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# DEIONIZATION MEASUREMENTS OF GRID-CONTROLLED THYRATRONS

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RESEARCH LABORATORY OF ELECTRONICS  
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Abstract

This paper describes a method of evaluating the deionization time of thyratrons by means of an accurately calibrated time sweep. The apparatus permits precise control of each of the pertinent parameters, such as the amplitude and duration of the currents and voltages during the conduction and post-conduction periods. The effect of the nature of the enclosed gas upon the deionization time is presented by a study of thyratrons containing argon, hydrogen, mercury vapor and xenon gas as the active elements. The individual effects of each of the parameters in the tube and of the associated tube circuit are illustrated by suitable graphical plots. Finally, the relative merits of many commercial tubes operating under typical dynamic conditions are summarized by comparative graphs which illustrate the corresponding deionization times.



# DEIONIZATION MEASUREMENTS OF GRID-CONTROLLED THYRATRONS

## I. Introduction

Deionization time is defined as the length of time from the cessation of the anode current in a thyatron until sufficient recombination and diffusion of the ions and electrons has occurred to permit the grid to regain control. This period of time is influenced by such factors as the applied negative grid voltage, the grid circuit parameters, the anode current, the anode voltage, the nature of the enclosed gas, the gas pressure and the electrode dimensions and orientation. Furthermore, this time is also strongly influenced by the rate of rise of the reapplied anode voltage.

A capacitor-discharge circuit is used in the conventional methods of measurement of deionization time (1). Such a circuit assumes a constant reignition voltage, is a function of the discharge capacitor, ignores positive-ion current and requires numerical computation for the evaluation of the deionization time. In this type of circuit, the rate of rise of the reapplied anode voltage is not a constant but is a function of the discharge parameters. Obviously, such a method of measurement is not quite satisfactory.

Since the deionization time varies with many parameters, it is essential to know the exact conditions under which the measurements are made. Therefore, successive tests, under identical conditions in which only one parameter is changed, are necessary for correct interpretation of this parameter variation. In making these tests the method of measurement must be a rapid one, as the number of parameters is large.

## II. Experimental Apparatus and Method of Measurement

A circuit diagram illustrating the layout of electrical equipment and the anode voltage and current waveforms of the test thyatron V1 is shown in Figure 1. The deionization time is defined as the time interval between the cessation of anode current at  $t_1$  and the minimum time  $t_2$  at which the anode voltage may be reapplied to V1 without its going into continual conduction.

In this circuit the synchronizer controls the sequence of all operations. Trigger T1, supplied by the Model 5 synchroscope, fires the thyatron V1 and initiates the discharge of a current pulse, the duration of which is determined by the pulse-forming network (hereafter referred to as the PFN) (2). The anode voltage during the current pulse is a constant-amplitude, negative or positive voltage determined by the impedance match between the PFN and the load resistance  $R_L$ . The anode voltage remains at this constant value until some specified time later when the variable-delay



The deionization measurements are obtained in the following way.

1. A constant-temperature oil bath is used to insure constant gas pressure.
2. The PFN impedance and the load impedance are adjusted to provide the desired anode voltage during the post-conduction period.
3. The supply voltage is adjusted to provide the selected value of arc current.
4. The grid circuit parameter is assigned.
5. The value of deionization time is measured for various values of applied grid voltage.

A curve which relates the deionization time and the applied grid voltage is therefore obtained. The magnitude of one of the variables, e.g.,  $R_g$ , is then changed by a desired amount and the process is repeated. Thus a family of curves is attained with one of the variables as a parameter.

### III. Deionization Time of the Hydrogen Thyratrons

In this investigation, thyratrons containing argon, hydrogen, mercury vapor and xenon gas were tested. Of these, the hydrogen thyatron had the shortest deionization time. Pure hydrogen has a high electron mobility and a low ionization. These properties were advantageous in the construction of switching devices for radar application and resulted in the development of one hydrogen thyatron.\*

In order to permit a direct comparison of the effects of the different factors upon the deionization time, the same 3C45 hydrogen thyatron was tested under a number of only slightly different conditions. The effect of grid resistance upon the deionization time is illustrated in Figure 2. The large values of grid resistance limit the positive-ion current flow from the grid-cathode region during the post-conduction period. A further reduction in deionization time is effected by the use of the proper value of grid inductance, as shown in Figure 3. A large grid bias and a low grid impedance provide a large inverse grid current and a low deionization time. Corresponding to the grid inductance of 1, 5, and 10 mh, the maximum grid currents are 180, 75 and 50 ma, respectively. It is evident, therefore, that a compromise is necessary between the maximum allowable grid current and the minimum deionization time.

The effect of the anode current upon the deionization time is shown in Figure 4. As the arc current is increased, the positive-ion concentration is increased, with a resulting increase in the deionization time.

Although the presence of a negative voltage at the anode during the

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\* K. J. Germeshausen of M.I.T. is largely responsible for the design and development of the hydrogen thyratrons.

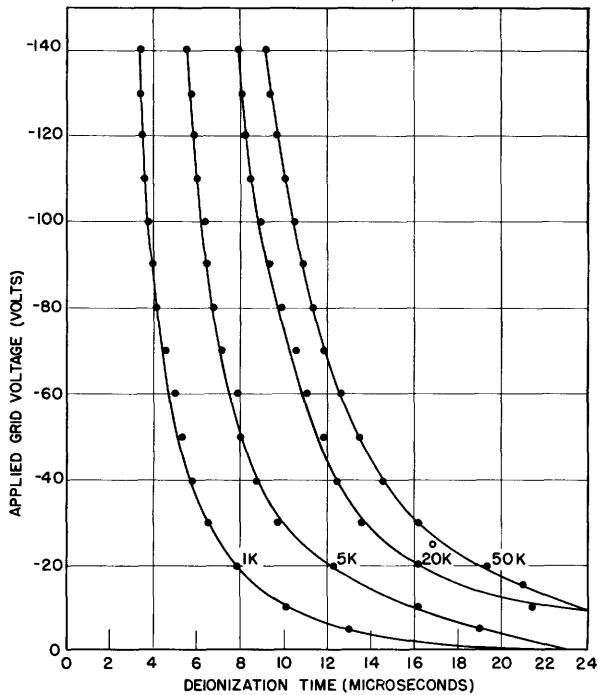


Fig. 2 Influence of grid resistance upon the deionization time. Sylvania 3C45: anode voltage, 900 volts; anode current, 10 amp; repetition frequency, 1000 cps; pulse duration, 1  $\mu$ sec; gas pressure, 480 microns; gas, hydrogen

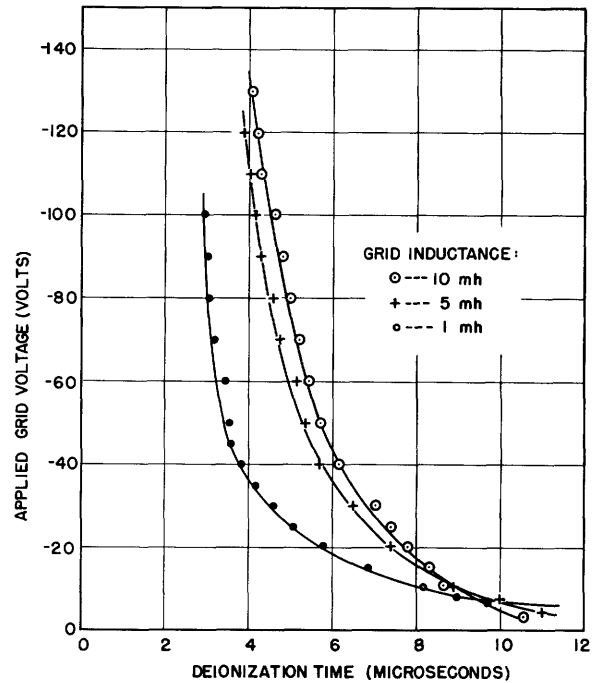


Fig. 3 Influence of grid inductance upon the deionization time. Sylvania 3C45: anode voltage, 900 volts; anode current, 10 amp; repetition frequency, 1000 cps; pulse duration, 1  $\mu$ sec; gas, hydrogen.

post-conduction period is frequently recommended to decrease the deionization time, the inverse anode voltage does not decrease the deionization time but provides an additional period of time before the anode voltage reaches the reignition value. In the usual condenser-discharge method of measurement, the inverse voltage changes the rate of reapplication of the anode voltage and thereby provides misleading results. In contrast, the method employed in this investigation provides a constant rate of reapplication of the anode voltage.

The deionization time is only slightly influenced by the repetition frequency when the interpulse interval is long enough to permit deionization to occur. Furthermore, a revision of the test circuit which provides a variable pulse duration up to 1200 microseconds shows that the deionization time is independent of pulse duration.

The pressure of the gas within the tube determines the gas concentration. If a uniform field distribution is assumed, it can be shown that the deionization is inversely proportional to the pressure. In thyratrons the field distribution is not uniform, and a rigorous analysis of the deionization process is not feasible. The experimentally obtained data for several 3C45 hydrogen thyratrons with different gas pressures is shown in Figure 5.

These tubes are Kuthe Laboratory tubes with identical electrode dimensions and orientation (within manufacturing tolerances). The deionization time is essentially independent of the applied grid voltage at pressures less than 400 microns of Hg.

An exact evaluation of the effects of the electrode dimensions upon deionization time is not possible, using only commercially available tubes. In such tubes, several dimensions are changed simultaneously and the individual effects cannot be segregated. It is of interest, however, to compare the three hydrogen thyratrons, 3C45, 4C35 and 5C22, since these tubes are of a similar design. The test data for three tubes of these types with an approximate gas pressure of 480 microns and obtained under identical test conditions is shown in Figure 6. The effects of anode current and gas pressure in the 4C35 are illustrated by Figures 7 and 8.

The experimental data presented up to this point deal with tubes in which hydrogen is the active gas. Some indication of the effects of the nature of the enclosed gas upon deionization is obtained from tests on tubes containing argon, hydrogen, mercury vapor and zenon as the active gas (with atomic weights of 40, 1, 200, and 130, respectively).

The FG67 is a mercury-vapor thyratron particularly designed for rapid deionization. The close spacing between the glass wall, and the anode and the upper grid structure increases the recombination of the ions at the walls and electrodes. The deionization time of the FG67 with the anode current as a parameter is shown in Figure 9. Although this tube has the

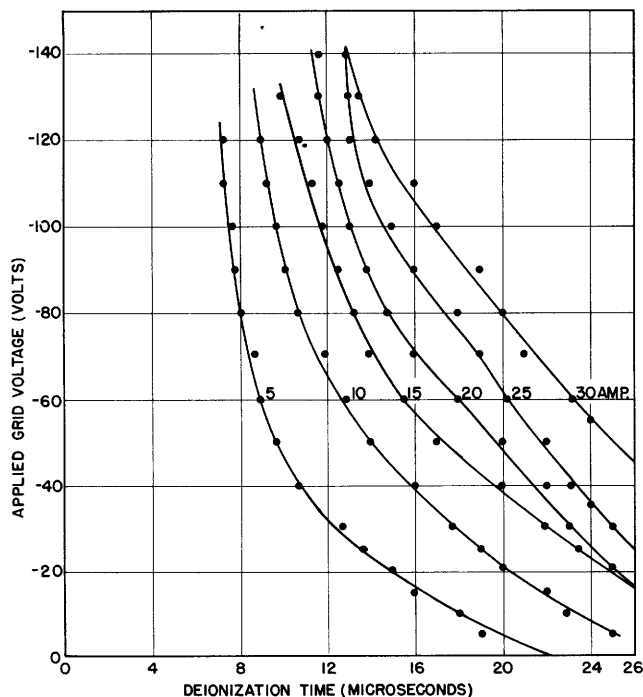


Fig. 4 Influence of anode current upon deionization time. Sylvania 3C45: grid resistance, 20 K; repetition frequency, 250 cps; pulse duration, 1 μsec; gas, hydrogen.

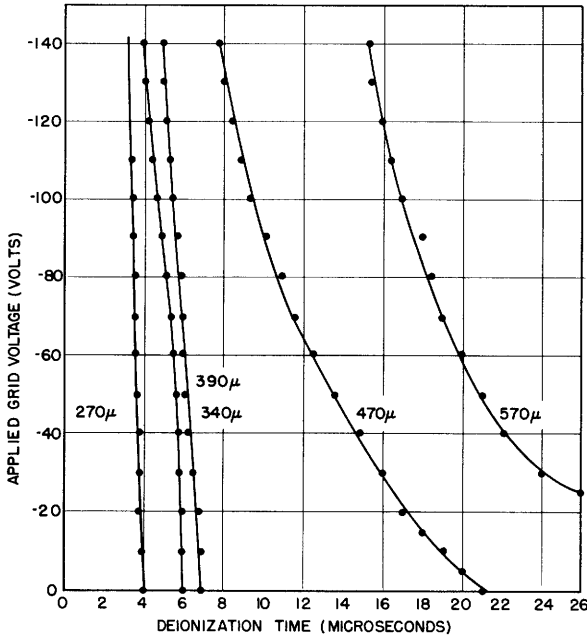


Fig. 5 Influence of gas pressure upon the deionization time. Sylvania 3C45: anode voltage, 900 volts; anode current, 10 amp; grid resistance, 20 K; repetition frequency, 250 cps; gas, hydrogen.

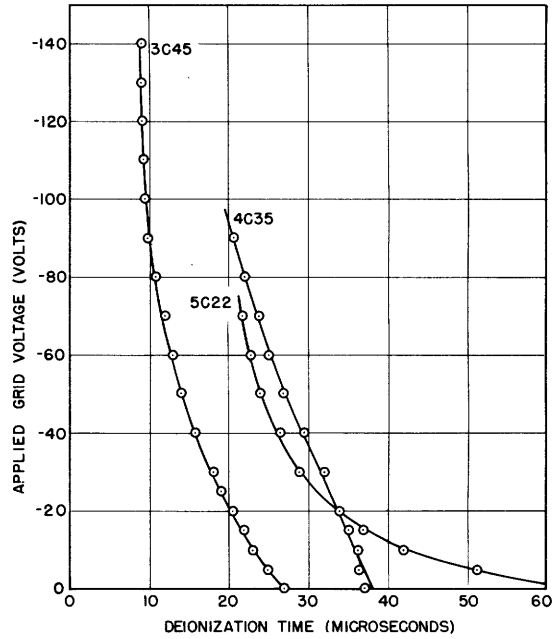


Fig. 6 Deionization time of the hydrogen thyratrons. Anode voltage, 900 volts; anode current, 10 amp; grid resistance, 20 K; repetition frequency, 250 cps; pulse duration, 1 μsec.

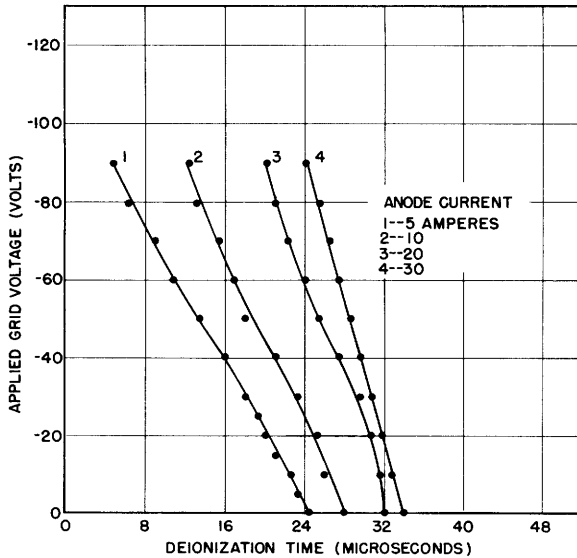


Fig. 7 The effect of anode current upon the deionization time. Sylvania 4C35: grid resistance, 50 K; repetition frequency, 1000 cps; pulse duration, 0.5 μsec; gas pressure, 480 microns; gas, hydrogen.

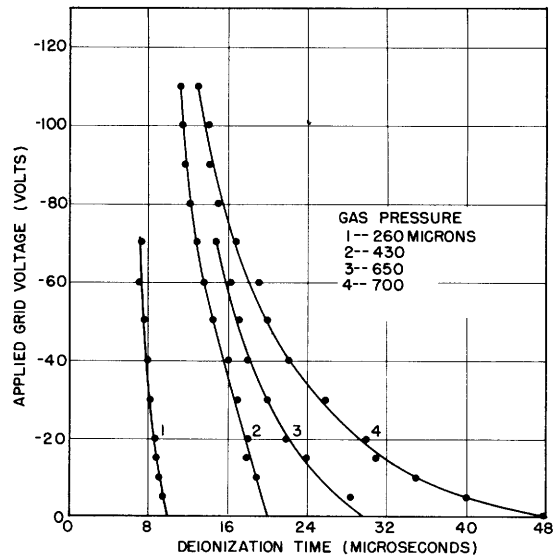


Fig. 8 The effect of gas pressure upon the deionization time. Sylvania 4C35: anode voltage, 900 volts; anode current, 10 amp; grid resistance, 20 K; pulse duration, 1 μsec; repetition frequency, 250 cps; gas, hydrogen.

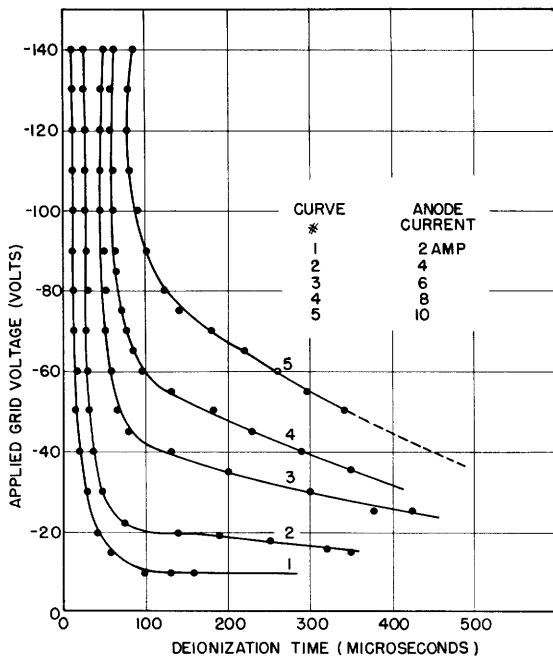


Fig. 9 The effect of anode current upon deionization time. FG67: Grid resistance, 20 K; oil-bath temperature, 65°C; vapor pressure, 0.035 mm; pulse duration, 0.5  $\mu$ sec.

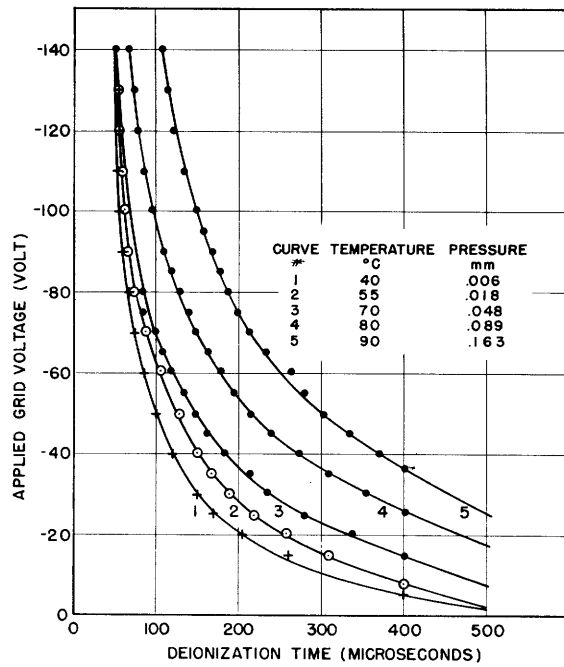


Fig. 10 The effect of vapor pressure upon deionization time. KU627: anode voltage, 200 volts; anode current, 2 amp; grid resistance, 20 K; pulse duration, 1  $\mu$ sec.

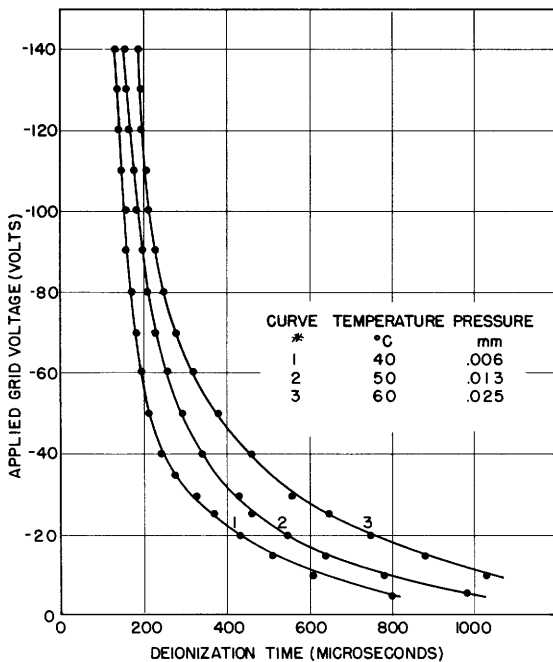


Fig. 11 The effect of vapor pressure upon deionization time. 3C23: anode voltage, 480 volts; anode current, 5 amp; grid resistance, 5 K; pulse duration, 5  $\mu$ sec.

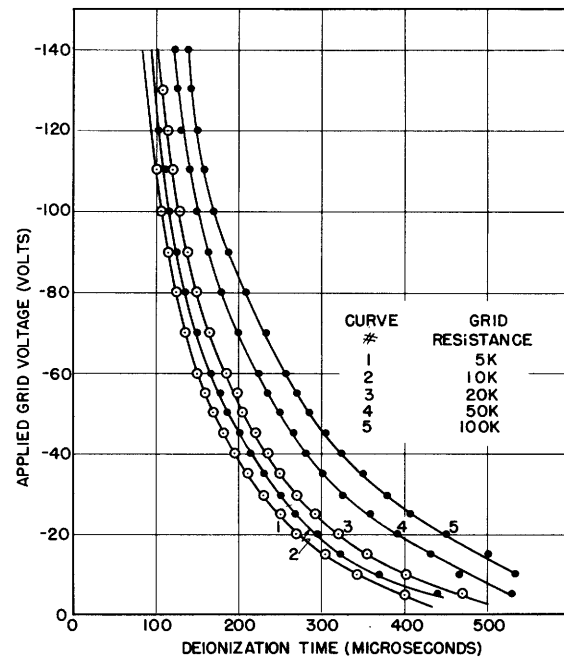


Fig. 12 The effect of grid resistance upon the deionization time. FG17: anode voltage, 220 volts; anode current, 2 amp; vapor pressure, 0.00278 mm; oil-bath temperature, 30°C; pulse duration, 5  $\mu$ sec.

shortest deionization time of the mercury thyratrons which were tested, it also is the most inconsistent of the group. This variation is probably due to its double-valued control characteristic. The increase in the time scale of the graphical results of the FG67 should be observed.

The KU627 showed very consistent results when similarly tested. The effects of vapor pressure upon the deionization time are shown in Figure 10. The recently developed 3C23 mercury thyratron compared favorably with the KU627. The effects of its vapor pressure are shown in Figure 11. The effects of grid circuit resistance upon the deionization time for the FG17 and FG57 are illustrated in Figures 12 and 13.

The xenon-filled EL ClB thyratron is often used in conjunction with servo motors in various control systems. The deionization time of this tube, using anode current and grid resistance as parameters, is shown in Figure 14. Again, the increased time scale should be observed. The deionization time is much larger than that of the KU627.

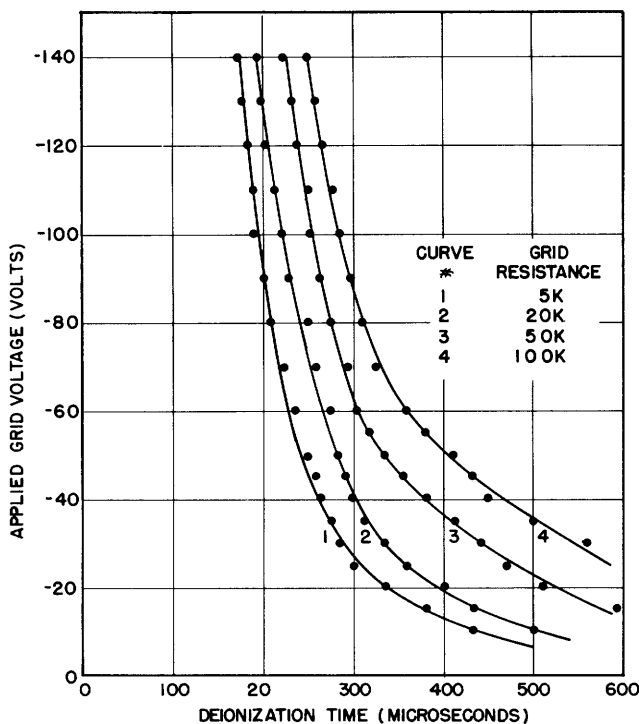


Fig. 13 The effect of grid resistance upon the deionization time. FG57: anode voltage, 550 volts; anode current, 5 amp; vapor pressure, 0.0089 mm; oil-bath temperature, 45°C; pulse duration, 5  $\mu$ sec.

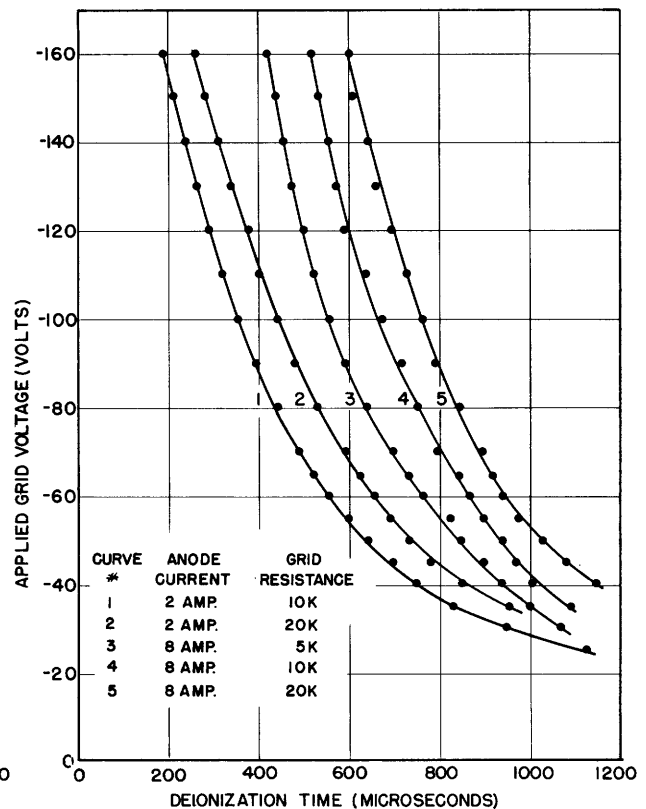


Fig. 14 The effect of anode current and grid resistance on deionization time. El ClB: anode voltage, 440 volts; pulse duration, 5  $\mu$ sec; repetition frequency, 250 cps; gas, xenon.

Tube Number	Active Gas	Maximum Peak Anode Voltage (volts)	Maximum Peak Anode Current (amp)	Maximum Instantaneous Grid Current (amp)	Average Tube Drop (volts)
3C45	Hydrogen	3000	45		18
4C35	Hydrogen	8000	100		18
5C22	Hydrogen	16000	325		18
EL C1B	Xenon	450	8		8
EL C67	Xenon	750	77		9
EL C16J	Xenon	1000	100		11
FG17	Mercury	5000	2.0	0.25	11.5
FG57	Mercury	1000	15.0	1.0	11.5
FG67	Mercury	1000	15.0	1.0	11.5
FG95	Mercury	1000	15.0	1.0	11.5
FG98	Inert Gas	500	2.0	0.25	11.5
3C23	Inert Gas Mercury	1250	6.0	0.05	11.5
KU627	Mercury	1250	2.5	0.25	15

#### IV. Conclusion

A considerable amount of quantitative data were obtained for various thyratrons which were operated under dynamic conditions similar to those encountered in practice. The concluding table lists a few of the characteristics of some of the thyratrons which were used in this investigation. In general, a small anode current, a low gas pressure, a large grid bias, a low-impedance grid circuit, a large plasma cross section, a short axial plasma length, and a small electrode separation favor a shorter deionization time.

The method of measurement of deionization time used in this investigation is to be preferred to the conventional capacitor-discharge circuit for several reasons: (a) The anode voltage during the post-conduction period is maintained at a constant value and can be reapplied instantly (within 0.3 microsecond) whenever desired. The time of voltage reapplication provides an exact reference point (independent of reignition voltage) to which time measurements can be made. (b) The rate of rise of the reapplied anode voltage is a constant value, irrespective of test conditions. (c) Since no numerical computation is necessary, this circuit provides a rapid means of evaluating the deionization time.

### Acknowledgment

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