RADC-TR-65-82

October 1964

RESEARCH AND DEVELOPMENT ON L-BAND CROSSED-FIELD AMPLIFIER CHAIN

by

H. L. McDowell

A. Wilazek

Report No. 7

Quarterly Progress Report

June 1964 to September 1964

Contract Nr. AF 30(602)-2533

ARPA Order No. 136.61

Rome Air Development Center Research and Technology Division

Air Force Systems Command, United States Air Force

Griffiss Air Force Base, New York

S•F•D laboratories, inc.

Union, New Jersey

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ABSTRACT

During this quarter, life tests were continued on the Group C, SFD-209 tubes. Tubes L30E, D37F, and L48E are operating in parallel from a common RF source and dc power supply. A total of 8349 hours of operation has been accumulated. Apparent degradation of performance has been traced to external circuit faults. With circuit faults corrected, tube L48E had no significant change in performance after 3268 hours of operation. Tubes L30E and D37F are operating satisfactorily after 748 and 769 hours, respectively.

Construction of the new Group D design was started. These tubes incorporate changes found to be necessary as a consequence of life tests. These changes include improved control electrode cooling and a new input window.

Tubes F63F and G35F of the new Group D design were tested and found to be satisfactory. Tube G35F was used to observe the effects of increased anode-cathode separation. The increased separation allows operation in the region of lower power output, where under conditions of less separation, the output would contain some π mode oscillations. Starting delay in tube G35F was also studied. Starting delay times of less than 20 nanoseconds were observed for a 5 kw peak input over a 1000 volt range of cathode voltage encompassing the normal operating values.

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PUBLICATION REVIEW

This report has been reviewed and is approved. For further technical information on this project, contact Mr. Schneider, EMATE, Extension 4251.

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LIST OF FIGURES

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1.0 INTRODUCTION

During the quarter covered by this report, life tests were continued on tube L48E and two additional tubes (L30E and D37F) were placed on life test. By the end of the quarter, tube L48E had operated for 3268 hours and the two additional tubes had operated for about 750 hours each. The changes in the V-I characteristic and some of the starting jitter previously reported were found to be caused by circuit rather than tube problems and these were corrected.

Construction of the new Group D design driver tubes was started. These tubes incorporate changes found to be necessary as a consequence of the life tests. These changes include improved control electrode cooling and a new input window. Three of these tubes were completed and construction of another three was started.

Hot test characterizations of three tubes were made during the quarter. Results on three similar tubes show a good degree of reproducibility of characteristics. Tests on another tube with an increased anode-to-cathode spacing show that this change reduces the tendency toward π-mode oscillation at low currents.

2.0 LIFE TEST RESULTS

During this quarter, life tests were continued on tube L48E and tubes L30E and D37F were placed on life test during the first part of July. All three tubes operate satisfactorily from a common dc power supply and RF source. By the end of August 1964, tube L48E had accumulated 3268 hours of operating life. Tubes L30E and D37F had accumulated 748 and 765 hours respectively. The life test program had accumulated a total of 8349 hours of operation by the end of August. Table I is a summary of the Group C SFD-209 tube status and life test results as of the end of August 1964. Table II is a summary of the Group D SFD-209 tube status.

Figure 1 shows that the three tubes (L39E, L48E and D37F) had very nearly the same V-I characteristics at the beginning of the life test. The three tubes are identical except for an improved thermal path between the control electrode and cathode in tube D37F. The high thermal impedance between the control electrode and cathode is partly a consequence of thin kovar members sealed to the control electrode insulator. As discussed in previous reports, it is suspected that this high thermal impedance causes the control electrode to operate at a temperature which gradually causes its recrystallization. This, in turn, is believed to cause a change in its secondary emission properties which leads to starting jitter. A quick but significant improvement in control electrode heat transfer was made by brazing copper heat shunts over the kovar members of the control electrode support assembly in tube D37F. It was assumed, quite correctly, that this improvement would not affect the V-I characteristic of the tube.

Some insight into the problems encountered during life testing was obtained when the two additional tubes were added to the life test system. It had been reported in the last quarterly report (Report No. 5, RADC-TDR-64-236) that the V-I characteristic of tube L48E had degraded during the life test. This observation was difficult

Tube No.	Serial No.	Seal In Date	Control Electrode Type	Total Life Test Hours	Comments	Present Status
1	H19E	9/13/63	Notched titanium	-- --	Voltage breakdown through cracked insulator	Rebuilt as H19E-1 with modified insulator
1a	H19E-1	10/8/63	Notched titanium	--	Poor starting performance	Rebuilt as H19E-2
2	J10E	10/19/63	Notched titanium	--	Poor starting performance	Rebuilt as J10E-1
2a	J10E-1	10/28/63	Notched aluminum	750 End of life	Improved starting but still marginal; removed from life test because of excessive starting jitter	Tested to end of life and opened for analysis
3	K6E	11/15/63	Stepped aluminum	223 End of life	Good performance; damaged by equipment failure on life test; some starting jitter appeared on life test prior to failure	Repumped as K6E-1; now awaiting RF test for analysis of jitter problem
4	L1E	12/12/63	Stepped aluminum	1288 End of life	Good performance; damaged by equipment failure on life test; some starting jitter appeared on life test prior to failure	Being analyzed
5	L30E	12/19/63	Stepped aluminum	748 Cont'g	Performance OK	On life test and operating
6	L48E	1/2/64	Stepped aluminum	3268 Cont'g	Developed starting delay and jitter of 0.3 μsec	On life test and operating
1b	H19E-2	1/8/64	Stepped aluminum		Performance OK on quick check	Awaiting RF testing
3a	K6E-1	2/6/64	Stepped aluminum		Tube K6E removed from life; repumped as K6E-1 without opening; initial quick check shows starting jitter	Awaiting testing for analysis of jitter problem
7	D34F		Stepped aluminum "Heat shunts" on support assembly			Awaiting hot test
8	D37F		Stepped aluminum "Heat shunts" on support assembly	765 Cont'g		On life test and operating

TABLE I SUMMARY OF GROUP C SFD-209 TUBE STATUS AND LIFE TEST RESULTS AS OF 27 AUGUST 1964

Tube No.	Serial No.	Seal-In Date	Description of Tube and Comments	Present Status
1	F63F	6/29/64	Standard anode-cathode spacing	On hot test for average power capability evaluation
2	G35F	7/22/64	Anode-cathode spacing increased 10%	Hot tested - awaiting life test
3	H29F	8/27/64	Absorber located behind C_{13} couplers - absorber cracked	Awaiting repair
4			Anode-cathode spacing increased 5%	Under construction
5				Under construction
6			Dispenser type cathode	Under construction

TABLE II SUMMARY OF GROUP D SFD-209 TUBE STATUS AS OF 27 AUGUST 1964

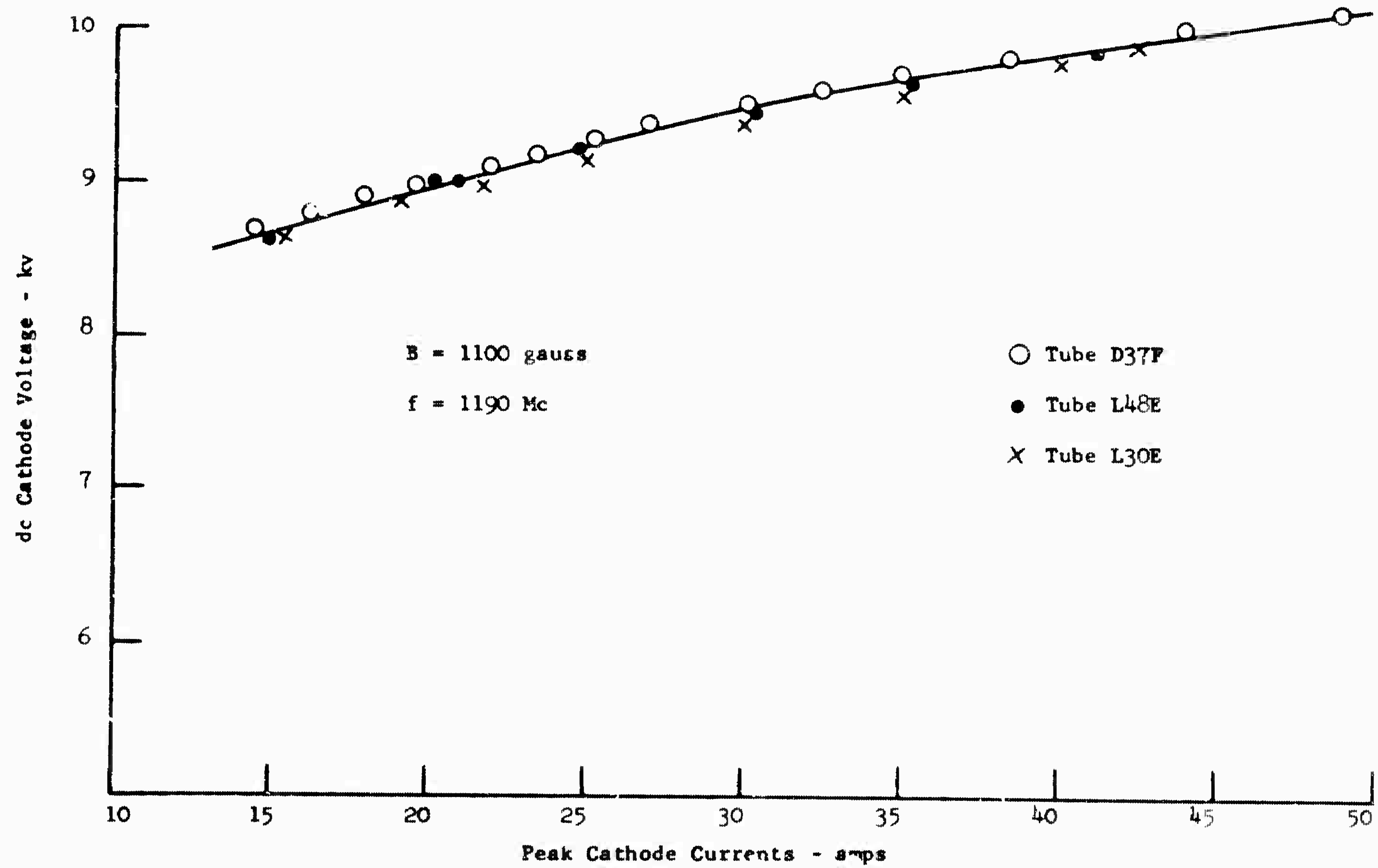

FIGURE 1 V-I CURVES OF TUBES AT START OF LIFE TEST

to explain since the cathode current is believed to be space charge limited. If the cathode was to degrade, it was expected that the maximum available current might decrease but that the shape of the V-I curve at lower currents should not change. The shift in the V-I curve appeared to indicate that this simple viewpoint regarding space charge limitation was not correct. In the process of adding the additional tubes to the life test, it was discovered that the shift in the V-I curve was the result of an external circuit fault rather than a degradation of the tube. The fault involved the failure of the RF load terminating the directional coupler input in the RF drive power division network. The directional coupler is of the quarter wave contra-coupling type with two ports available on the coupled line. One port provides the input power to the crossed-field amplifier and the second port, one quarter wavelength down the line, is terminated in a matched load to obtain the directivity for the directional coupler. Under normal conditions, when the main line is terminated with a matched load, very little power is transmitted to the matched termination on the coupled line. For this reason, the termination supplied with the directional coupler had a low power capacity.

As the directional coupler is used in the life test system, the termination on the coupled line will be subjected to any power directed back from the crossed-field amplifier input, which under normal operating conditions, may be approximately 2 per cent of the crossed-field amplifier output power. The average power output from the crossed-field amplifier is between 200 watts and 300 watts so that the termination is subjected to 2 watts to 6 watts of power. The termination supplied with the directional couplers appear to have been designed for approximately 1 watt capacity. When the low power termination was destroyed, the termination became an open circuit. The open circuit caused standing waves to be set up which, in turn, reduced the input power fed to the tube to be about half the proper value. The resulting tube behavior was initially interpreted as a degradation of performance, but it is now apparent that the tube behaved as it should with a reduced RF input drive.

Figure 2 shows the result of measurements on tube L48E made at 2862 hours of operation and after the fault had been corrected. The results of measurements after 2500 hours of operation but before the fault was corrected are also included. The measurements show that the V-I characteristics of tube L48E are essentially the same as the initial hot test characteristics. The RF input power is still slightly below the value at the start of life test, and this may account for the remaining difference in the characteristics.

The starting delay and jitter on tube L48E, although still present, were considerably reduced when the termination fault was corrected. The reduction of starting time delay indicates that the starting delay and jitter are a partial function of RF input drive power. The input drive power is still below normal, but steps are being taken to correct this situation and further improvement is expected. This experience led us to conduct a more detailed study of the effects of RF drive and operating voltage on starting delay and jitter. The results of this investigation are discussed in a later section.

The performance of tubes L30E and D37F follow the same pattern as does tube L48E with the exception of starting delay and jitter. Tube L30E developed starting delay and jitter in much the same way as did tube L48E; however, tube D37F has shown no starting delay or jitter after 750 hours of operation. This observation is significant, since tube D37F has an improved thermal path between control electrode and cathode, which we would expect to inhibit the appearance of jitter. However, it is too soon to conclude that the jitter has been alleviated by this step.

Further diagnostic tests were conducted during this quarter on tube L1E which was removed from life test in May. This tube had operated for 1288 hours when loss of a control modulator coupled with

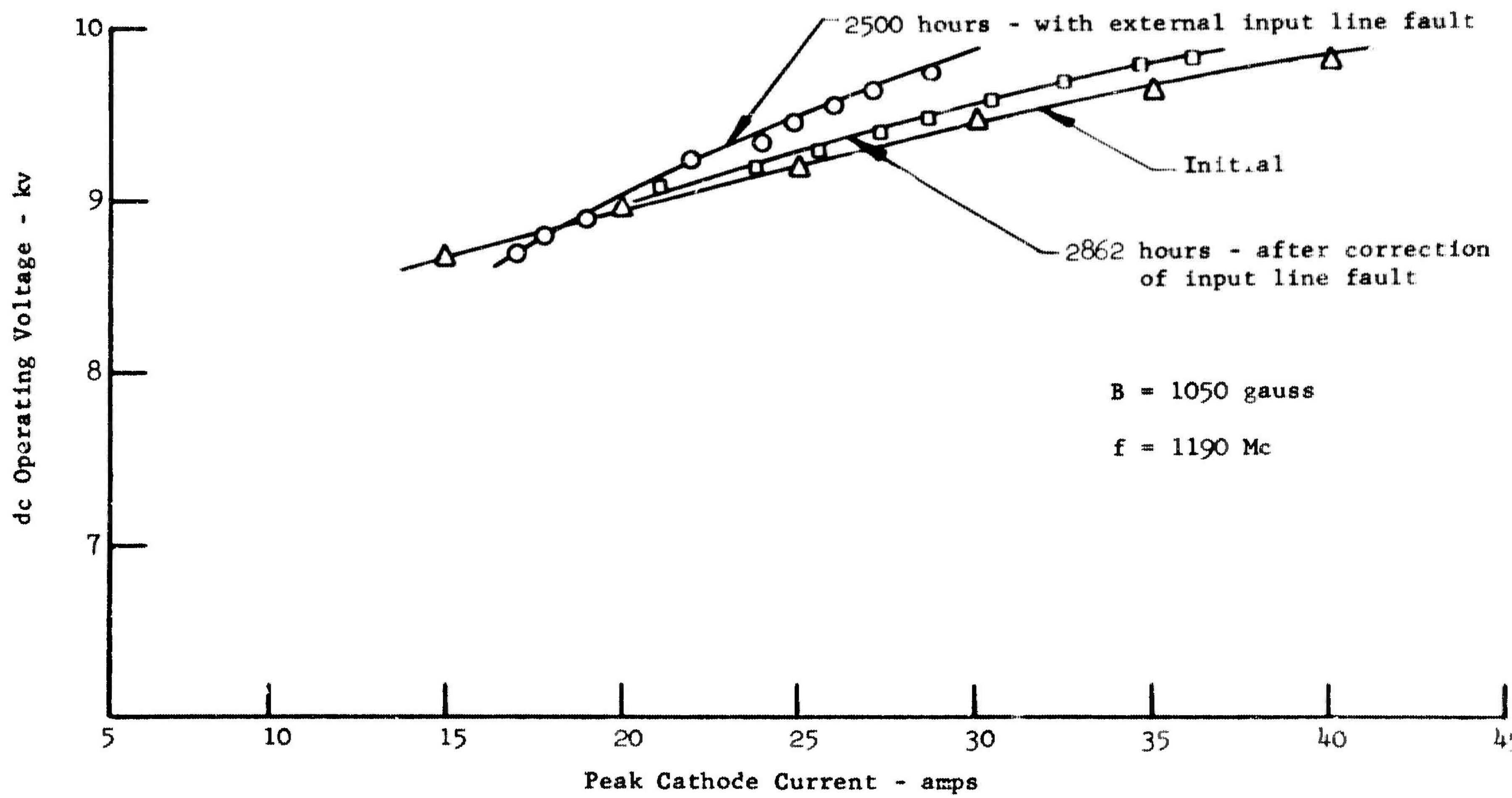

FIGURE 2 V-I CURVES OF TUBE L48E BEFORE LIFE TEST; AFTER 2500 HOURS WITH A DAMAGED TERMINATION IN THE INPUT POWER DIVISION NETWORK; AND AFTER 2862 HOURS WITH THIS TERMINATION REPLACED. RF INPUT POWER AT 2862 HOURS IS SLIGHTLY LESS THAN INITIAL VALUE

the failure of a protective circuit caused the tube to gas up. As was stated in the last report, some tests were made to determine what changes, if any, had taken place during life test. Measurements of the cold transmission and reflection were recorded, and it was found that the match of the tube had degraded significantly. This had been the first time we had observed a change in cold circuit properties during life tests. In an attempt to evaluate the source of the change, X-ray pictures of the tube were taken. The photographs revealed a significant amount of eccentricity in the output coaxial line; however, this eccentricity could not fully account for the change in circuit properties. Another possibility was a deposit found on the input window as a consequence of arcing in the input line. The input window was replaced first by an identical 3/8 inch window, and then with a 7/8 inch window without any significant changes in the cold properties of the tube. It is now strongly suspected that a shift in the matching section has taken place. Such a change could occur as stresses set up in the tube or the first circuit bar were "relieved" by heating. The source of the stresses in this particular tube might have been introduced when the cold match was adjusted. As was previously reported, a repair had been necessary in the can of tube L1E, and, as a consequence, dimensions were not held as well as in the standard tubes. For this reason, more than the normal amount of adjustment had to be made in the matching section. The next step will be to open the tube for a visual inspection. The chances of reclaiming this particular tube are good.

Before tubes L30E and D37F were placed on life test, an experiment was performed on tube L48E in an attempt to determine the cause of the starting delay and jitter. A dc bias voltage was applied to the control electrode in an attempt to alter the electron trajectories in the drift space during the starting interval. A bias, negative with respect to the cathode, had no appreciable effect below 1000 volts but caused increased starting delay above 1000 volts.

A positive bias of approximately 400 volts reduced the starting delay perceptibly. From 400 volts to approximately 1000 volts, no effect was observed, but, above 1000 volts, delay time increased. It had been expected that a negative bias would prevent electrons from striking the control electrode during the starting interval. Since, as discussed in a previous report, many of these strikes occur at low electron energy, they were believed to result in a decrease in the space charge as it traversed the drift space. We had reasoned that a negative bias would prevent this loss and improve the starting. We were thus surprised to find that the negative bias had no effect. We were equally surprised to find that the positive bias helped the starting. This effect also appears to require the assumption that electrons strike the control electrode following cycloiding trajectories. The positive bias would cause the electrons which strike the control electrode the first time to do so with greater energy and thus greater production of secondaries. Thus, the observed result cannot be explained by present theories. We now suspect the possibility of trapping electrons between control electrode and cathode when the bias is negative. This whole subject of the effects of control electrode bias on starting deserves further study. It could possibly shed a considerable amount of light on the starting process.

3.0 SFD-209 GROUP D DESIGN

Performance tests and life tests on the SFD-209 have shown the desirability of several design changes. A group of six new tubes known as the Group D tubes is being constructed to incorporate these changes. From life tests, we have learned that the control electrode operates at a temperature which was higher than anticipated. The control electrode support was redesigned to incorporate a beryllia insulator which has a high thermal conductivity in place of the alumina insulator in the previous design. The new method of mounting the insulator also avoids the use of the thin kovar members of the previous design. As a net result, we expect a considerable improvement in the heat transfer from the new control electrode support.

A second design change, shown to be necessary from the life tests, involves the input window. Visual inspection of the input windows on tubes removed from life test revealed evidence of sparking between the inner and outer conductors on the atmospheric side of the window. It was therefore decided to change the input window to a 7/8 inch coaxial size.

Three tubes, incorporating the design changes, have been completed during this quarter and three more started. The best estimate is that the last three tubes will be completed by the end of September or the first week in October. The first of the completed tubes, F63F, was sealed in and pumped on 29 June 1964. This particular tube s ffered a number of rebrazing operations in excess of the usual brazes. The rebrazing operations were necessary to seal a porous metal detail in the anode flange. The rebrazing operations rendered this tube non-standard; however, subsequent hot test results indicate that the tube performs very much like the standard tubes.

The second tube in this group, G35F, was sealed in and pumped on 22 July 1964. This tube incorporated the above-mentioned design changes but also incorporated a cathode with a diameter which was 10 per cent smaller than a standard cathode. This change in cathode diameter was made to investigate the effect of anode-cathode spacing on the tendency for the tube to oscillate in the π-mode at low currents. The results of this experiment were encouraging and are reported in the Hot Test Section (4.0) of this report.

Another area where performance measurements indicated that improvement may be desirable is in the further suppression of the region of π-mode oscillations at low currents. Such oscillations have not been present in any of the RF performance measurements quoted in the preceding quarterly and semi-annual reports. It is known that there is a region of π-mode oscillations at low drive power levels and at the low operating voltages on the left-hand side of a typical performance chart. If the oscillations can be suppressed, the input drive power can be reduced with little change in output power, thereby increasing the gain. Even if the tube is to be operated with approximately the 5 kw of input drive used in our RF testing, it would be advantageous to decrease the required input power for satisfactory operation and thereby provide a greater degree of insensitivity to effects of the antenna VSWR. To further suppress the π-mode, we incorporated a selective π-mode attenuator in H29F, the third tube of this group. The attenuator is in the form of a ceramic absorber mounted between the C_{13} coupler rings and the vacuum envelope. Cold tests performed previously with a linear version of the circuit indicated that this type of selective absorption was feasible and cold tests on the tube verified the observation. Unfortunately, a broken piece of the ceramic came loose during a high temperature braze and lodged against one of the C_{13} couplers in the center of the circuit. The removal of the dislodged ceramic introduced a relatively small disturbance on the circuit, and it was decided to proceed with the construction of the tube. The tube, H29F, was sealed in and pumped on 27 August 1964. The bake out apparently loosened the remainder of the broken ceramic which again appears to have lodged against the C_{13} coupler. It is now necessary to reopen the tube and remove the broken ceramic.

4.0 HOT TEST MEASUREMENTS

During this quarter, hot test measurements were made on tubes D37F, F63F, and G35F. The V-I characteristics and frequency response of tube D37F (Group C design) are shown in Figures 3 and 4 respectively. Tube D37F was subsequently placed on life test and has accumulated approximately 750 hours of operating life with no change in performance.

Although tube F63F (Group D design) had been classified as mechanically non-standard due to repeated brazing operations, measurements show that it may be classified electrically as standard. The V-I characteristics and frequency response of tube F63F are shown in Figures 5 and 6. This tube will be used to evaluate the high average power capability of this new design.

In tube G35F, the anode-cathode spacing was increased by 10 per cent by decreasing the cathode diameter to observe the effect of the increased spacing on the dynamic operating range of the tube. During the initial test, it was discovered that the control electrode diameter was not reduced proportionately to the cathode diameter, and therefore, the control electrode protruded radially outward from the cathode in the drift space. Upon completion of the test, the tube was reopened, corrected and repumped as G35F-1. The subsequent measurements gave an evaluation of the effect produced by the protruding control electrode. Figure 7 shows the frequency response of the tube under both conditions. It is evident that the protruding control electrode causes a reduction in output power and efficiency. The frequency response of tube G35F-1, operating at a higher dc potential, is also shown in Figure 7. Figure 8 shows the V-I characteristics for this tube.

The V-I characteristics of tube G35F-1 are compared with the V-I characteristic of tube F63F in Figure 9. The effect of the increased anode-cathode separation becomes evident. The increased separation allows operation in the region of lower power output where,

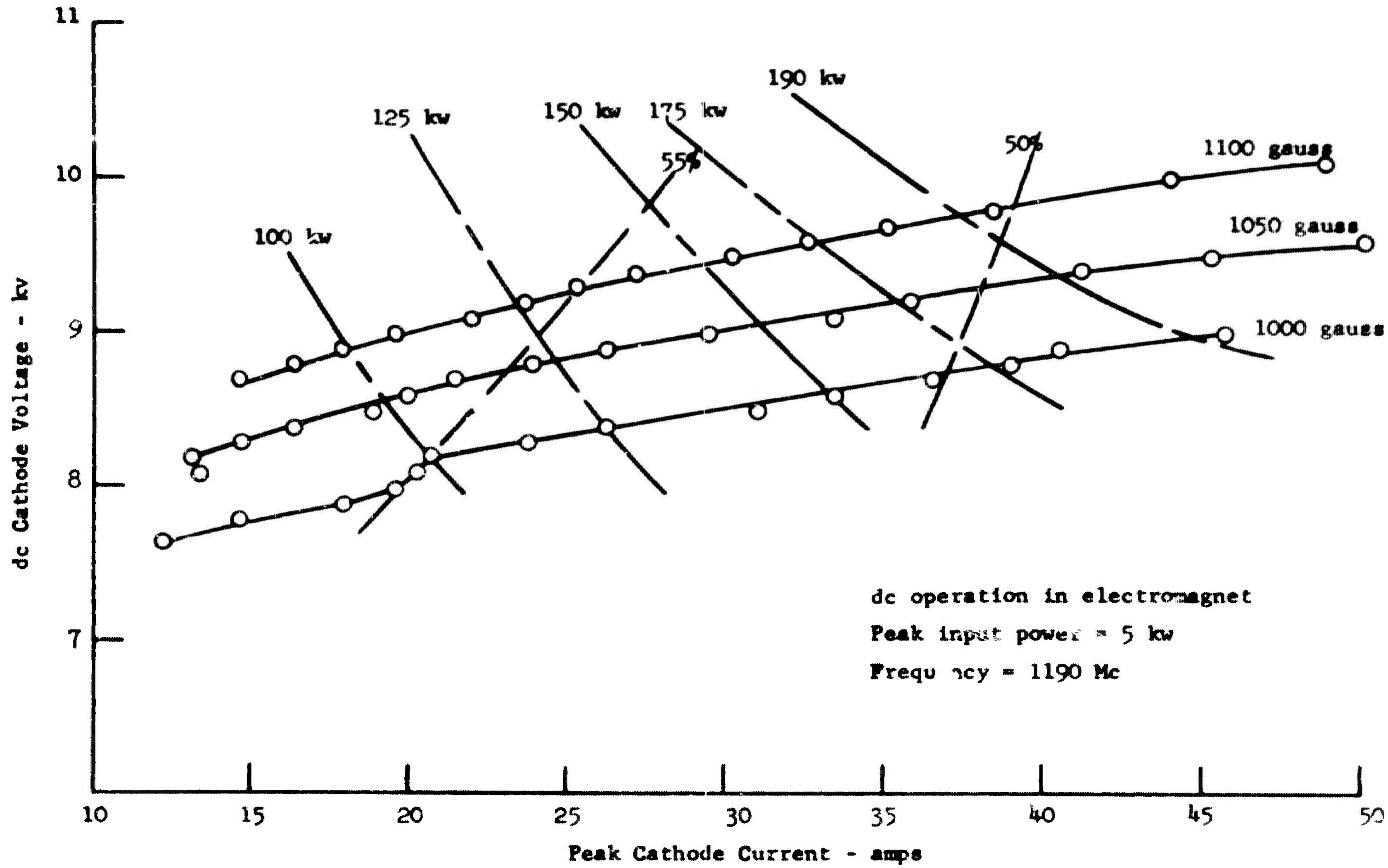

FIGURE 3 PERFORMANCE CHART FOR SFD-209, TUBE D37F

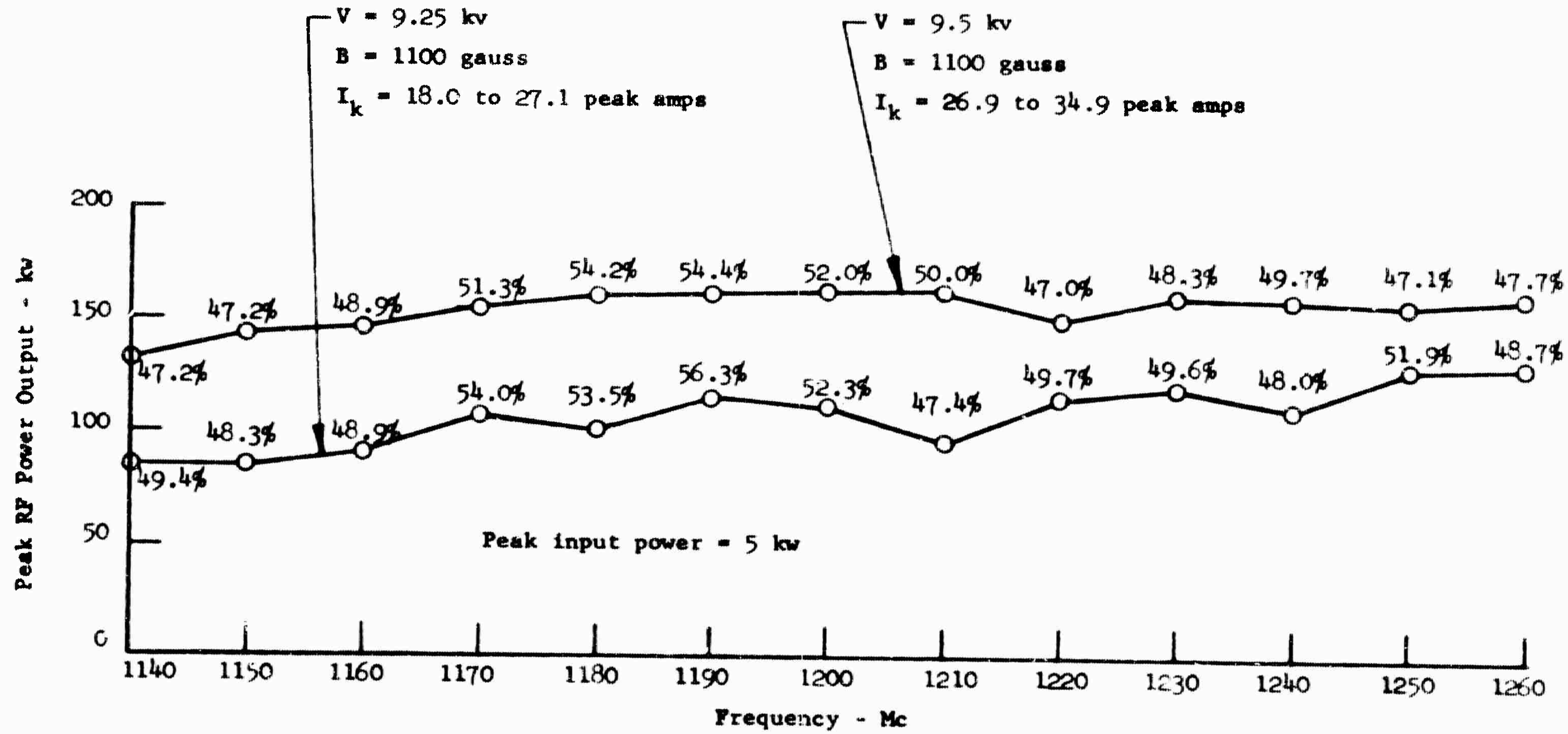

FIGURE 4 OUTPUT POWER VERSUS FREQUENCY AT FIXED ANODE VOLTAGE FOR SFD-209, TUBE D37F

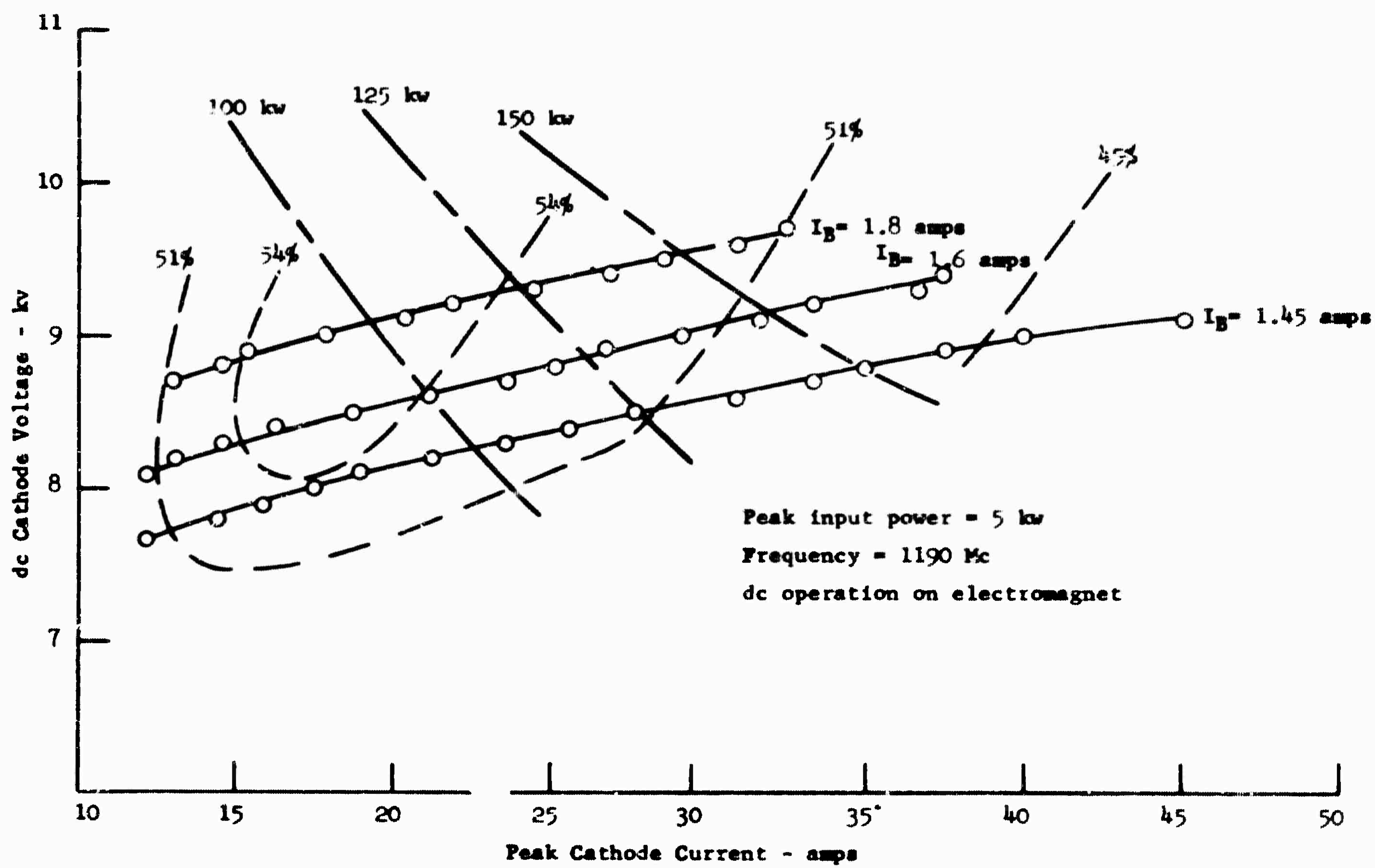

FIGURE 5 PERFORMANCE CHART FOR SFD-209, TUBE F63F

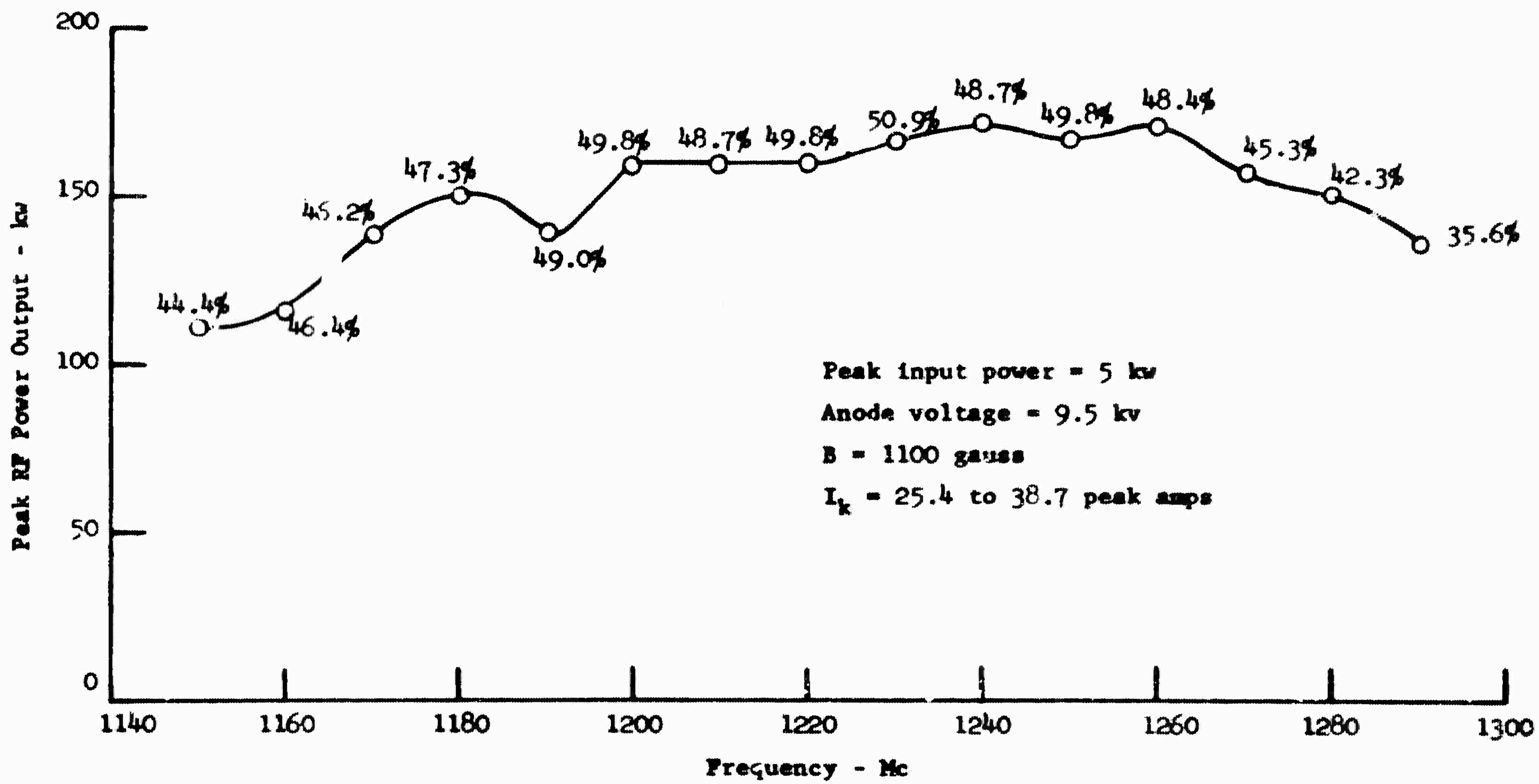

FIGURE 6 OUTPUT POWER VERSUS FREQUENCY AT FIXED ANODE VOLTAGE FOR SFD-209, TUBE F63F

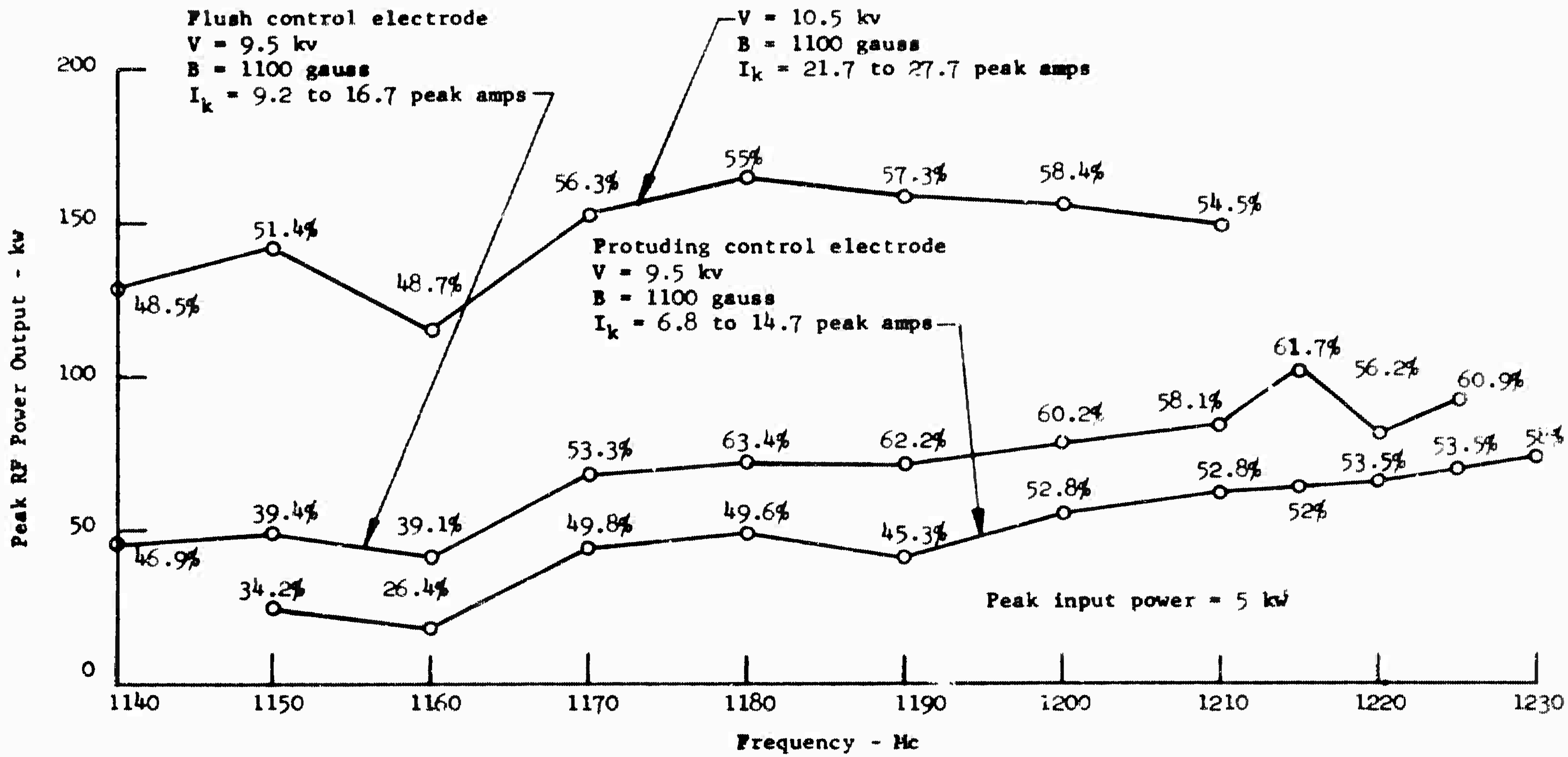

FIGURE 7 OUTPUT POWER VERSUS FREQUENCY AT CONSTANT ANODE VOLTAGE FOR SFD-209, TUBE G35F-1

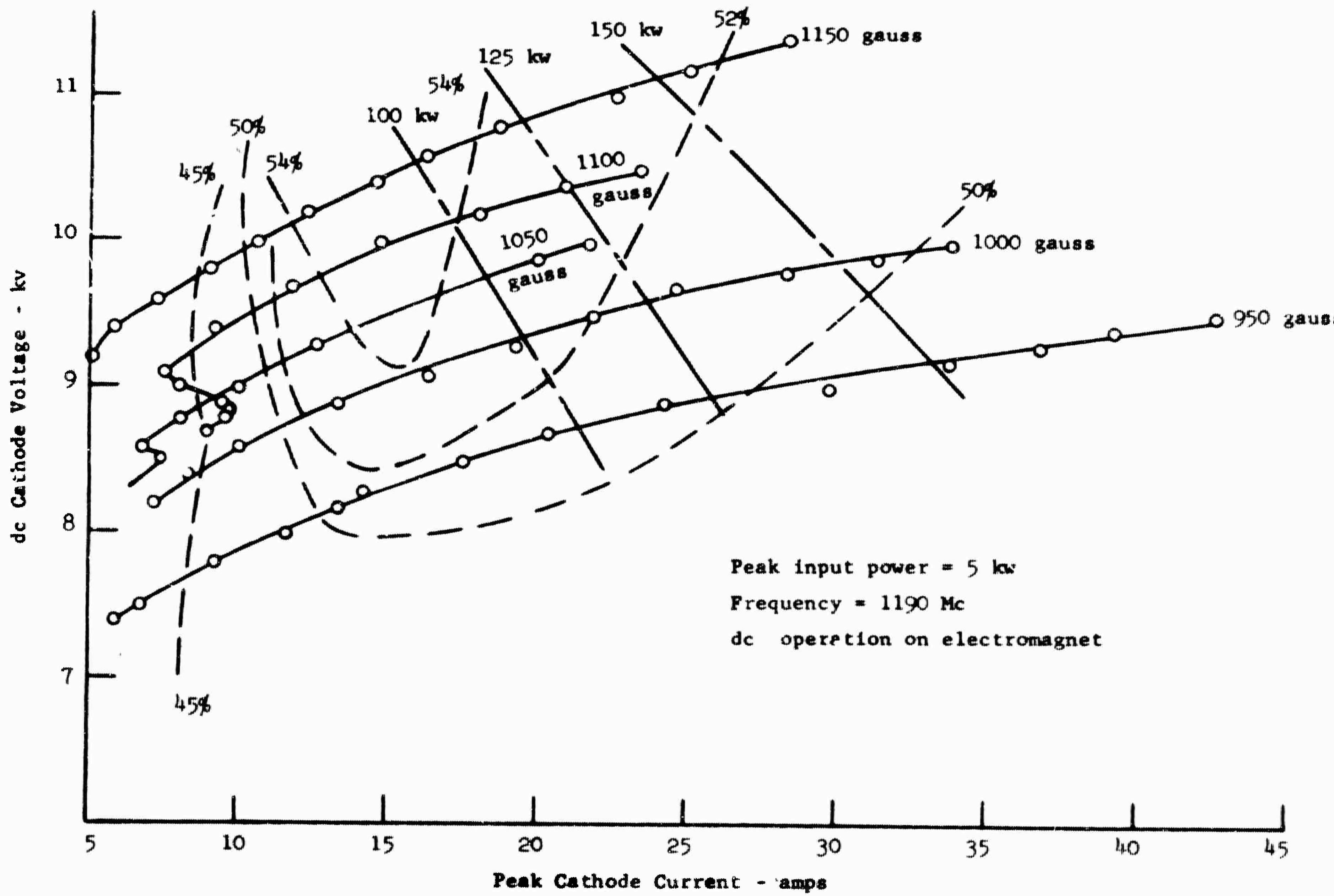

FIGURE 8 PERFORMANCE CHART FOR SFD-209, TUBE G35F-1

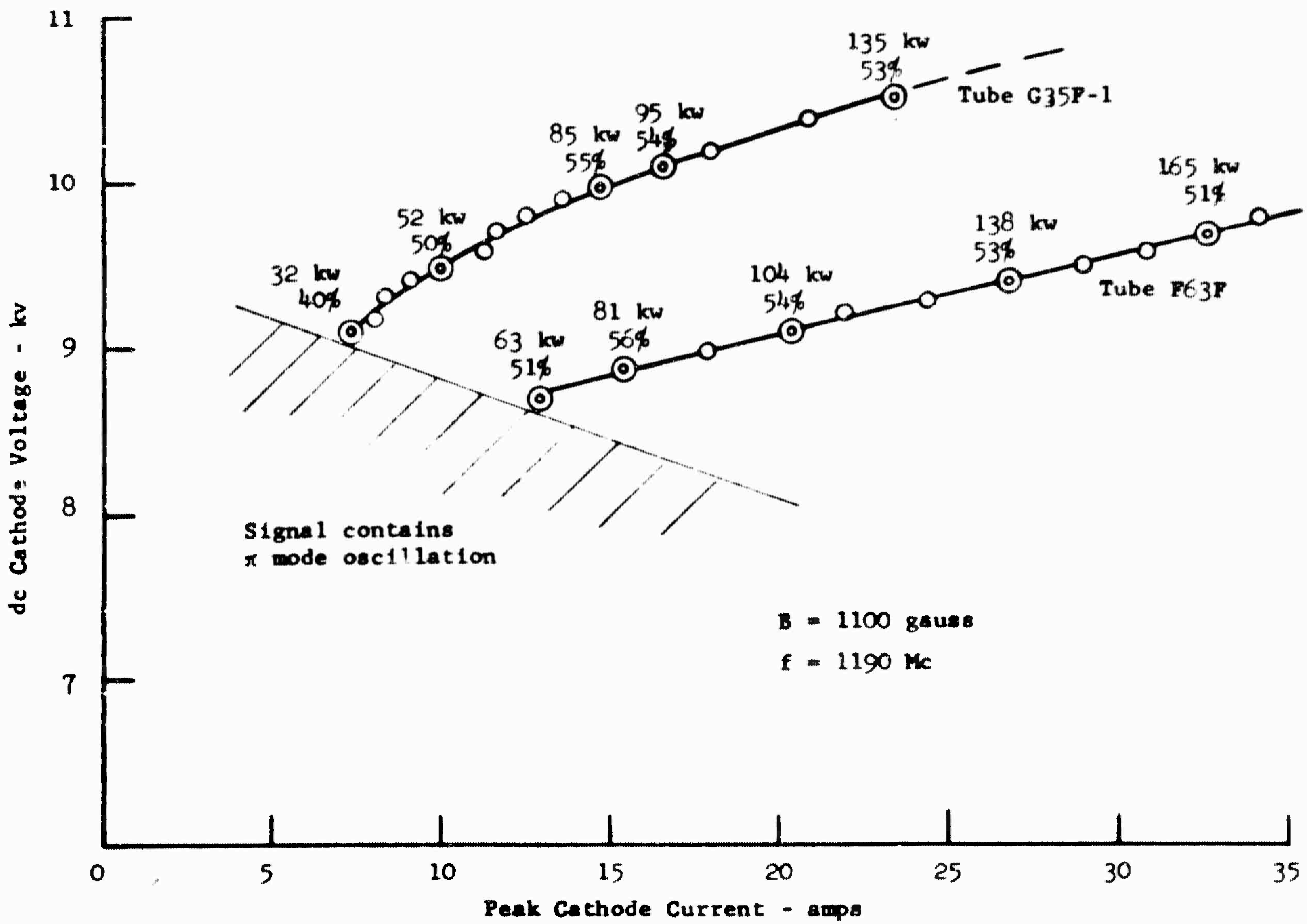

FIGURE 9 COMPARISON OF V-I CURVES OF TUBES F63F and G35F-1 AT 1100 GAUSS. ANODE-CATHODE SPACING IS INCREASED BY 10% IN TUBE G35F-1

under conditions of less separation, the output would contain some π-mode oscillations. It is also seen that, at a given percentage of the characteristic current, the power output and efficiency are approximately the same and, at a given current, the tube with the larger anode-cathode separation operates at a higher voltage. Therefore, the net effect resulting from increased anode-cathode separation, in a given magnetic field, is to move the V-I curve upward toward high voltage and left toward lower current. This shift in operating conditions increases the dynamic operating range by extending the low power region without sacrificing the higher power region.

In an attempt to understand the starting delay and jitter observed in the tubes presently on life test, the starting delay time in tube G35F-1 was studied. The delay time was measured as a function of anode voltage and input power at several magnetic fields. These measurements showed a starting delay of less than 20 nanoseconds for a 5 kw peak input over a 1000 volt range of cathode voltages encompassing the normal operating values. (The delays quoted here are in excess of the pulse envelope transit time through the tube and thus represent a shortening of the pulse as sketched in Figure 10). For lower peak input powers, delays were greater and the range of operating voltage for minimum delay was reduced. At 1 kw peak input drive, the minimum delay was 40 nanoseconds and delays of several tenths of a microsecond were encountered when cathode voltages were raised to the values required for outputs over 100 kw peak.

The minimum delays are believed to occur when electrons are able to pick up enough energy on a single cycloid trajectory during the starting interval to make the secondary emission ratio greater than one. Delays are encountered when this ratio does not exceed unity. Under this condition, an initial interval is required during which space charge is accumulated by the trapping of electrons which give up energy to the RF fields. This stored space charge gradually lengthens the cycloid trajectories until the required energy for unity

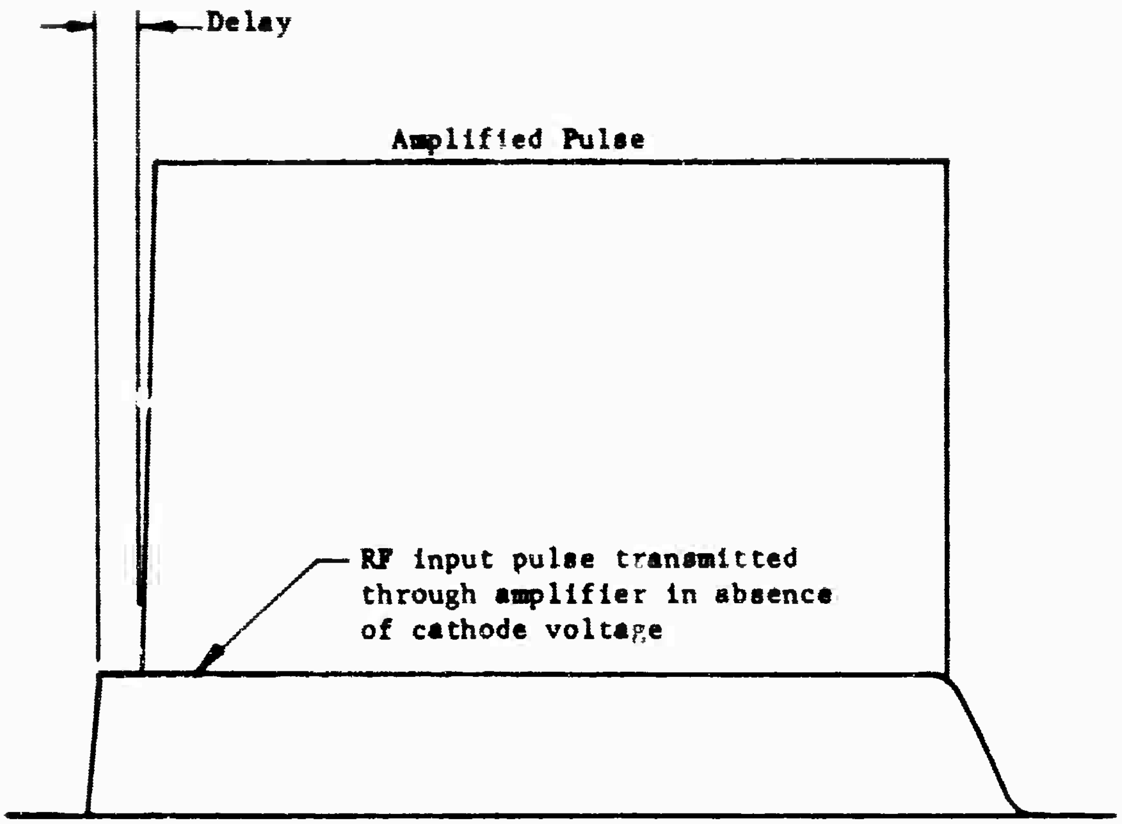

FIGURE 10 PULSE SHAPES OF RF INPUT PULSE AS TRANSMITTED THROUGH TUBE IN ABSENCE OF CATHODE VOLTAGE AND AMPLIFIED RF PULSE WHEN CATHODE VOLTAGE IS APPLIED. STARTING DELAY IS MEASURED AT APPROXIMATELY 85% POINTS. THE AMOUNT OF DELAY IS EXAGGERATED IN THIS SKETCH AND IS ORDINARILY LESS THAN 20 NANOSECONDS

secondary emission ratio can be picked up along a single cycloid trajectory. Once this happens, the tube proceeds to turn on rapidly. This mechanism accounts for the delay interval before starting in which nothing appears to happen followed by the very sudden turn-on. It also accounts for the dependence of delay on peak input power. The dependence on voltage is a consequence of the necessity of the cycloid trajectories along which electron multiplication is occurring, maintaining synchronism with the circuit wave. At the higher cathode voltages, the conditions for synchronism are violated and multiplication can occur along only a few cycloids before the trajectory falls out of synchronism with the circuit wave. Thus, the rough outlines of a satisfactory theory of starting are on hand. This subject will be discussed in more detail in future reports as more data become available.

For our present purposes, it is sufficient to note that starting delays are small under normal operating conditions but can become appreciable (several tenths of a microsecond) at low input powers and high cathode voltages. Under such conditions, the amount of delay is very sensitive to voltage. For the future, it is to be noted that the range of conditions over which delays are negligible can be increased by improving the secondary emission properties of the cathode so that less striking voltage is needed for unity secondary emission ratio. It should also be pointed out that since the delays depend on transit times of electrons, they will scale down proportional to wavelength in higher frequency tubes.

The measurements of starting delay time in tube G35F-1 provide some insight to the behavior of the tubes being life tested. The starting delays observed during life tests can be explained in terms of changes in RF input power and operating voltage. It was mentioned earlier in this report that tube D37F shows no sign of either starting delay or jitter after 750 hours of operation, while the other tubes do have both starting delay and jitter. The simultaneous occurrence of delay and jitter was also observed in other tubes life tested. Thus, there exists a strong possibility that starting jitter will only appear in a tube that has a starting delay. A possible explanation of this lies in external circuit properties and in the sensitivity of delay to voltage under conditions of low RF input drive. Thus, if starting delay occurs on one pulse, less total energy may be drawn from the energy storage capacitor than if no delay had occurred. If external circuit time constants are long enough so that this higher voltage is still applied to the tube at the start of the next pulse, the delay for the next pulse may be even greater. An effect in the opposite direction is the drawing of greater peak current and greater total energy from the storage capacitor for higher cathode voltages. Between these two effects, there may be a tendency for a slight pulse-to-pulse jitter in applied voltage and therefore in starting delay. Proper design of the external circuitry may possibly eliminate jitter though it will not affect starting delay which is a property of the tube itself. This possibility will be studied further when time permits. (Correction of the low power condition on our life test sets has essentially eliminated jitter so the effect is not readily studied on life test at the present time.)

5.0 SECONDARY EMISSION TESTS

A secondary emission tester was set up to evaluate changes in secondary emission ratio which might take place during life. To make it possible to use actual tube parts as the target electrode, the tester was set up in a bell jar vacuum system. To first validate the performance of the secondary emission tester, a molybdenum target was tried. In a succession of experiments, continual difficulty was experienced in obtaining proper results for a molybdenum target. Successive measurements were not reproducible and the targets had shown evidence of discoloration. It was believed that the test surfaces were being contaminated by some substance in the bell jar system. To reduce the possibility of target contamination, the secondary emission tester was mounted in a demountable metal envelope. In a previous program, this type of tester had given satisfactory results for a molybdenum target.

Measurements made in the self-contained secondary emission tester have been reasonably successful. Secondary emission ratios for a molybdenum target have been measured at values reasonably close to the theoretical values. The measurements have been reproducible and the target did not become discolored. Typical results are shown in Figure 11. An alumirum target was tried next. The aluminum target received basically the same treatment as a cathode for a tube. The results of secondary emission measurements on this target are also shown in Figure 11. The maximum secondary emission ratio measured for the aluminum target was 2.2. This value might be considered to be high, but since the surface of the target is not pure aluminum but an aluminum oxide, a ratio of over 2 is not unreasonable. Further tests will be made to verify this result and some additional materials will also be tested in this manner. The tester will then be employed for its original purpose of examining surfaces removed from tubes on life test.

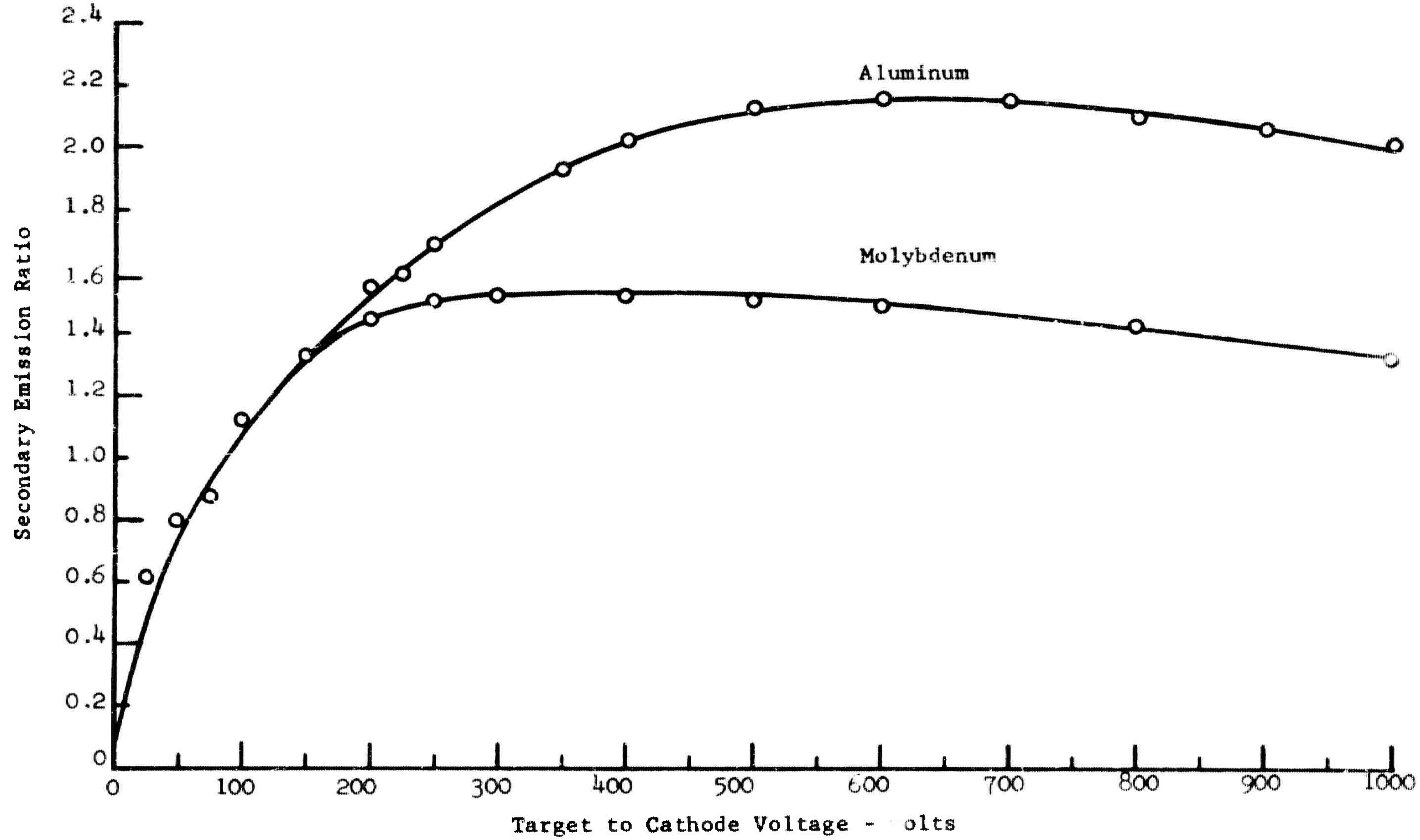

FIGURE 11 MEASURED SECONDARY EMISSION RATIOS FOR ALUMINUM AND MOLYBDENUM AS A FUNCTION OF STRIKING POTENTIAL

6.0 CONCLUSIONS

Conclusions which may be drawn from the effort during this quarter are:

1. The reproducibility of characteristics appears to be good. (See Figure 1)

2. The improved heat transfer from the control electrode in tube D37F appears to have alleviated the starting jitter problem (a tentative conclusion).

3. A slight increase in anode-to-cathode spacing decreases the tendency to oscillate at low anode currents.

7.0 PROGRAM FOR NEXT QUARTER

1. Complete construction and characterization of Group D tubes.
2. Continue life tests and evaluate failures.
3. Start phase measurements.
4. Investigate average power capability of the design.

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