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MAGNETIC FIELD EFFECTS IN HYDROGEN THYRATRONS*

by

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I. INTRODUCTION

Modern high-power systems are imposing more and more stringent requirements on the hydrogen thyratron. Higher peak and average power levels, tighter anode delay-time stability, higher anode hold-off voltages, and faster repetition rates are some of the performance characteristics that are now required.

One potential means of improving existing hydrogen thyratron performance, which has been under investigation at the Stanford Linear Accelerator Center, is the use of weak magnetic fields to control breakdown characteristics. Limited tests to date have been made on thyratrons from the 5C22 variety to the larger gradient grid tubes, such as the Tung-Sol CH 1191 and the I.T.T. KU-275A. The latter two tubes are the thyratrons used in the two-mile accelerator and are referred to as "SLAC tubes" in this paper.

II. ANODE VOLTAGE

The maximum anode hold-off voltage can be increased as much as 35% in some tube types. In the thyratrons tested to date, the maximum anode voltage at the center reservoir point is controlled by the voltage distribution from anode to cathode, or field penetration from the anode into the cathode region, rather than by anode grid breakdown or Paschen breakdown. In general, electrons from the cathode are attracted through the control grid structure to the anode by the weak anode field that penetrates the control grid and cathode baffling. As the anode voltage is raised, a critical grid current or plasma density is reached at the control grid aperture, which initiates the cumulative breakdown process, and the switch tube commutates or fires through. If the baffling in a given tube is tight, better anode hold-off and recovery characteristics are obtained; however, tight baffling increases the triggering requirements, grid dissipation, and anode delay time so that the grid structure and baffle structure must be optimized for the best overall tube performance.

For a given grid and baffle configuration, the required grid voltage or anode field penetration necessary to initiate ionization of the grid cathode space may be controlled by applying a transverse magnetic field. Most of the tests conducted at Stanford have utilized permanent magnets for this controlling field. In general, electrons emitted from the cathode in an electric field with a transverse magnetic field move in a series of cycloid paths. If the transverse field is strong enough for a given electric field in the cathode region, the electrons are prevented from acquiring sufficient velocity to cause ionization.

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Figure 1 shows a plot of maximum electron energy attained in a uniform electric field of 100 volts/cm with a transverse magnetic field in a vacuum. This curve would have to be modified in the presence of gas molecules due to collisions between the electrons and the molecules which, in turn, are controlled by gas pressure. To date we have not had a means of measuring hydrogen pressure; in addition, most existing hydrogen thyratrons are constructed with some ferrous alloys which affect the magnetic field configuration. Tubes with Pirani gauges mounted on them for measuring tube pressure are on order, as are some tubes constructed of non-magnetic materials.

Figure 2 is a plot of the grid breakdown characteristics ($E_{py} = 0$) of a SLAC thyratron with and without transverse magnetic fields. This particular tube was used because there is comparatively little magnetic material in the gap region. Note that the grid voltage required to break down the grid-cathode space is at least four times greater with a field of 165 gauss than without a magnetic field. When the grid-cathode space breaks down, the steady-state plasma drop is higher with a magnetic field. This increase in grid-cathode drop or plasma drop is probably caused by a modification of the electron/ion trajectories when acted on by the magnetic field, which in turn alters the plasma neutralization and causes an increase in plasma drop.

Figure 3 shows the maximum dc hold-off voltage vs. reservoir voltage with and without a transverse magnetic field in a 5949 tube. The required magnetic field is higher in the 5949 than it was in the KU-275A, probably due to the coaxial nickel-iron construction which shunts the field out of the control grid gap region. It is possible that like results could be achieved with lower magnetic fields if the tube were made of non-magnetic materials.

Figure 4 is a plot of anode delay time vs. control grid keep-alive current for a 5949 tube with a 600-gauss field and with no magnetic field. The drive voltage is 1200 volts with a 25-ohm source impedance. The peak charging voltage is 10 kV; the peak current is 100 amps. The critical grid current in this graph is that positive dc current which will cause a tube to go into continuous conduction. As can be seen, considerably more grid current can be drawn with a magnetic field before this critical point is reached than is possible without. This is probably due to the fact that the plasma due to grid current is being deflected away from the control grid aperture so that the anode breakdown phenomena is not initiated. In addition, there is a substantial margin between the control grid current required for time stabilization and the critical grid current with a magnetic field. However, with no magnetic field present, the grid current for good time stabilization approaches critical grid current, so that control grid keep-alive operation without a magnetic field is not too practical if maximum time stability and maximum anode hold-off voltage are required.

The critical control grid keep-alive current with a 600-gauss field and 43-kV peak anode voltage was approximately 400 mA, so there is an adequate safety margin between this current and that required for good time stabilization (100 mA). The anode fall time, or ionization time, was approximately 80 nanoseconds either with or without a magnetic field of 600 gauss. In pulse operation at 40 pps, with 15 milliamperes of control grid keep-alive current, the maximum charging voltage on the 5949 tube was 48 kV. At this voltage, the tube arced over the surface of the glass. This tube was run at 42 kV, with one ampere average current and 2400 amperes peak current, for 6 hours before the cathode pin seal on the base opened up. (The maximum peak charging voltage without magnetic field and without positive control grid keep-alive current was 33 kV.)

Figure 5 shows anode delay time vs. control grid keep-alive current with a 600-gauss field, 43-kV charging voltage, 2400 amperes peak power, and 1.5 amperes average power. The increase in the minimum delay time from 60 nanoseconds to 80 nanoseconds, as shown in Fig. 4, is probably caused by the change in the inner electrode spacing due to thermal effects at the high-power level.

Figure 6 shows dc hold-off voltage vs. reservoir voltage with and without a 65-gauss transverse field in a 7390 tube. The relatively weak magnetic field required to accomplish the increase in reliable hold-off voltage is probably explained by the fact that there is very little magnetic material in the grid gap region.

Figure 7 is a plot of keep-alive current vs. anode delay time variation for the 7390 tube in pulse operation at 24 kV charging voltage, 60 pps, with and without magnetic field.

Figure 8 is a plot of keep-alive current vs. anode delay time variation at 43 kV charging voltage, with a 65-gauss transverse field. The 7390 tube would snap on at 45 kV with such a field; however, the maximum snap-on voltage without a magnetic field was 33 kV.

III. REQUIRED RECOVERY TIME

Some tests have been made at Stanford on the maximum anode voltage rate of rise as affected by magnetic field. It appears from these tests that it is possible to increase the rate of rise of anode voltage and decrease the required recovery time.

Figure 9 is a photograph of the post-pulse condition with a 150-μsec rise time and a 40-μsec recovery time with 15 μsec of inverse voltage recovery time using a thyratron. The switch tube would snap on and operate at 30-kV peak charging voltage without a magnetic field and would operate and snap on at 40 kV with a 165-gauss transverse field in a positive match condition. This tube would not operate above 20 kV with a field in a negative match mode. It is conceivable that a stronger magnetic field with this rate of rise would allow satisfactory operation, although no further investigation has been made to date. This, of course, would allow higher pulse repetition rates for a given tube.

IV. AXIAL FIELDS

The foregoing work has been with transverse magnetic fields, but some work has been done with axial magnetic fields to reduce ionization time or anode fall time.

In the 5949 tube, the anode fall time was reduced from a nominal 80 nanoseconds to less than 8 nanoseconds using an axial field of approximately 160 gauss. If an axial field is used through the control and grid-cathode region, source degeneration in the maximum hold-off voltage occurs.

In the SLAC tubes, the combination of an axial field in the grid gaps for fast ionization and a transverse field in the grid cathode region was used. The anode fall time was reduced from 50 nanoseconds to 20 nanoseconds with good time stability and anode voltage hold-off.

It appears that axial fields could be used where fast rise time pulses are required. However, further investigation on the effects of axial fields needs to be done.

V. CONCLUSIONS

In order to take full advantage of magnetic focusing, tubes should be built with non-magnetic materials. If control grid structures were optimized for use with magnetic fields, a higher average current for a given grid dissipation could be achieved. Higher anode hold-off voltages for a given tube can be obtained through the use of transverse magnetic fields. Improved delay time stability can be obtained on existing hydrogen thyratrons when control grid keep-alive current is used in conjunction with magnetic fields. Less required recovery time and higher pulse repetition rates can be obtained with magnetic focusing on existing thyratrons.

A combination of axial and transverse fields may be used for fast ionization at maximum anode voltage.

The information presented in this paper summarizes what has been observed using existing hydrogen thyratrons. However, we feel that much better results can be achieved with tubes built to take advantage of the magnetic field effects. Such tubes should exhibit better life, higher anode hold-off voltages, higher average currents, higher pulse repetition rates, faster rise times, and better time stability.

ACKNOWLEDGEMENTS

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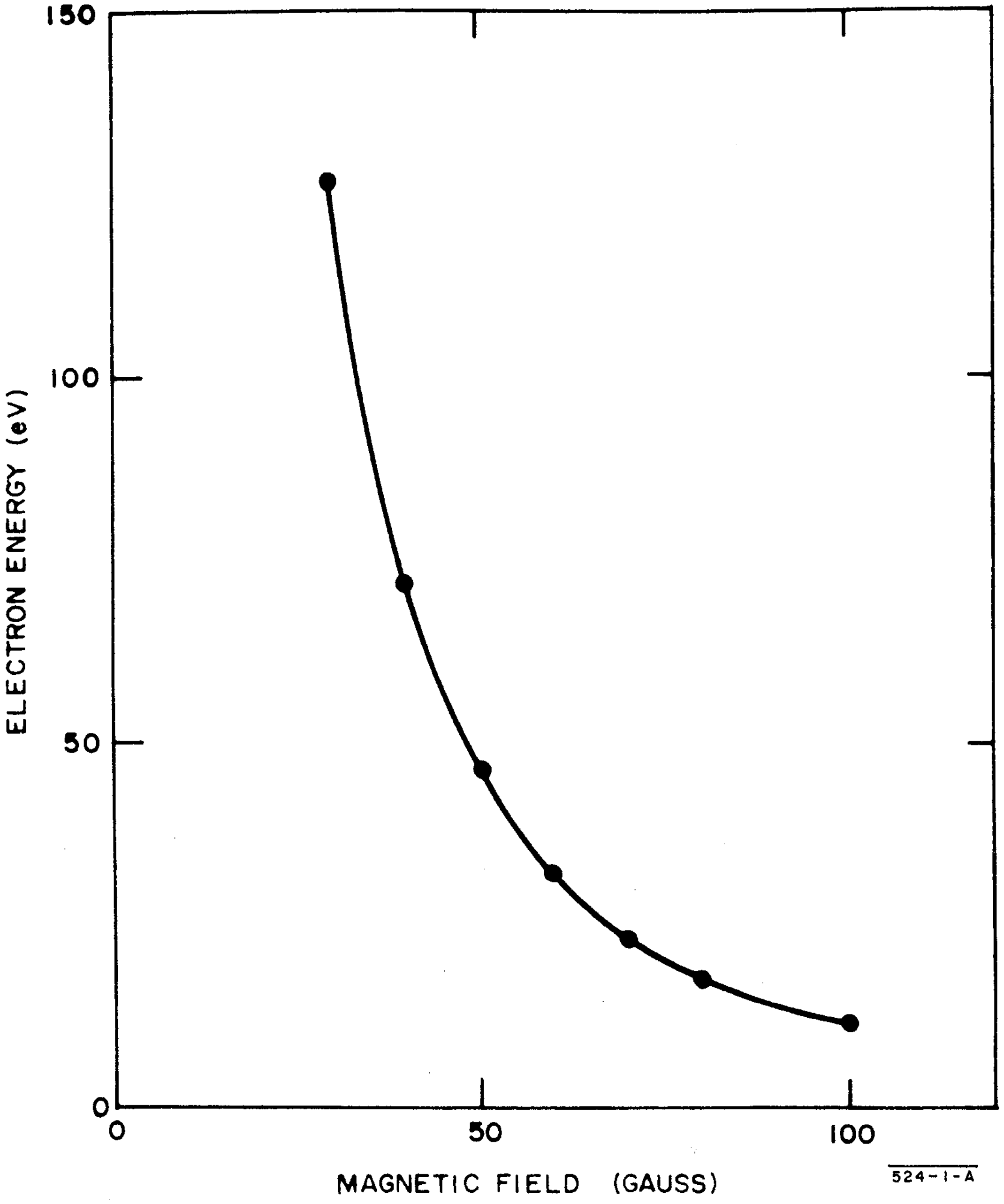


FIGURE 1 - MAXIMUM ENERGY ACQUIRED BY AN ELECTRON IN A UNIFORM ELECTRIC FIELD OF 100 VOLTS /cm WITH A CROSSED MAGNETIC FIELD.

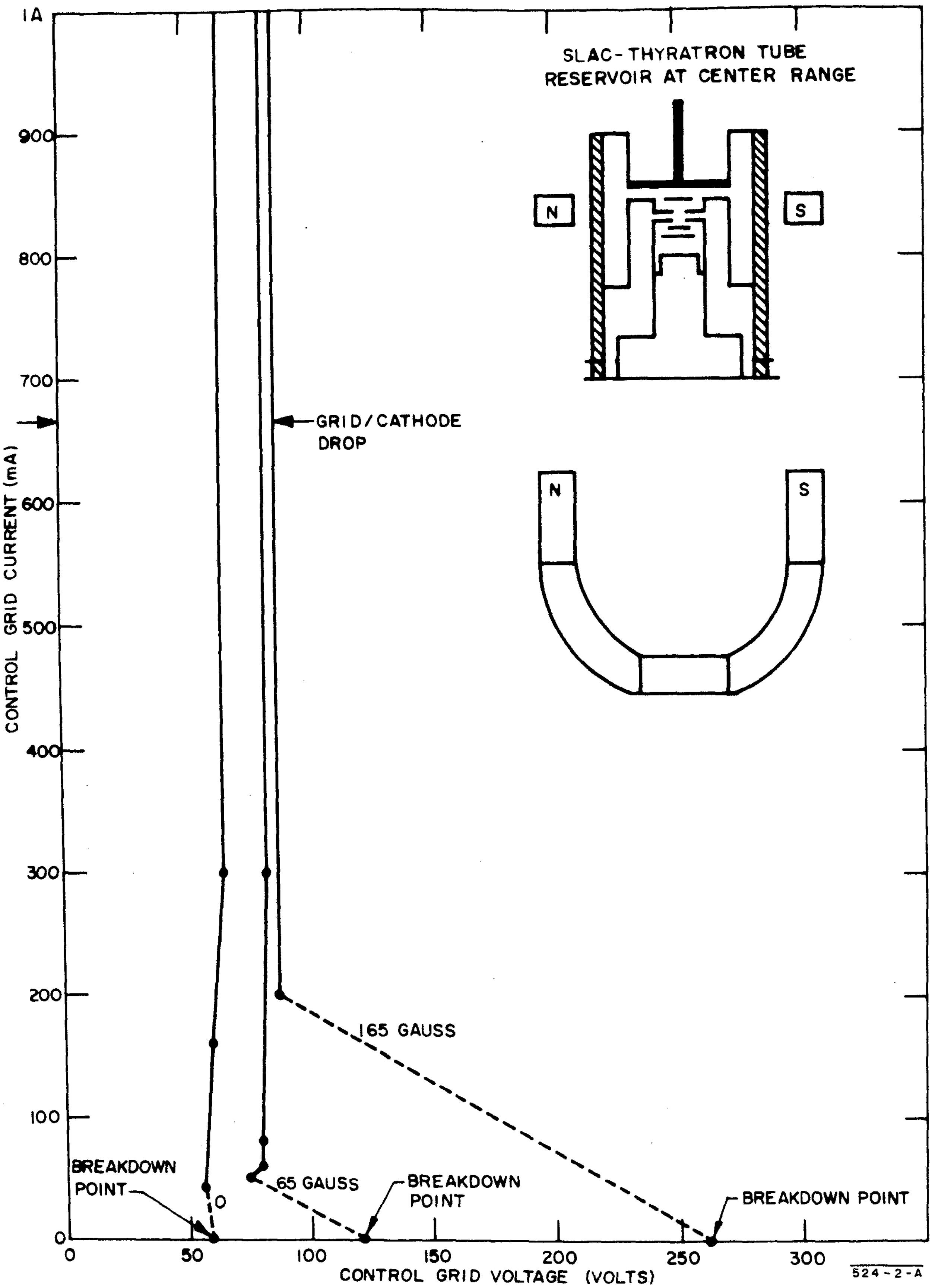


FIGURE 2- CONTROL GRID CHARACTERISTICS FOR VARIOUS MAGNETIC FIELDS

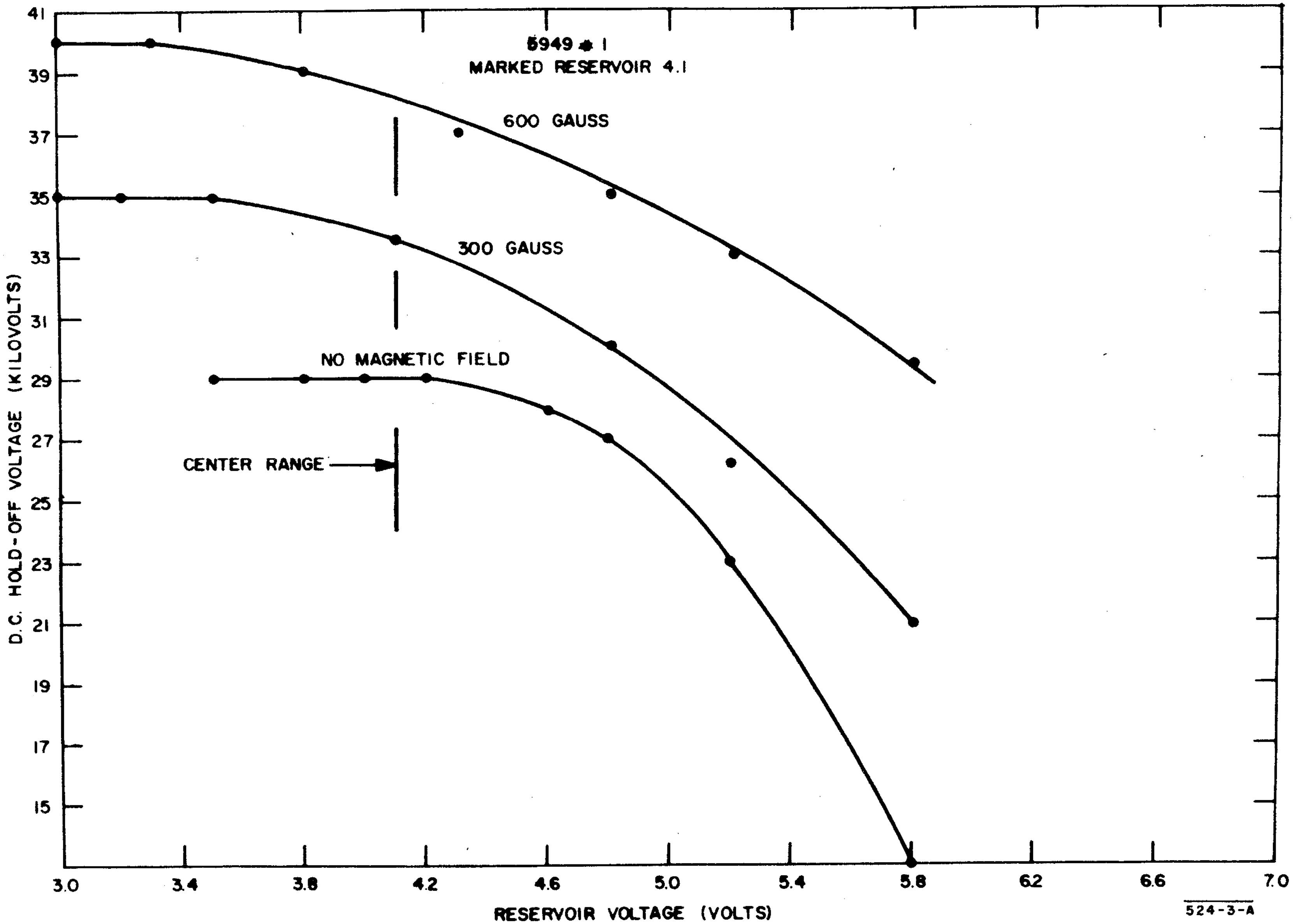


FIGURE 3 - DC HOLD-OFF VOLTAGE VS RESERVOIR VOLTAGE FOR VARIOUS MAGNETIC FIELDS

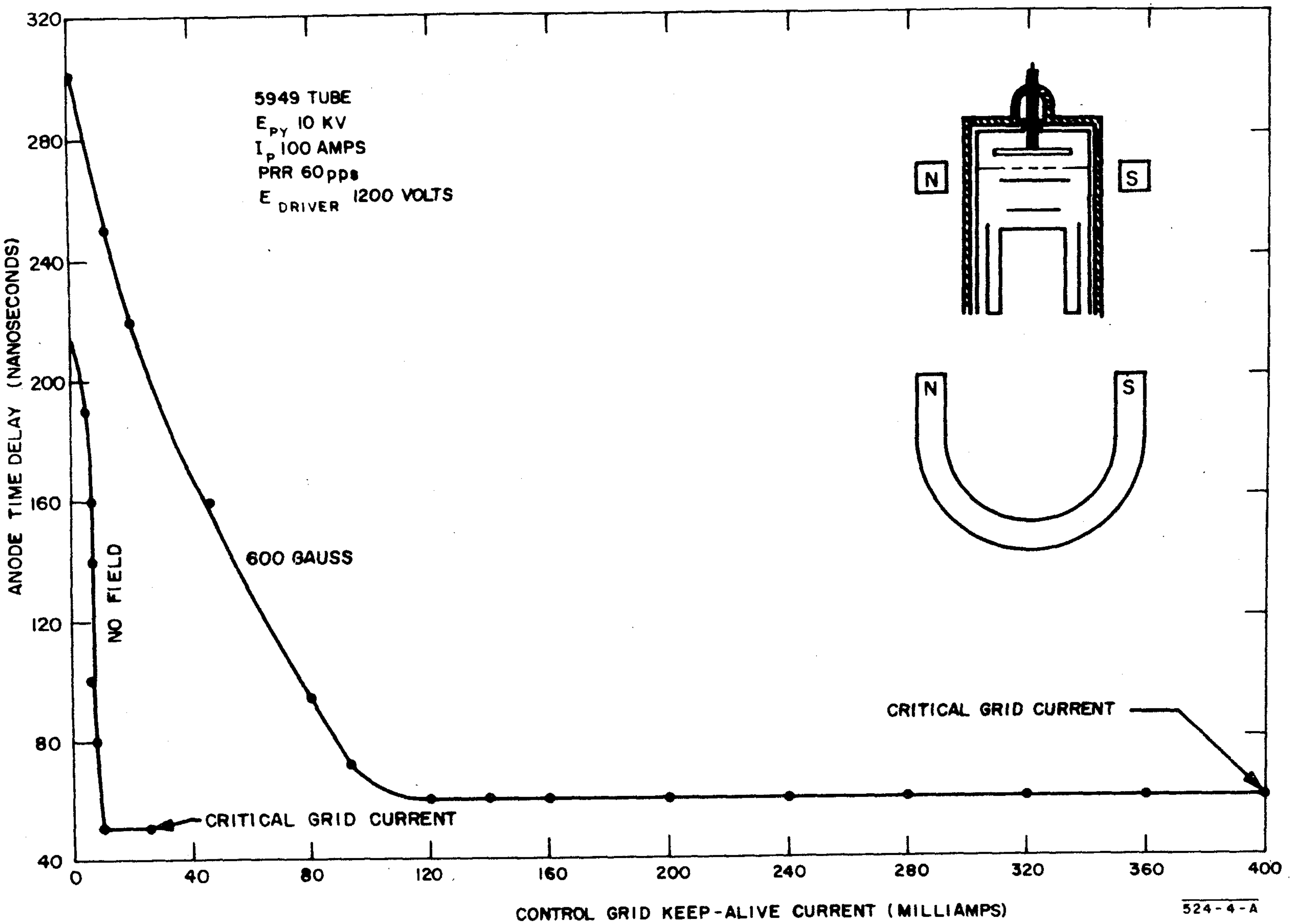


FIGURE 4 ANODE TIME DELAY VS CONTROL GRID CURRENT WITH AND WITHOUT MAGNETIC FIELD (LOW POWER LEVEL)

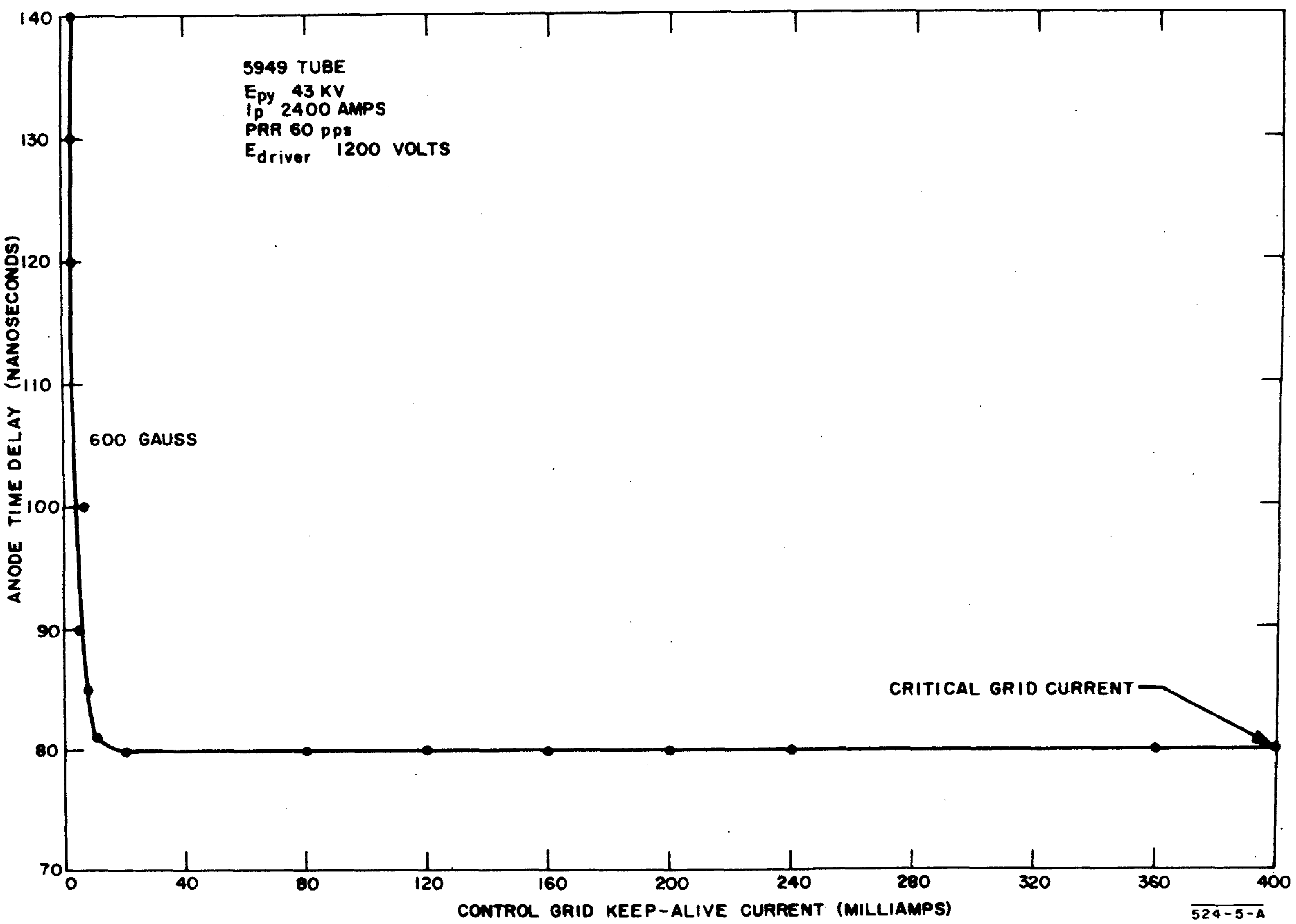


FIGURE 5 - ANODE TIME DELAY VS CONTROL GRID CURRENT (HIGH POWER LEVEL)

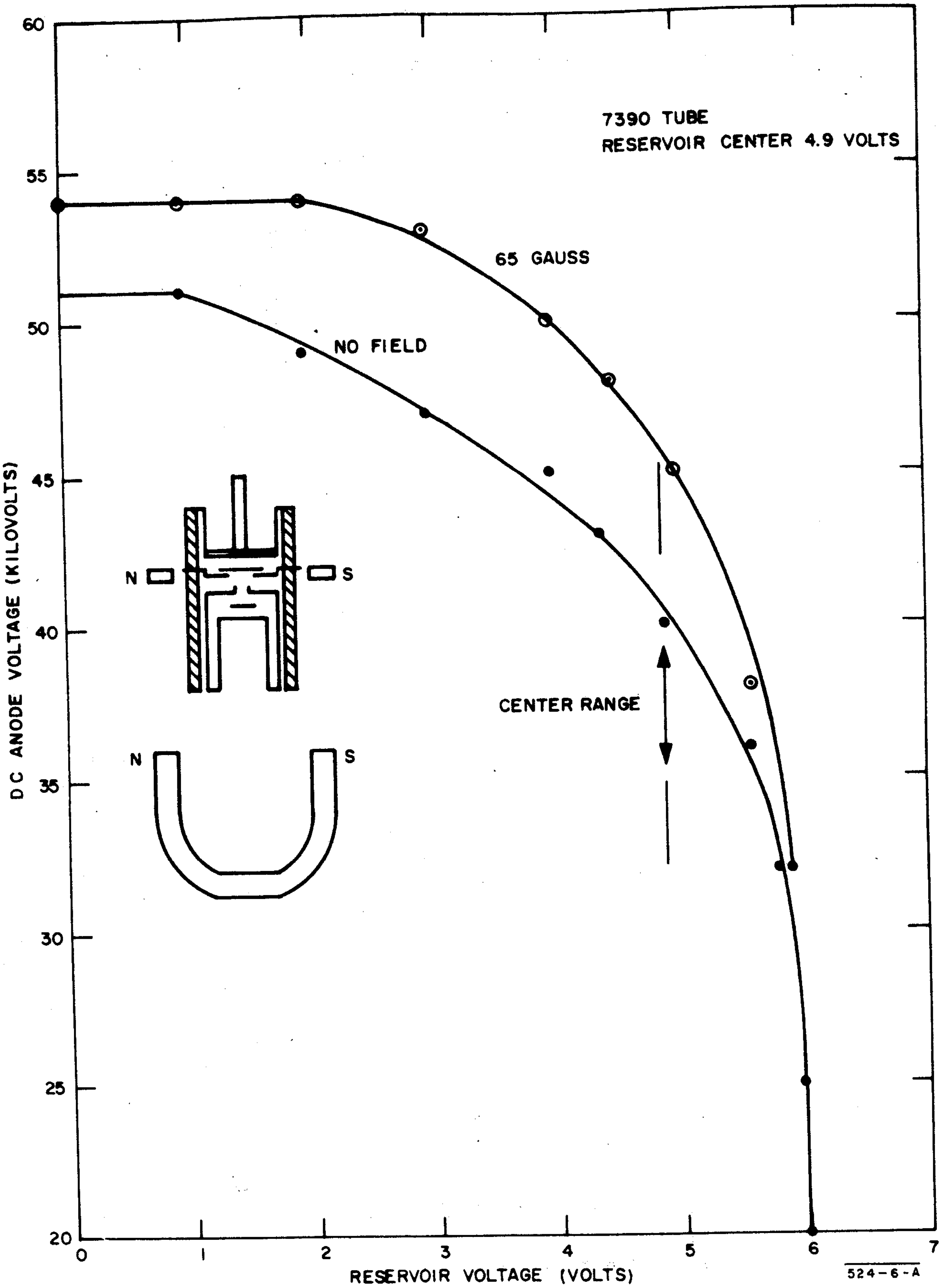


FIGURE 6 – D C HOLD-OFF VOLTAGE VS RESERVOIR VOLTAGE WITH AND WITHOUT MAGNETIC FIELD

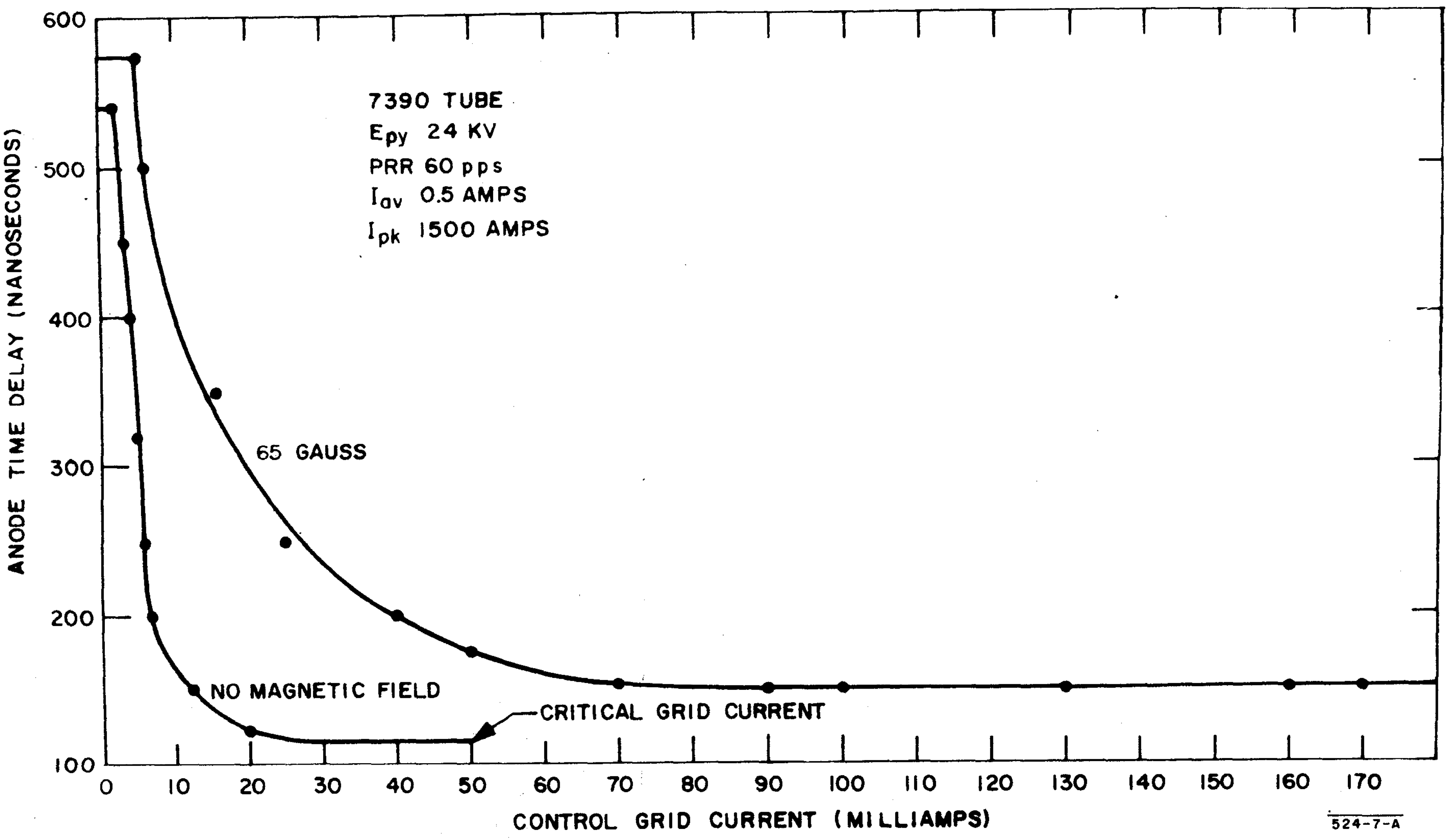


FIGURE 7 – ANODE TIME DELAY VS CONTROL GRID CURRENT WITH AND WITHOUT MAGNETIC FIELD

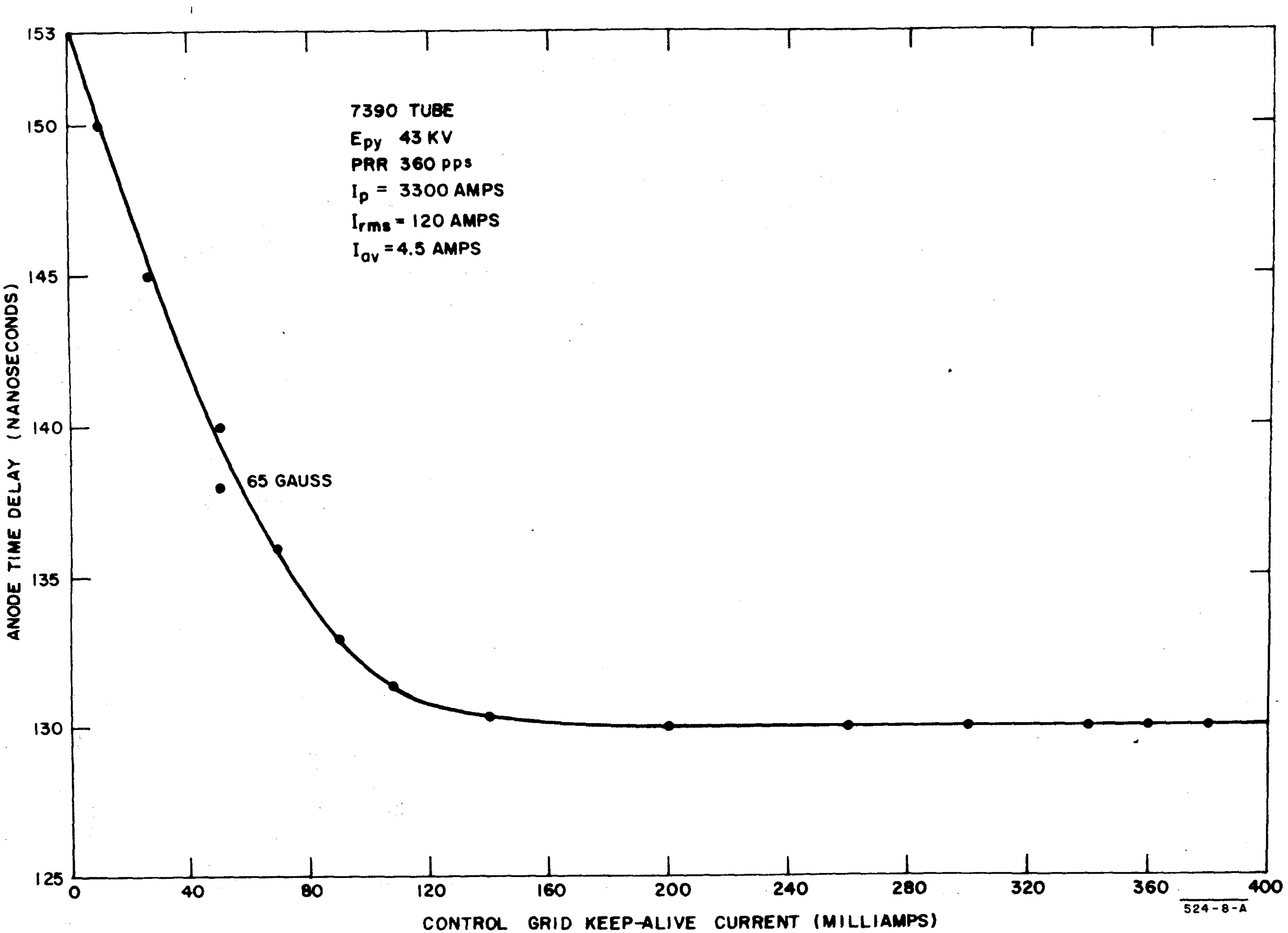
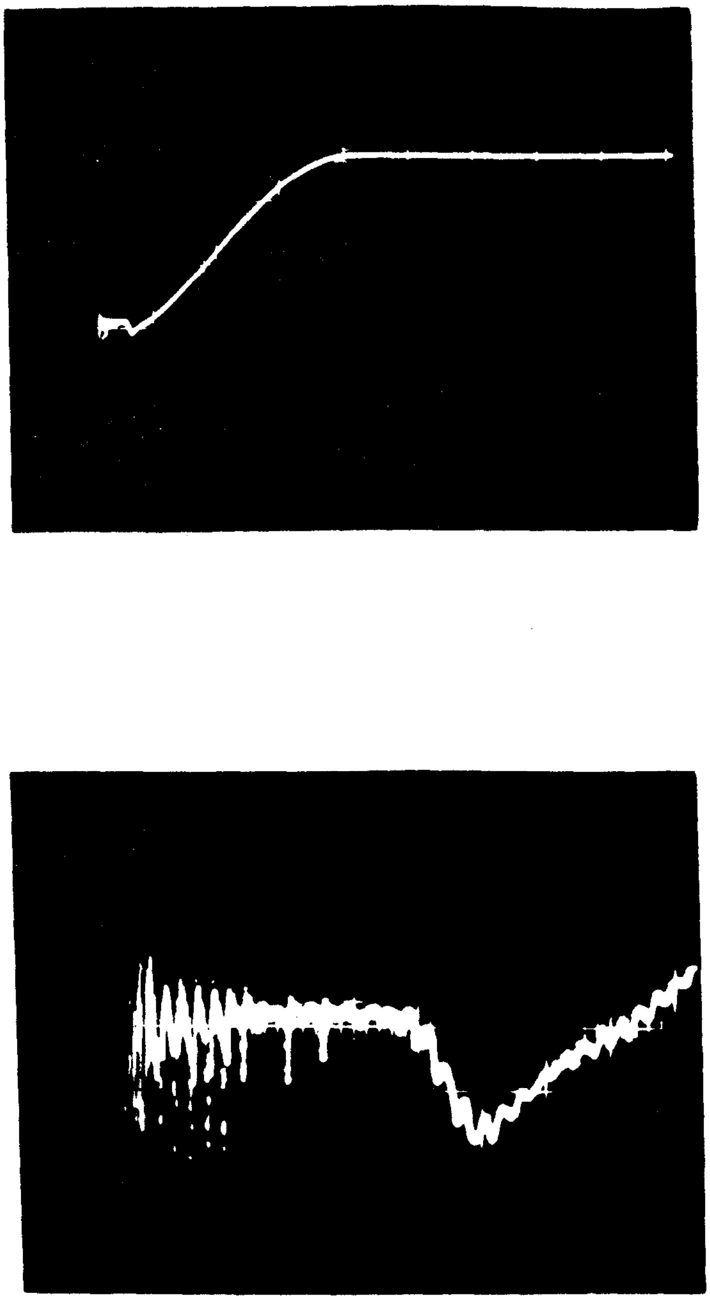


FIGURE 8 - ANODE TIME DELAY VS CONTROL GRID KEEP-ALIVE CURRENT FOR A 7390 TUBE AT FULL SLAC POWER



50 µsec / cm
15 KV / cm
E_{py} 40 KV
PRR 40 pps

1 KV / cm
5 µsec/cm
E_{py} 40 KV
I_{AV} 1.2 AMPS
PRR 40 pps
NO FIELD

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FIGURE 9 - ANODE POST-PULSE CONDITION FOR A KU275A THYRATRON WITH A 150-MICROSECOND CHARGING TIME.