line. It is suggested that, in order to afford maximum reliability, individual pulsing units be installed in each tube position on the aging conveyor.

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