A LOW GRID-CURRENT VACUUM TUBE

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Abstract

The various factors that may cause a current to flow to the control grid of a high vacuum tube are outlined. The magnitudes of the separate components are experimentally determined, and methods are given by which these currents may be greatly reduced. A tube is described which has a grid current of 10^{-15} ampere and a mutual conductance of 25 microamperes per volt. As an input resistance of 4×10^{11} ohms may be used, a current of 10^{-17} ampere may be detected when a galvanometer having a sensitivity of 10^{-10} ampere per millimeter is used in the plate circuit. Under this condition the sensitivity is 250,000 millimeters per volt.

Introduction

It would appear that since the grid of a high vacuum tube exerts electrostatic control of the plate current such a tube could be used as an electrometer. It is ordinarily found, however, that the grid current is not negligible. It is the purpose of this paper to show the amount and cause of this current, and to describe a tube which has the grid current reduced to a minimum and yet retains a considerable amount of control. This is an important factor in its use as an electrometer as has been shown by numerous investigators.[1,2,3] In a great part of the previous work done in this field little or no attempt has been made to analyze the cause of the grid currents or to develop tubes with a greatly reduced grid current.[4]

Sources of Grid Currents

The grid current in a high vacuum tube, when the grid is sufficiently negative to repel all electrons, may be due to any or all of the following causes:

(1) Leakage over glass or insulation.
(2) Ions formed by gas present in the tube.
(3) Thermionic grid-emission due to heating of grid by the filament power.
(4) Ions emitted by the filament.
(5) Photo-electrons emitted by the control grid under action of light from the filament.
(6) Photo-electrons emitted by the control grid under action of soft x-rays produced by the normal anode current.

[1] P. I. Wold, U. S. Patent No. 1232879 (1916).
[2] Wynn-Williams, Proc. Camb. Phil. Soc. **23**, 810 (1927).
[3] Nottingham, Jour. Franklin Inst. **209**, 287 (1930).
[4] During the preparations of this paper a description of a tube for measuring currents as small as 10^{-14} ampere has appeared. H. Nelson, Rev. of Scientific Inst. **1**, 281 (1930).

The leakage over insulation is relatively small compared to the other currents and may be reduced to a minimum by the usual methods.

Attempts were first made to maintain a vacuum high enough to permit operation of the tube at voltages above the ionization potentials of any gas present, but it was found that with the highest obtainable vacuum the positive ion current was greater than 10^{-13} ampere. When all potentials were held below 8 volts no current which could be attributed to ionization of gas present was found.

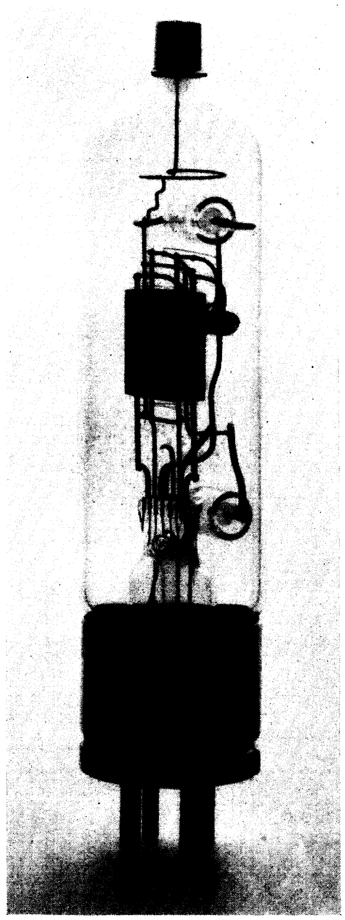

Fig. 1. Photograph of new Type FP-54 low-grid-current pliotron tube.

Any effects of the grid heating may be eliminated by using low filament power and large open structures.

It has been shown by Smith,[5] Wahlen[6] and others that positive ions are emitted by a hot filament in large numbers. These ions are drawn to the negative control grid and may amount to as much as 10^{-12} ampere from a

[5] L. P. Smith, Phys. Rev. **35,** 381 (1930).

[6] Wahlen, Phys. Rev. **34,** 164 (1929).

small tungsten filament. To overcome this effect a space-charge grid is placed between the filament and control grid which repels all ions since it is operated at a positive potential. This grid, of course, also increases the mutual conductance of the tube.

While photo-electrons are not emitted by pure nickel or molybdenum grids under action of light from the filament, there is invariably enough contamination to cause an appreciable current. This effect is greatly reduced by using thoriated filaments operated at a low temperature.

In order to determine the magnitude of the current emitted by soft x-rays from the anode several special tubes were constructed in which a nickel or molybdenum plate was so mounted that it received only soft x-rays produced by the impact of 4 to 10 volt electrons. With potentials above 6 volts the currents were in all cases greater than 10^{-15} ampere. Photoelectric emission due to such soft x-rays has been demonstrated by numerous investigators.[7,8] By the use of very low anode voltages the currents due to this cause were reduced to an inappreciable value.

Description of Tube Developed

The tube as finally developed is, as mentioned, a space-charge grid tube. The control grid is brought out of the top of the bulb, while the other elements terminate in a standard UX base. The control grid is mounted on quartz beads shielded to prevent surface contamination. The filament is of thoriated tungsten and consists of two legs in parallel to keep the voltage low. The general structure is shown in the photograph. (Fig. 1).

The most desirable operating conditions and the characteristics at these conditions were found to be as follows:

Filament voltage	= 2.5 v.	Filament current	= 100 ma.
Plate voltage	= 6.0 v.	Plate current	= 40 μa.
Control grid voltage	= −4.0 v.	Mutual conductance	= 25 μa/v.
Space charge grid voltage	= 4.0 v.	Amplification factor	= 1.0
		Plate Resistance	= 40000 ohms.

Under these conditions representative tubes have a grid current of about 10^{-15} ampere while the input resistance is of the order of 10^{16} ohms. The input capacity is about 2.5×10^{-12} farad. Fig. 2 shows plate current and grid current plotted against grid voltage for such a tube.

The effects of filament temperature are shown in Fig. 3. The rapid increase in grid current above 2.5 volts on the filament is attributed to photoelectric emission from the grid due to the light from the filament. Fig. 4 shows the effects of plate-voltage variation. The considerable increase in grid current above 6 volts is due to photoelectric emission caused by soft x-rays, while the great increase above 8 volts is due to ionization.

[7] O. W. Richardson, Proc. Roy. Soc. **A110**, 247 (1926).
[8] C. H. Thomas, Phys. Rev. **25**, 322 (1925).

Methods of Measuring Small Currents

The method used in measuring the grid current of the tubes consists in determining the rate of change of grid potential when the grid is free. The plate current of the tube serves as the indication of grid voltage. Of course, $i_c = C_g de_c/dt$. The input capacity C_g may be measured quite accurately, while the rate of change of grid voltage is readily determined with a stop watch. With this method there is practically no minimum limit on the mag-

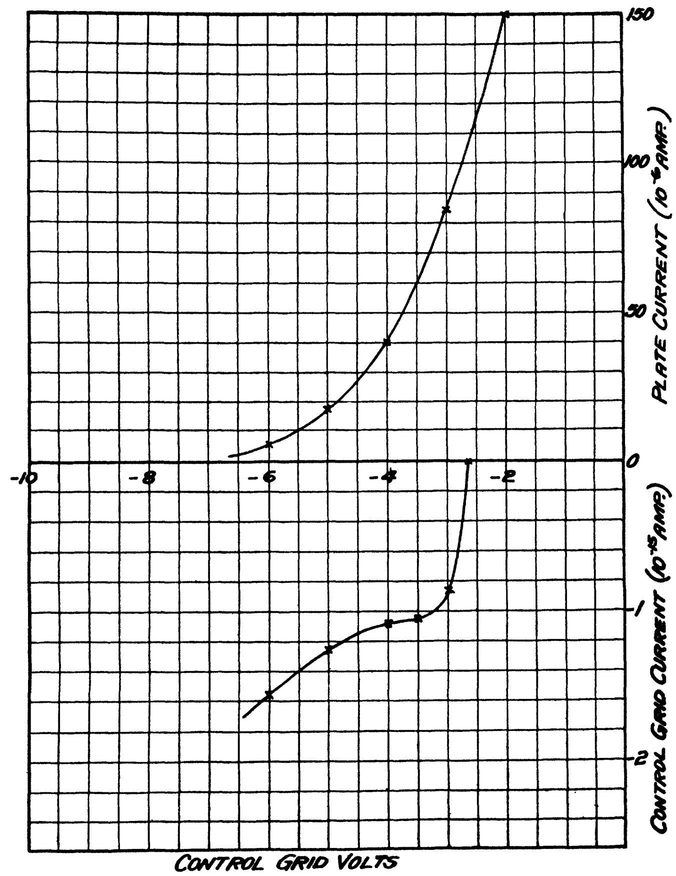

Fig. 2. Plate current and control grid current as a function of grid voltage.

nitude of the grid current which may be measured, except that imposed by the time required to obtain an appreciable deflection on the galvanometer used in the plate circuit.

This method may be applied to the measurement of any small current. If the current is of the order of 10^{-13} ampere or greater, the grid current may be neglected. For measuring smaller currents the grid current may be subtracted from the indicated value.

This tube may be used in any of the methods previously described[1,2,3] for indicating currents directly with better results than are obtained with ordinary tubes.

Neglecting for the moment variations in supply voltages, all currents of this tube are very steady, no drift in plate current being appreciable on a galvanometer having a sensitivity of 10^{-10} ampere per millimeter.

The variation in grid current should not produce an error of greater than 10^{-17} amperes in the measured current, so that the limiting value to be measured may be taken as of this order. If a direct indicating method is used the input resistance to give an appreciable deflection on a galvanometer of 10^{-10}

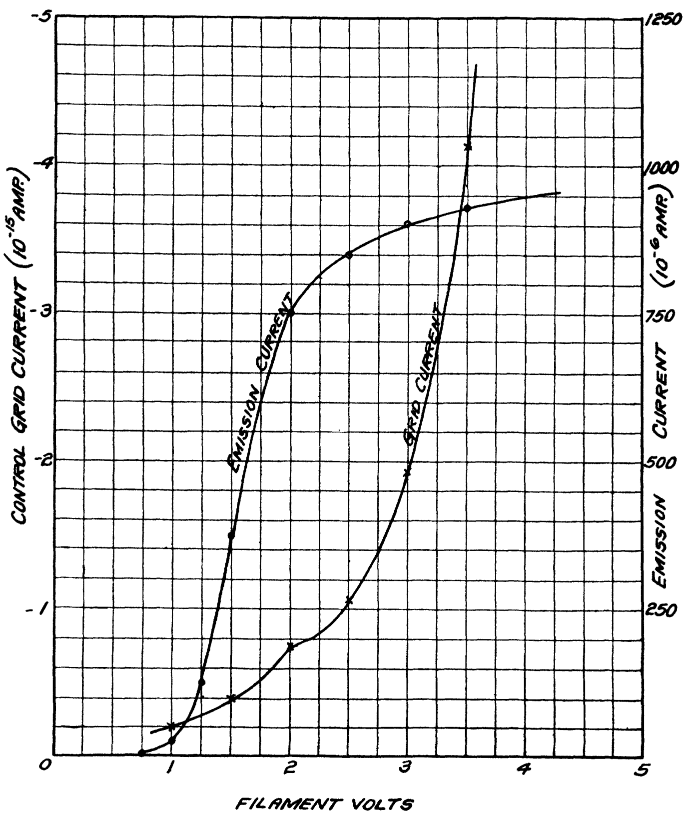

Fig. 3. Effect of filament temperature on grid current.

ampere sensitivity with a current of 10^{-17} ampere is 4×10^{11} ohms. Various means of obtaining such resistances have been described.[3,9] With this galvanometer the sensitivity of the unit is 250,000 millimeters per volt. If amplification is added after the electrometer tube a smaller input resistance may be used, or a less sensitive galvanometer.

No leakage troubles are experienced with these tubes provided they are used in dry air. This has been accomplished by operating the tube in a relatively air-tight container with a dryer such as phosphoric pentoxide.

[9] Mulder & Razek, J.O.S.A. & R.S.I. **18,** 470 (1929).

Drift of supply potentials has been minimized by using storage batteries of ample capacity. Since the voltages and currents are very low this presented no problem.

It is felt that the tube as described will prove to be a very useful scientific instrument, offering advantages in sensitivity and convenience over the common forms of electrometer.

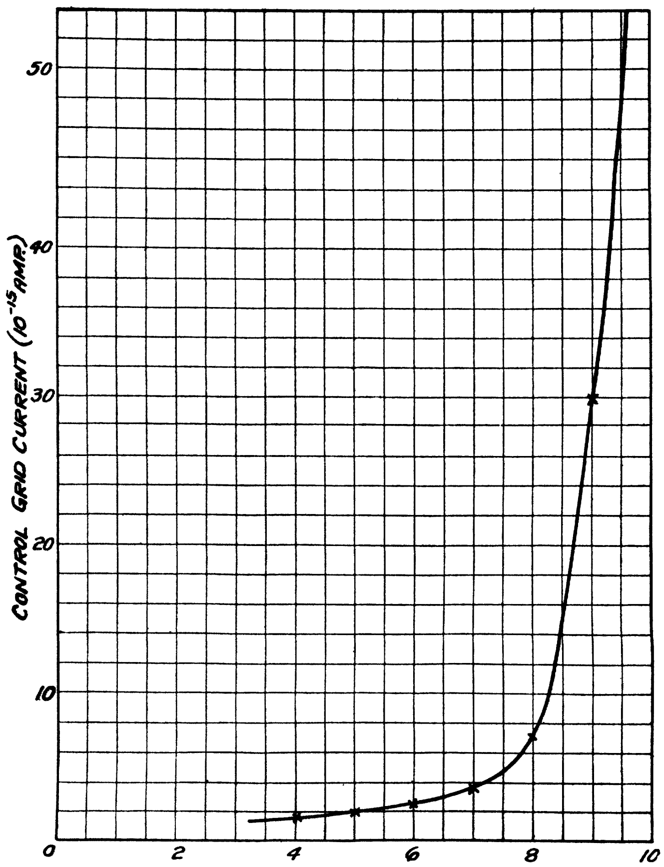

Fig. 4. Effect of plate-voltage variation on the grid current.

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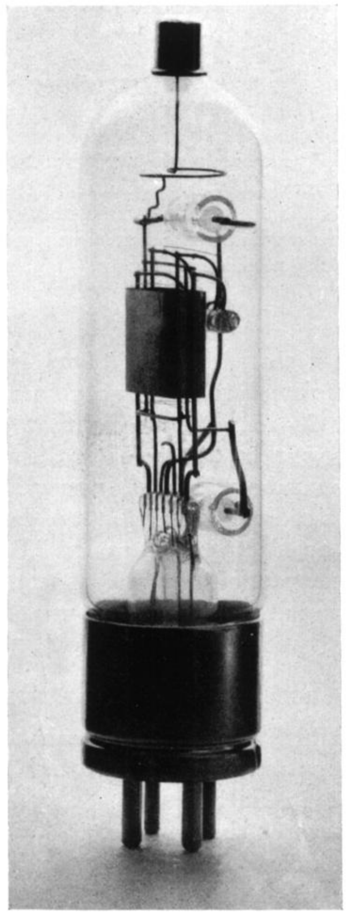

Fig. 1. Photograph of new Type FP-54 low-grid-current pliotron tube.