THE SPECIFICATIONS AND CHARACTERISTICS OF MOORHEAD VACUUM VALVES*

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The war has been responsible for some remarkable developments in radio apparatus, among which the vacuum valves have played an important part. The varied uses to which valves have been applied has necessitated the manufacture of large quantities of valves having uniformity of operating characteristics.

The British Government required a considerable number of vacuum valves, and while they were being built by hand in England, the supply was not sufficient. The valve adopted by the British Government was presumably copied from the French type, and complete specifications were submitted by the British Government which cover a large amount of detail. The writers will discuss part of these specifications in the following, calling attention to the careful mechanical measurements contained therein.

The Type "R," which is the British receiving tube, is of the three electrode type. The anode consists of a rectangular sheet of pure nickel 31 mm. × 15.2 mm. (1.22 × 0.6 inch), rolled into a cylinder 10 mm. (0.39 inch) external diameter, the thickness of the metal being 0.2 mm. (0.08 inch). The grid consists of a nickel wire 0.25 mm. (0.10 inch) diameter and 165 mm. (6.5 inches) long. This wire is bent into a spiral of 11 turns. The pitch of this spiral being 1.5 mm. (0.06 inch), the internal diameter is 4.25 mm. (0.17 inch). The filament is pure drawn tungsten

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wire, diameter 0.061 mm. (0.0024 inch) and 23 mm. (0.91 inch) in length when uncrimped.

The disposition of the electrodes is made as follows: The grid spiral and anode cylinder are placed so their axes are coincident with the filament. The grid is set so that 9 of its turns are within the cylinder and one turn projects at each end of the anode.

The size of the glass bulb specified is not to exceed 54.76 mm. (2.15 inches) external diameter, and the length from the remote end of the pins on the base to the tip 111.91 mm. (4.41 inches).

The British and French type of base is used, but was improved upon considerably by base manufacturers in this country. An unusual degree of mechanical accuracy was required in the base and terminal pins, a few figures for which are given here. The diameter of the terminal pin is 3.171 mm. (0.125 inch) and a tolerance of but 0.075 mm. (0.003 inch) is allowed. The length of the pin projecting from the base is 17.462 mm. (0.688 inch). Numerous test gauges are used in checking the assembled base and valve.

The electrical tests specified are characteristic of the mechanical details as contained in the specifications. To test the correctness of the disposition and proper dimensions of the elements, the filament is supplied with four volts, the anode being maintained at 80 volts positive with respect to the negative end of the filament, and a curve obtained by plotting as abscissas the potential difference of the grid in respect to the negative end of the filament and as ordinates the filament plate current. This curve must be a straight line for variations of grid potential between (minus three) and (plus twenty-five) volts, a variation of 1 volt grid potential producing a variation of plate current of at least 0.2 milliamperes. Furthermore, when the grid and plate are connected together and a potential of eighty volts applied to them, the current then obtained between the filament and these two electrodes must be above 8 milliamperes.

The bulb must be so evacuated that the "backlash" is between 0.5 and 0.02 microamperes. The method of obtaining the backlash is described here. A potential is applied to the grid, the anode being at 160 volts positive, and filament voltage 4. A curve is plotted, taking the grid current as ordinates and the negative grid voltage as abscissas. The negative current represented by the ordinate when the grid potential is 2 volts negative in respect to the filament, is the backlash. Further testing when the grid potential is removed, all other conditions the same, the positive current to the grid must not exceed 1.5 microamperes.

The electrodes and all internal parts of the valve must be so freed from gases that no deterioration of the vacuum occurs when the anode is dissipating 15 watts energy for three minutes continuously. The anode dissipation is measured in the following way: The filament is supplied with 6 volts, the anode with 400 volts, and the grid with positive potential until the plate current reads 37.5 milliamperes. During the continuance of this test, no blue glow must appear in the bulb.

The filament current when six volts are applied must be 0.84 ampere with a tolerance of 0.035 ampere. The contact of the leading-in wires with the elements must be such that, when the valve is used in a 4-stage amplifier, no crackling sounds are heard. The insulation of the base must exceed 150 megohms when the valve is not lighted. The valve has a life of 800 hours when four volts are used on the filament.

The British Type "B," which is a transmitting valve, will next be considered.

The anode is a rectangular sheet of nickel 31 mm. (1.22 inch) by 16 mm. (0.63 inch), rolled into a cylinder of 100 mm. (0.394 inch) external diameter, the thickness of the metal being 0.22 mm. (0.0087 inch). The grid consists of molybdenum wire, diameter 0.2 mm. (0.008 inch) and length 330 mm. (1.3 inch). This wire is bent into a spiral of 22 turns, the pitch being 0.75 mm. (0.040 inch), the internal diameter being 4.1 mm. (0.16 inch). The filament is drawn tungsten containing a small percentage of thorium, the diameter of this wire being 0.058 mm. (0.0023 inch) and the length 22 mm. (0.87 inch).

The valve is assembled like the Type "R," and the following electrical tests applied: disposition of electrodes, and correctness of dimensions. The anode is maintained at 600 volts positive; six volts are applied to the filament; the grid is maintained at the same voltage as the negative end of the filament. Then the plate current must be 17 milliamperes plus or minus 6 milliamperes. The grid is next supplied with 10 volts positive, and the plate current must exceed by 5.5 milliamperes that current observed in the previous case.

The vacuum is tested as in the type R case except that the anode must dissipate 50 milliamperes at 600 volts for three minutes continuously. During this test the anode becomes white hot. No backlash test is made, but the filament emission is measured by connecting the grid and plate together and applying 80 volts with respect to the negative end of the filament, which is supplied with 4 volts. The current thru the valve must then exceed 5 milliamperes.

The filament current when 6 volts are applied must be 0.85 ampere with a tolerance of 0.04 ampere.

The valves were constructed of materials produced in the United States, and the specifications followed carefully. When the completed valves were tested, they agreed with all the electrical measurements described above.

The type R valve however, had its elements mounted vertically. This was done as the specifications did not cover the position of the elements, and no samples were available in this country at that time. Samples did arrive, however, before the type B was made, and the elements were changed to a horizontal position to conform to the French sample.

The United States Navy type, SE-1444, was the next valve constructed, using the helical grid and cylindrical plate.

A few mechanical changes will be noted, namely, that the grid and plate supporting wires were separated as much as possible, and made of heavier material. The capacity was decreased by these changes, while the internal impedance and amplification constants remained about the same as the British valve.

This type of construction is still used in the valves supplied to the Marconi Wireless Telegraph Company, and known as the "Marconi V. T." However, the flash exhaust is not used in the Marconi V. T., class 2. That is, a vacuum permitting gas action is used in this particular class of valve.

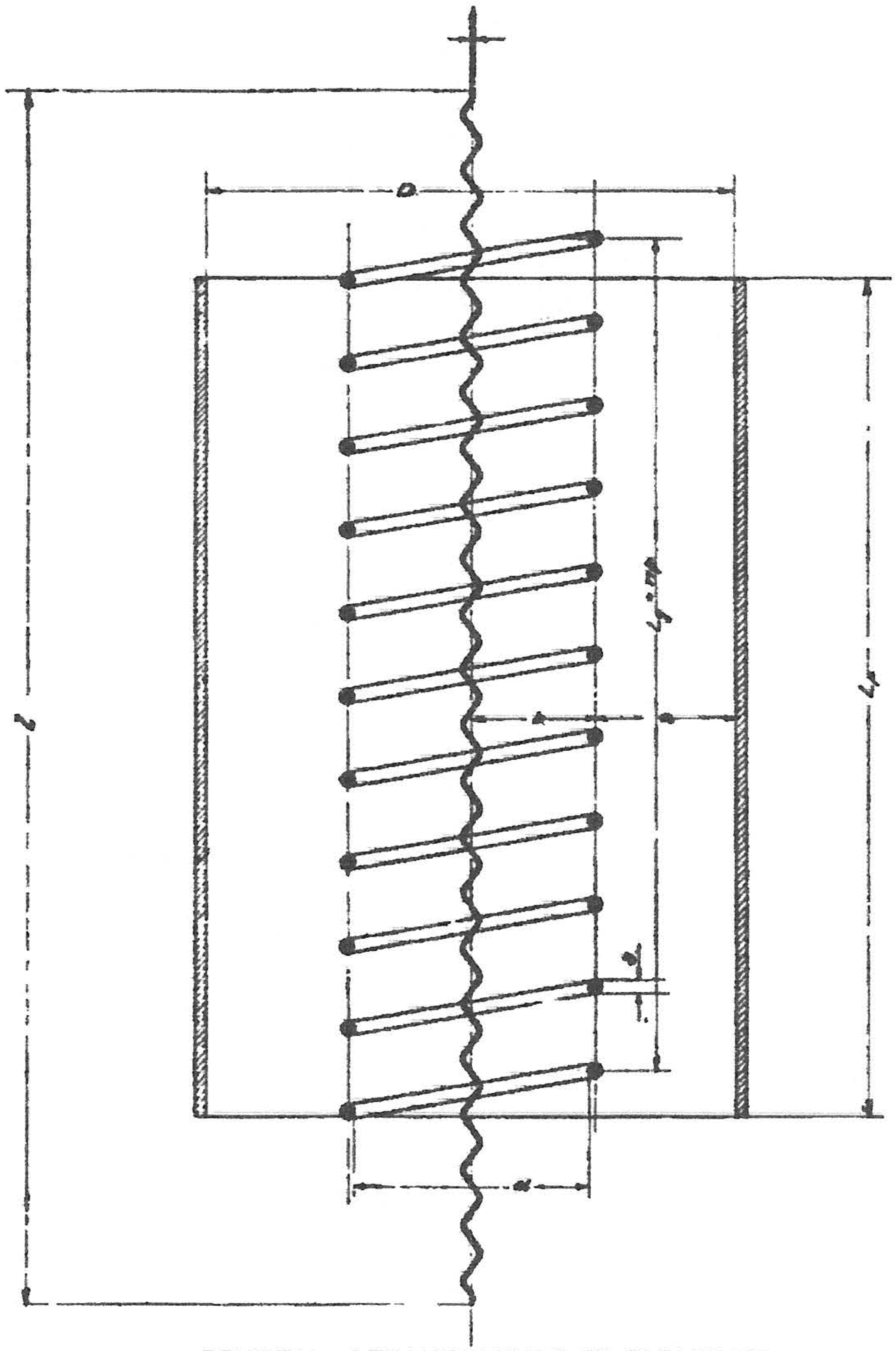
The tendency of the art at this time is to decrease the power consumption of vacuum valves for receiving purposes, and develop a valve which shall consume less than 1 watt, still retaining the high constants of the larger valve. The filaments will be so accurately mounted that no manual adjustment will be required, for the proper temperature and emission. The valve will be made much smaller, and a type of base with very low capacity will be used. This will also greatly decrease the cost of the present valve.

THE CHARACTERISTICS OF MOORHEAD VACUUM TUBES

The authors will not dwell on an historical review of vacuum tubes in general, nor will they go into a detailed description of tubes, such as the Fleming valve, kenotron, de Forest audion, pliotron, and so on because most radio engineers are familiar with these. For the same reason, and also because of detailed specifications given in the first part of this paper, further description of the Moorhead tube, or rather Moorhead tubes, will be omitted.

In general, the Moorhead tubes can be divided into two classes: the "soft" tubes and the "hard" tubes. To the first class belong the "Electron Relay" and "Class B," or "Class 1" tubes; to the second class belong the SE-1444, or "Class 2" tube, and the "Type C" tube, also the "British B" and "British R."

The "Key Figure" here given illustrates the general construction of these tubes and their dimensional nomenclature. The "Electron Relay" and the "Class 1" tube (also called "Moorhead Audion") belong to the class of detector tubes depending on the presence of traces of gas for their action. Figure 1 shows the representative characteristic curves of this type of valves.



Key Figure—Construction of Moorhead Tubes and Principal Dimensions

Both the "Electron Relay" and the "Class 1" tubes are identical in their action, there being only a difference in mechanical construction.

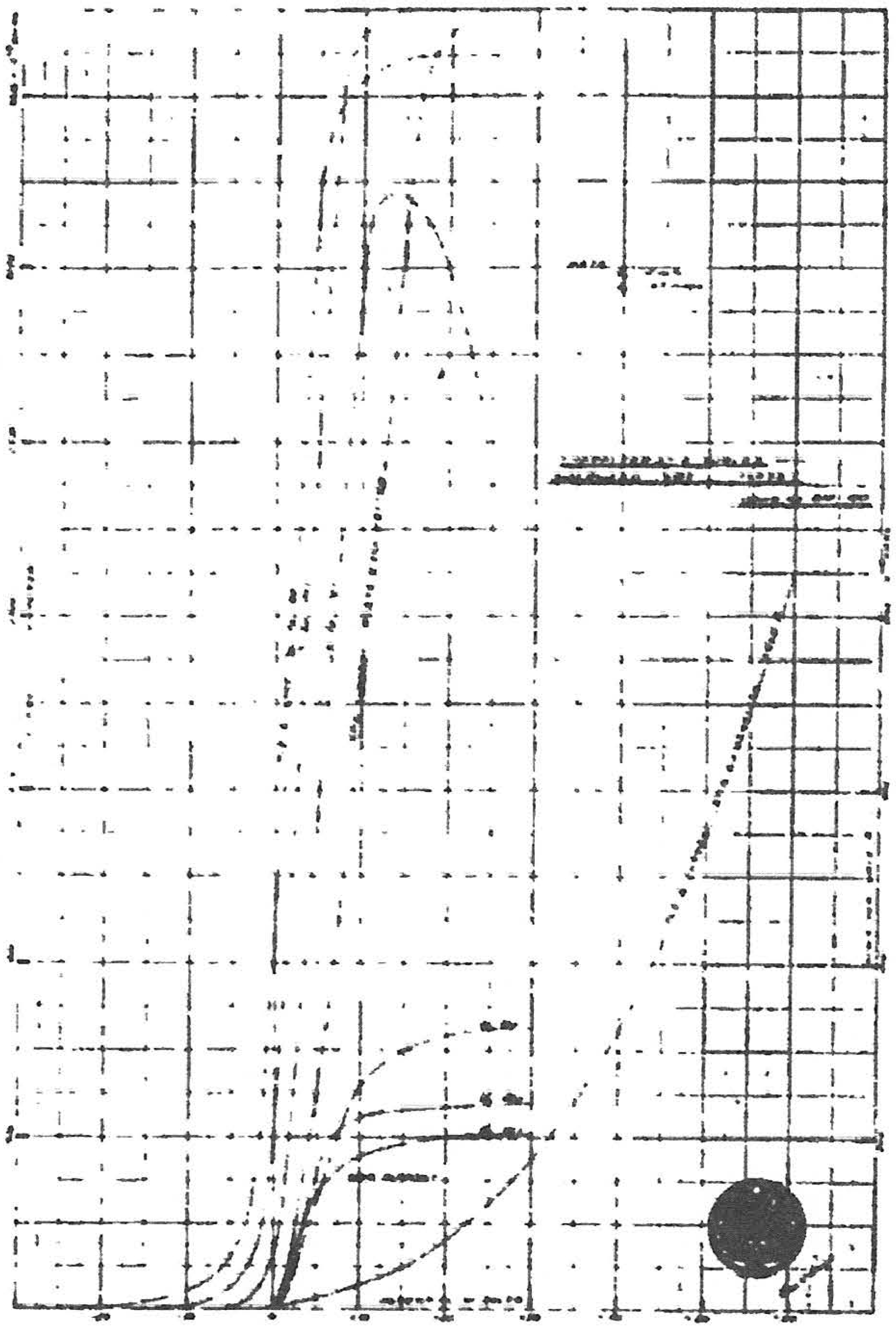


FIGURE 1

Paralleling the above class of tubes, a type of tube known as "British R" has been developed. This tube has a "hard" vacuum, but the elements are of such proportions as to permit the application of lower plate potentials for the use as a detector tube, this same tube making a comparatively good amplifier when higher plate potential is used. The characteristic curves of this type of tube are shown in Figure 2. These curves show that the plate potential should be between 20 and 40 volts when used as a detector with the grid potential about 2 volts.

Examining the curves of Figure 1, it becomes evident that the tube makes the best detector with about 20 volts plate potential and 0 volts grid potential; the higher plate potentials requiring higher negative potentials of the grid.

Comparing the curves of the two tubes we will find that the "Class 1" tube, or "Moorhead Audion," is a more sensitive detector than the "British R" tube.

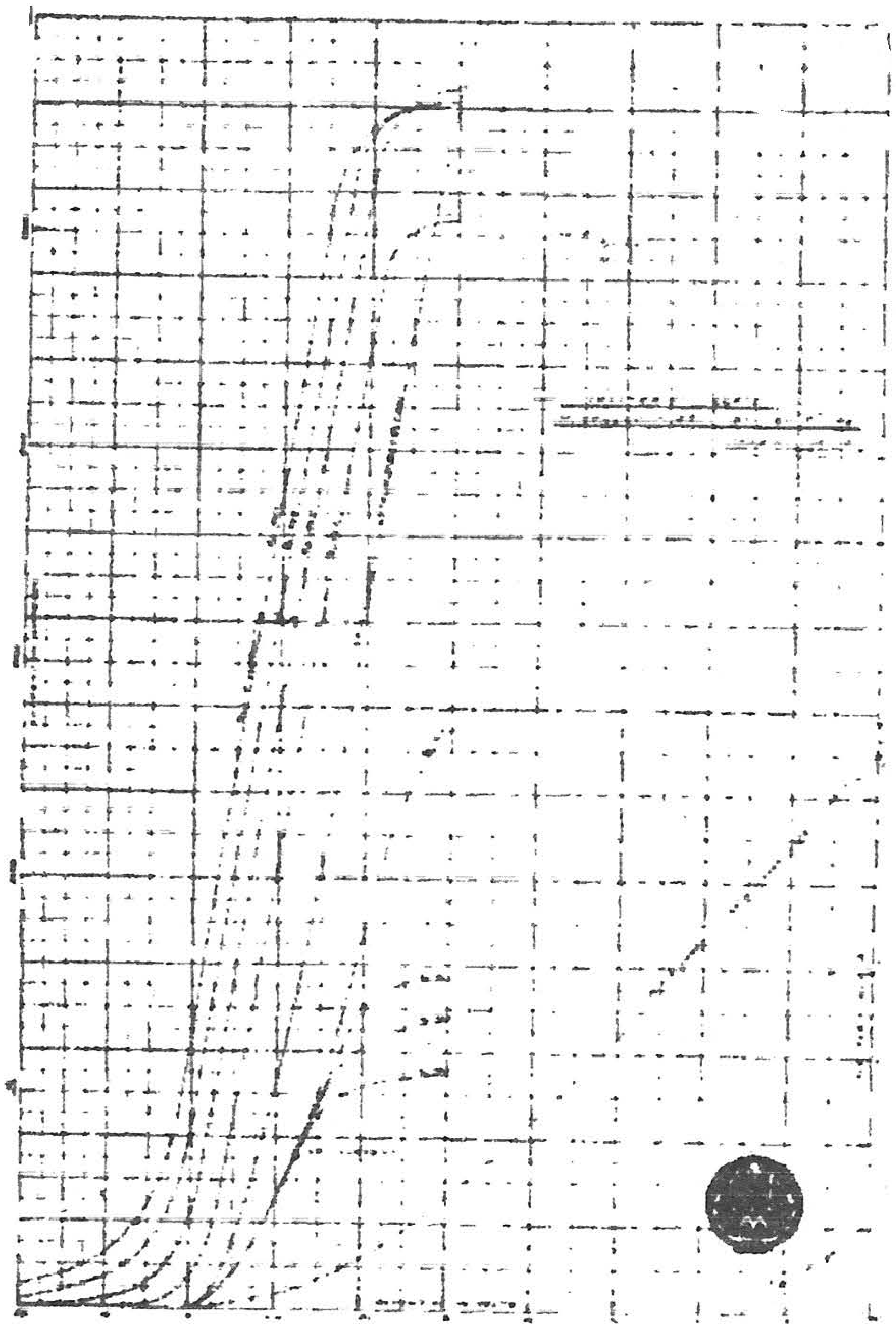


FIGURE 2

In general, as will be demonstrated later, two widely different designs of tubes should be adhered to: one for detector tubes and one for amplifier tubes. While the same tube may serve as detector and amplifier (for example, "British R" tube and SE-1444 tube), yet this is accomplished at a sacrifice of the best operating characteristics. From a number of tubes specially built for the purposes of research, the fact that a tube making the best amplifier makes a poor detector and conversely, has been brought out very clearly.

The authors' research work was undertaken chiefly with the purpose of developing a tube having high amplification and low resistance,—characteristics very much desired. The extent of research work is shown by the accompanying plots of tests of a few of the tubes selected in such a manner as to show the extreme results obtained. The static method in all cases was used, which, altho erratic to some extent, permits calculation of coefficients, or constants, as defined in Mr. Ballantine's paper (PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, April, 1919).

Particular attention was paid to the determination of following constants:

$$\mu = \frac{d\,E_p}{d\,E_g} = \frac{\text{change of plate potential}}{\text{change of grid potential}} = \text{amplification constant.}$$

(The author suggests the term "grid control coefficient.")

$$R_o = \frac{d\,E_p}{d\,I_p} = \frac{\text{change of plate potential}}{\text{change of plate current}} = \text{internal resistance.}$$

$$\rho = \frac{\mu}{R_o} = \frac{d\,I_p}{d\,E_g} = \frac{\text{change of plate current}}{\text{change of grid potential}}.$$

All of the three ratios, which are called constants, are by no means constant, their values varying within wide limits for the same tube. The accompanying curves of Figure 3 give the magnitudes of such variations in values of an SE-1444 tube. These variations are by no means accidental, but are inherent characteristics of every tube. Particular attention may be called to

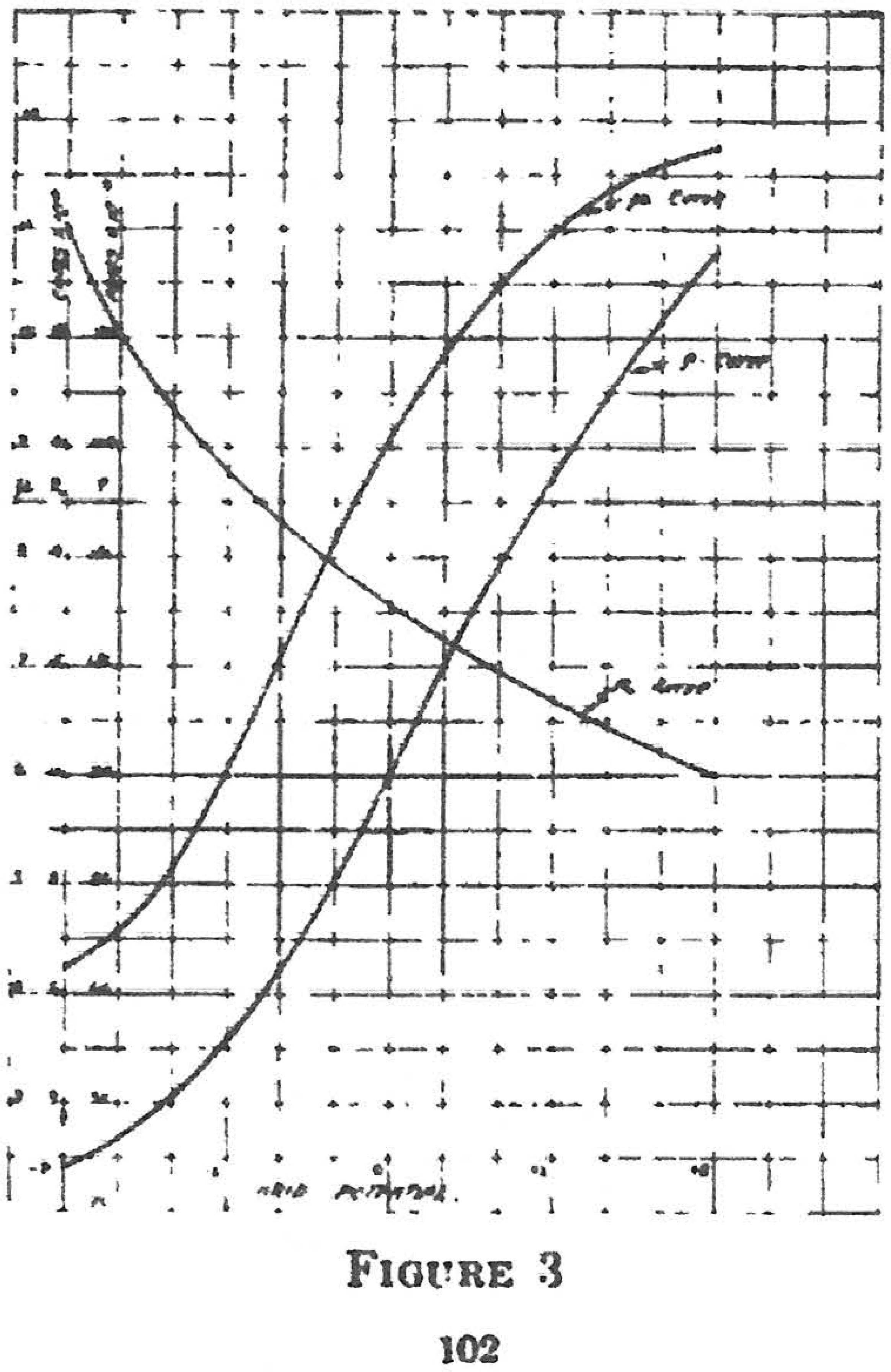


FIGURE 3

behavior of the two of the "constants," the amplification constant and the internal resistance. Every small gain in amplification results in an increase of internal resistance, and it does not seem possible to build a high power amplifying tube of low resistance.

Moreover, the same types of tubes, made in exactly the same way, with the same precautions during the process of manufacture, of the same materials, in short, tubes supposed to be identical in every respect, show variations with regard to the operating characteristics, in addition to the variations mentioned above. The magnitude of these variations is clearly shown in Figure 4.

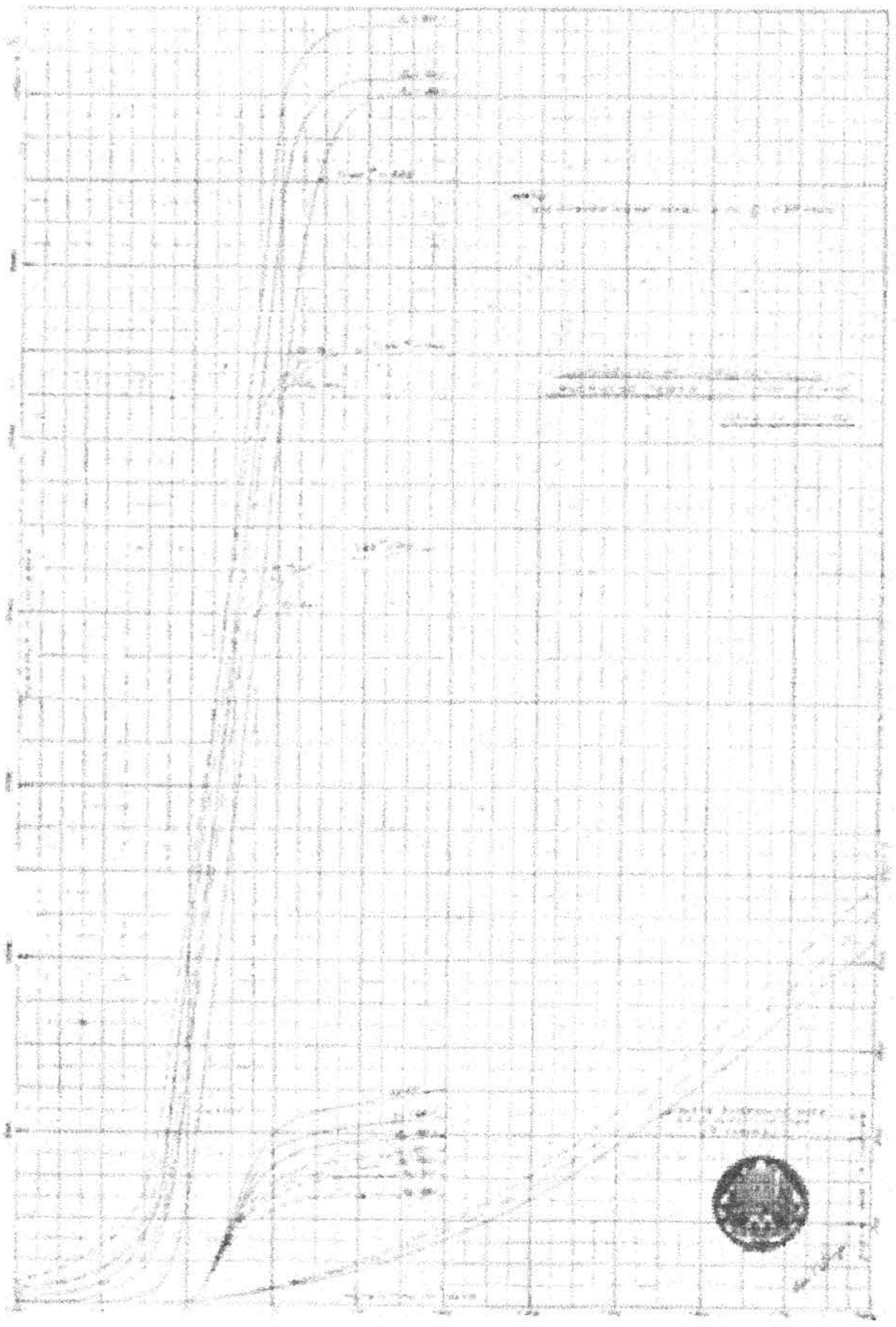


FIGURE 4

The three sets of characteristic curves plotted to the same scale very vividly show how minute defects, detection of which under ordinary conditions and with less sensitive apparatus would be termed "hair splitting," will change the characteristics of a tube.

The plate material strained a little while being rolled into the cylindrical shape and slightly opening when subjected to high temperature, will get away a fraction of a millimeter from the grid; the result is that the characteristic of the tube can hardly be recognized; slight variations of tension on the filament wire, uncertainty of supports retaining their shape when brought up to a temperature of about 800 degrees Fahrenheit (426° C.) during the exhaustion, or to a still higher temperature during the "blue-glow" process,—all these causes will have their effect. In addition, there are gases in the metal of tube elements, which gases, tho driven out of metal at very high temperature, defy the action of the "getter" and are re-absorbed by the metal to be driven out again when the tube is allowed to reach a high enough temperature—and we all know what a trace of a gas will do to the characteristic of tube. The result is that, to be exact, there is one chance in a thousand to get two tubes that will be absolutely alike. But this *is* "hair splitting." Thousands and thousands of tubes have been built and have given absolutely satisfactory service by slight variations of minor accessories of the circuits using a tube. On the whole, and for all practical purposes, the hard vacuum tube shows a consistent uniformity. A tube of définite design will give definite results within very close limits.

At this point, we shall temporarily abandon the discussion of general characteristics and consider the characteristics shown by each of the tubes tested by the authors, including even the soft tubes.

Up to the present date, as has been stated by an authority, quoted literally, "the vacuum tube art is in a very fluid state." The action of the tube in general has been studied and the tube has been made use of for several very different applications, all, more or less, successful. But in spite of wide applications of the tube, in spite of its being in use daily all over the world, no satisfactory solution of a mathematical theory has been given. The fact that all of the tubes (speaking of the three element tubes) have similar characteristics, their characteristic curves showing that they all belong to the same family, leads to the belief that one and the same law of action governs them all. Mathematical formulas have been advanced, but these formulas as tested by the authors, did not give satisfactory results. It is only to be hoped that more research work and more detailed study will be done in connection with the tube to arrive at the law determining the action of the tube, no matter what its shape, and no matter what its proportions may be.

In what follows, the authors will not try to advance any mathematical theory, but will confine themselves to presenting a few observations of the action of the tube elements, which actions being absolutely uniform may lead to a founding of a definite theory of the vacuum tube.

The first element to be mentioned is the tungsten filament. Taking measurements on different sizes of filament wire, both straight and crimped, the authors have found that the specific resistance of material of the filament was 0.000,005,58 ohms, or 5.58×10^{-6} ohms per cm.^{3}, which result corresponds very closely with that given by the Bureau of Standards, which is given as 5.6×10^{-6} ohms. The temperature coefficient was taken from the same source and used as an average of 0.0045 per degree Centigrade. It was found that the crimping added 27 to 30 per cent to the resistance, thus increasing the length of the filament wire about 30 per cent. Using a specific resistance $\rho = 5.6 \times 10^{-6}$ ohms, the curve of resistance of tungsten wire of different diameters has been calculated and is given in Figure 5.

All of the tubes used in the tests, except the "British B" tube, have 0.061 mm. (0.0024 inch) diameter filament wire 23 mm. (0.905 inch) between the supports. The average filament resistance is 0.565 ohm at about 20 degrees Centigrade; at this

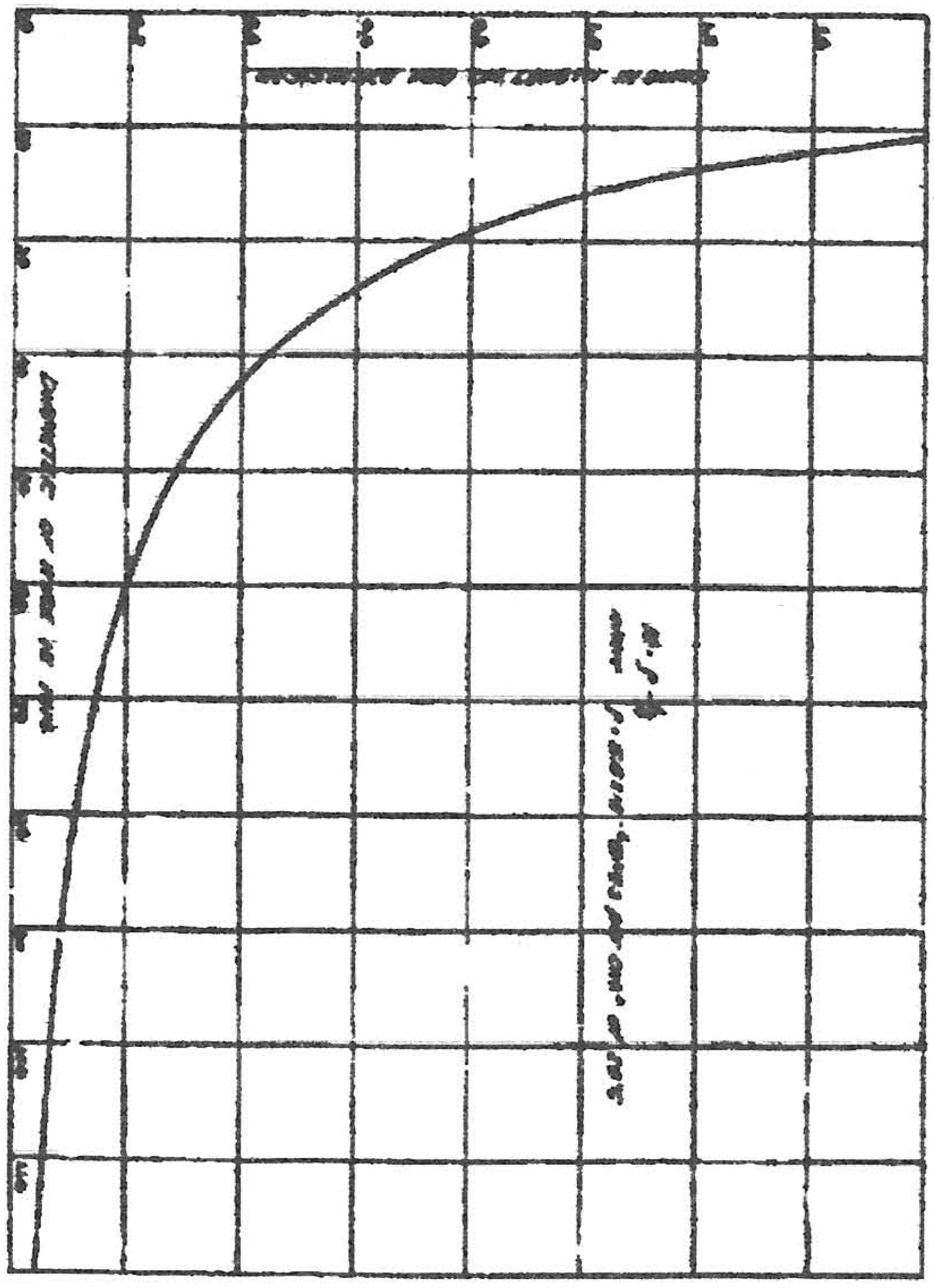


FIGURE 5

temperature the combined resistance of copper wire connections, platinum seals, and nickel supports measured 0.08 ohm. Figure 6 gives resistance, temperature and current curves of 0.061 mm. (0.00241 inch) and 0.058 mm. (0.00228 inch) diameter filaments. The temperature and resistance curves are those of 23 mm. (0.905 inch) long, 0.061 mm. (0.00241 inch) diameter filament. For practically all of the tests the filament voltage was kept at 4 volts.

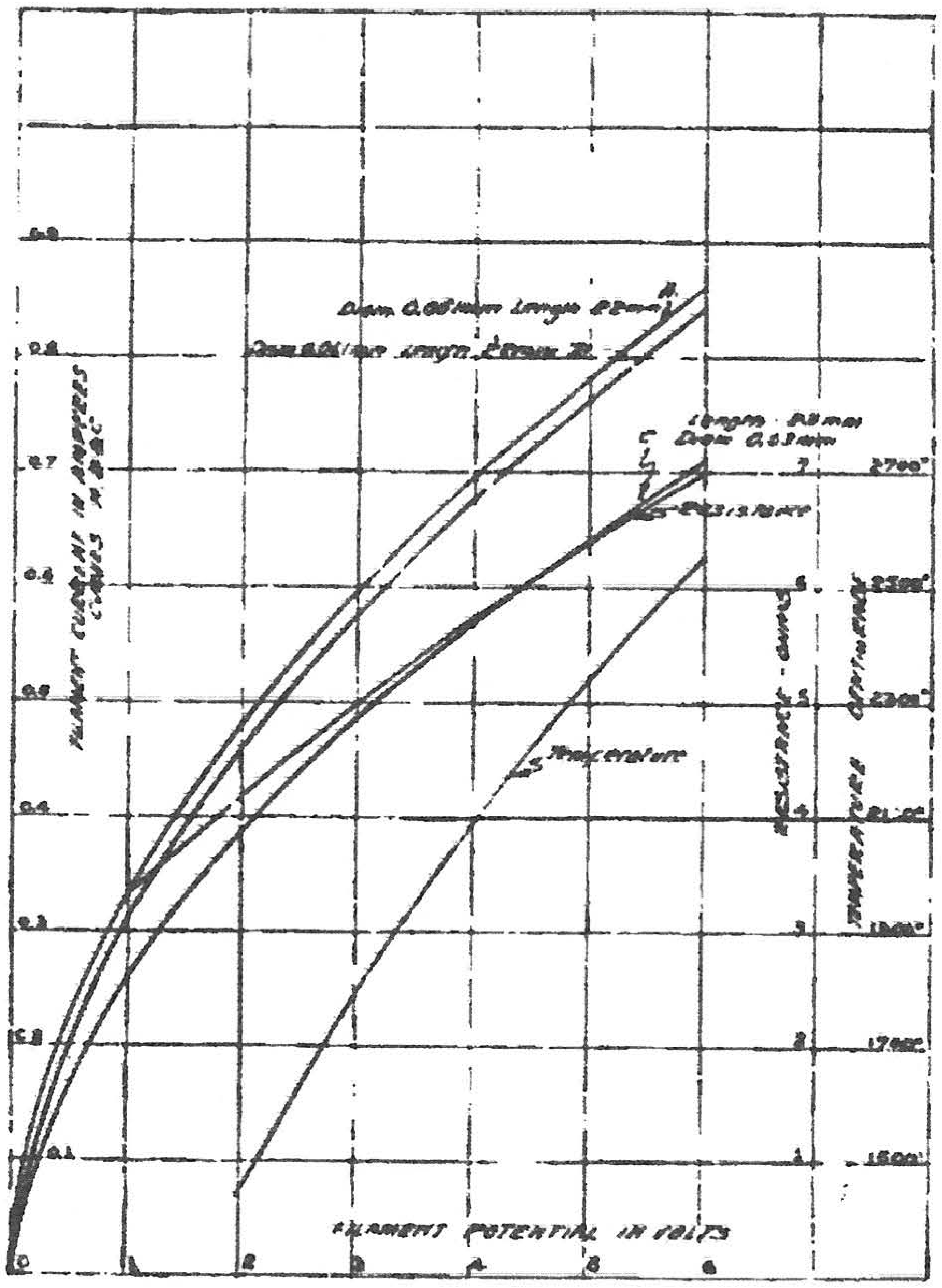


FIGURE 6

From Figure 6 it will be seen that the filament was at about 2, 100 degrees C. when using 4 volts, and that its temperature is raised to about 2,600 degrees C. using 6 volts. It was the authors' intention to give an account of every test at 4, 5, and 6 volts on the filament, but such comparative tests will be reserved for the future.

The electronic mission has been carefully studied by Richardson, who expressed the law governing the emission of electrons in an equation analogous to the equation of evaporation of liquids. This equation appears below, together with sample calculations of the current. The two constants entering into the equation were taken as calculated for tungsten by Langmuir.

The length of the filament being 23 mm. (0.905 inch) between the supports, or about $23 \times 1.3 = 29.9$ mm. (1.18 inch) effective, we have for the exposed area of filament

$$A = \pi d l = 3.146 \times 0.0061 \times 2.99 = 0.057 \text{ cm.}^2 \text{ (0.00086 sq. in.)}$$

Figure 7 shows a graph of the "thermionic" equation given by Richardson which is

$$i = A T^{\frac{1}{2}} \varepsilon^{-\frac{b}{T}}, \tag{1}$$

where T = temperature of filament (Kelvin or absolute)

$$a = 23.6 \times 10^9$$

$$b = 52.5 \times 10^3$$

or

$$i = 23.6 \times 10^9 \, T^{\frac{1}{2}} \varepsilon^{-\frac{52500}{T}} \text{ milliamperes/cm.}^2$$

Calculated emission at 2,100 degrees C.,

$$i = 14.95 \times 10^{-3} = 853 \times 10^{-6} \text{ amps.}$$

The above results represent the maximum electronic emission available at the surface of the filament as the equation is strictly "thermionic" and does not take into consideration the presence of a charged body or the separating space between, same.

On the other hand, we have an equation giving the maximum current in the cylinder with the wire filament at the axis of the same.

$$i_{max} = 14.65 \times 10^{-6} \frac{V^{\frac{3}{2}}}{r} \text{ amps./cm. length of the cylinder} \tag{2}$$

$$V = \text{applied potential}$$

$$r = \text{radius of the cylinder.}$$

Calculating the current which would flow in a tube having 10 mm. (0.394 inch) diameter plate and 15.2 mm. (0.6 inch) long, we would have for 10 volts potential of the plate

$$i_{max} = 14.65 \times 10^{-6} \times 1.52 < \frac{\sqrt{1000}}{0.5} = 14.1\,(10)^{-4} \text{ amps.}$$

This equation does not take into account the temperature of the filament, which is not quite correct, as the temperature of the filament has an effect on electronic emission,

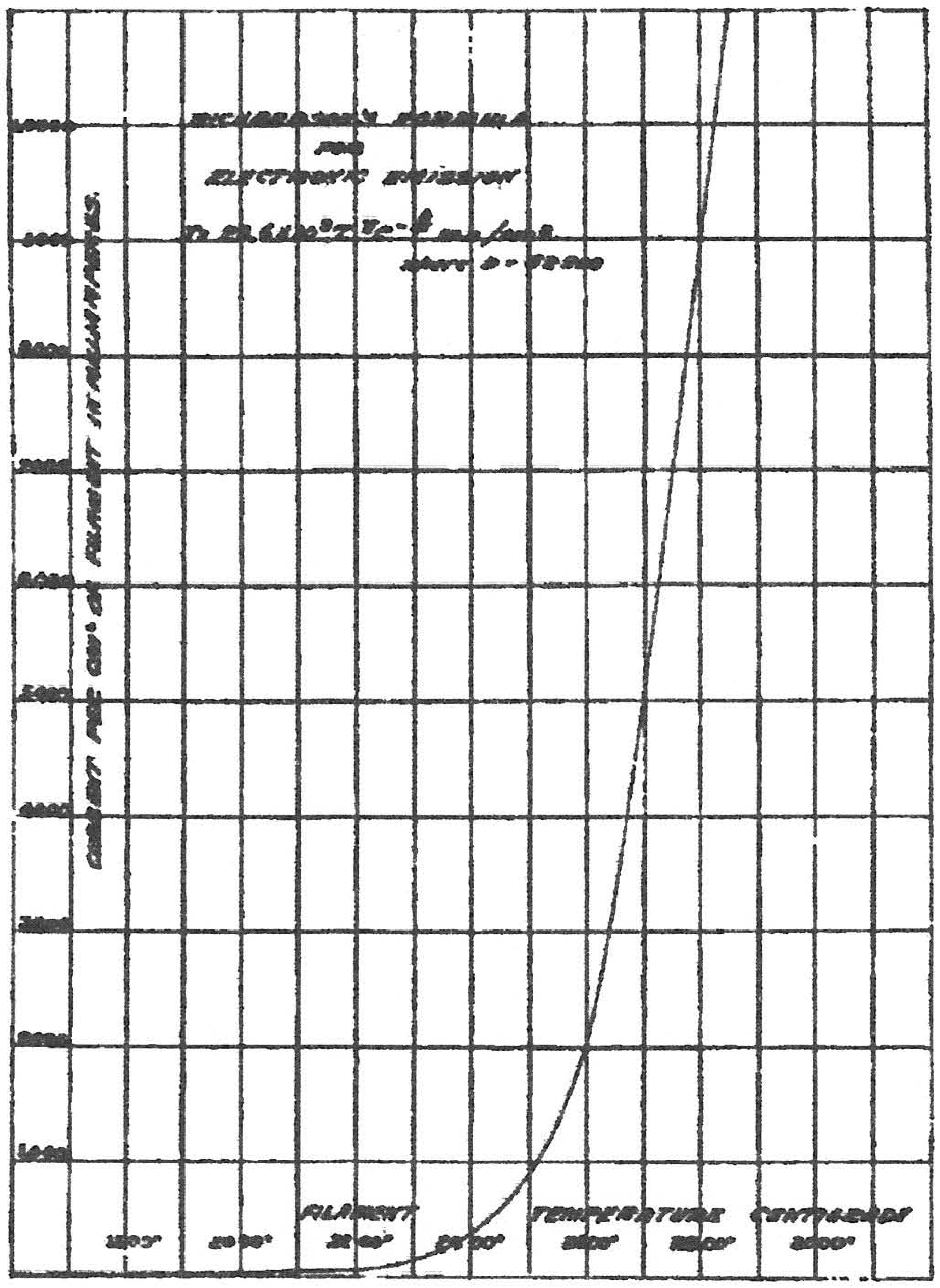


FIGURE 7

more noticeable as the potential increases. Figure 8 shows the plate potential curves of two hard vacuum tubes without grids at 4 and 5 volts filament potential; two soft tubes without grids were also tested and it will be noted that, up to the potential of 10 volts on the plate, the curves show uniform rise but for the higher potentials on the plate the saturation of the soft tubes becomes very marked. The difference between the 4- and 5-volt curves is very slight, demonstrating that the increase of the temperature of the filament does not materially increase the flow of the current. Carrying out the calculation for 20 volts plate potential, we will have

$$i_{max} = 14.65 \times 10^{-6} \times 1.52 \times \frac{\sqrt{8000}}{0.5} = 39.9\,(10)^{-4} \text{ amps.}$$

The theoretical curves have been plotted in Figure 8. The curve in dashes indicating the position the curve for 5 volts should be corrected as the voltmeter was later found to be reading 1.5 volts too high.

With the above correction, the theoretical and the actual curves are brought close together.

Examining the equation for the current of the tube with cylindrical elements, or

$$i=\frac{2}{9}\left(\frac{2e}{m}\right)^{\frac{1}{2}}\frac{V^{\frac{3}{2}}}{r},$$

we note that the diameter of the filament wire is not taken into consideration at all. The formula makes it appear that the current is altogether independent of the diameter of the filament, which, in the opinion of the authors, is not correct. As will be demonstrated later, the size, or diameter, of the filament is a very important factor in the analysis of the action of the tube and in determining the velocity of emission of the elementary charge. Reference may be had to the curve of forces due to an electric

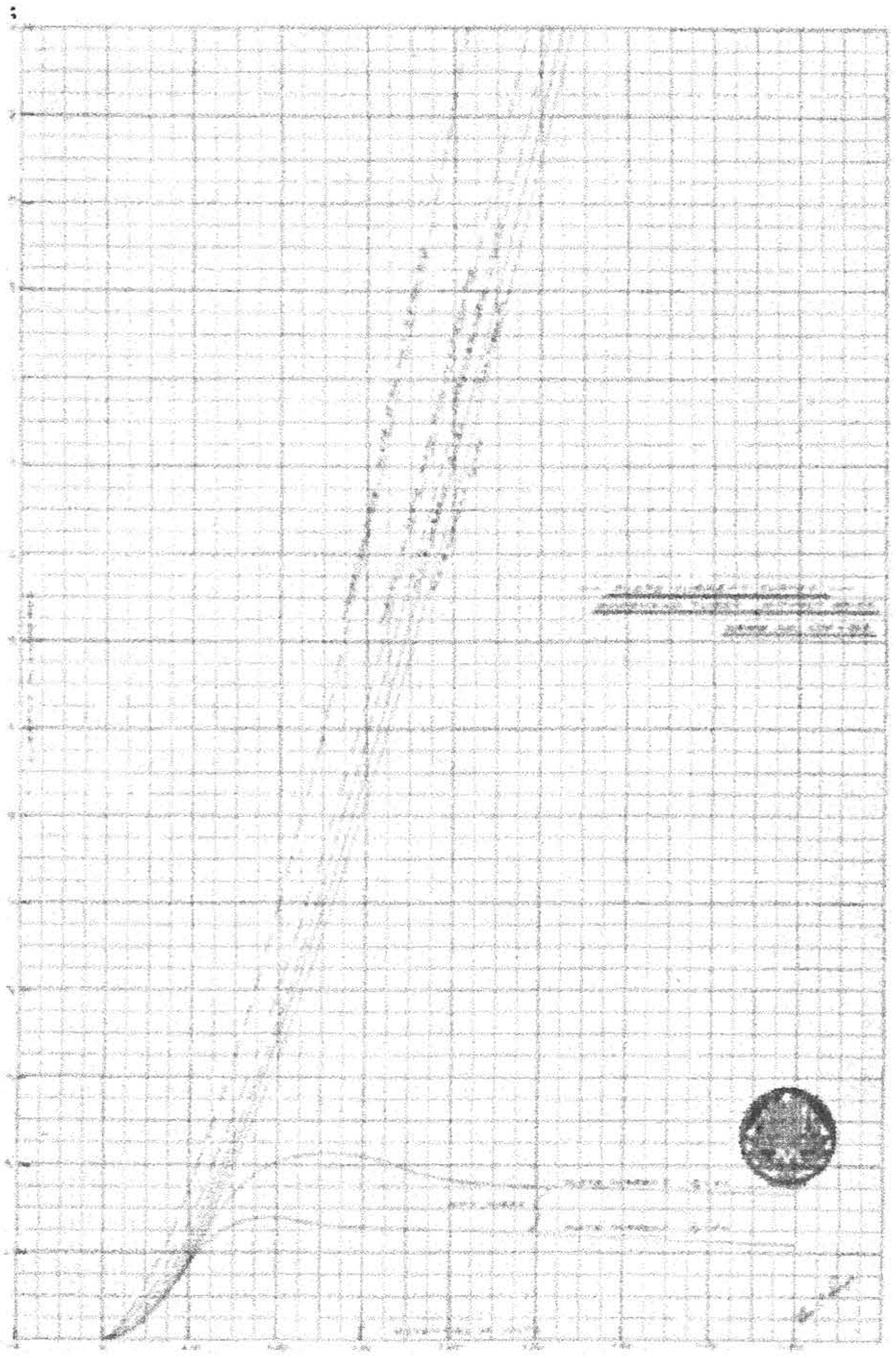


FIGURE 8

charge on a cylindrical conductor such as filament. The formula gives higher results than are obtainable in actual tubes.

Figure 9 gives a series of plate and grid currents, with all elements assembled in place, except one which shows the curve of the plate current of a two-element tube (the same as Figure 8).

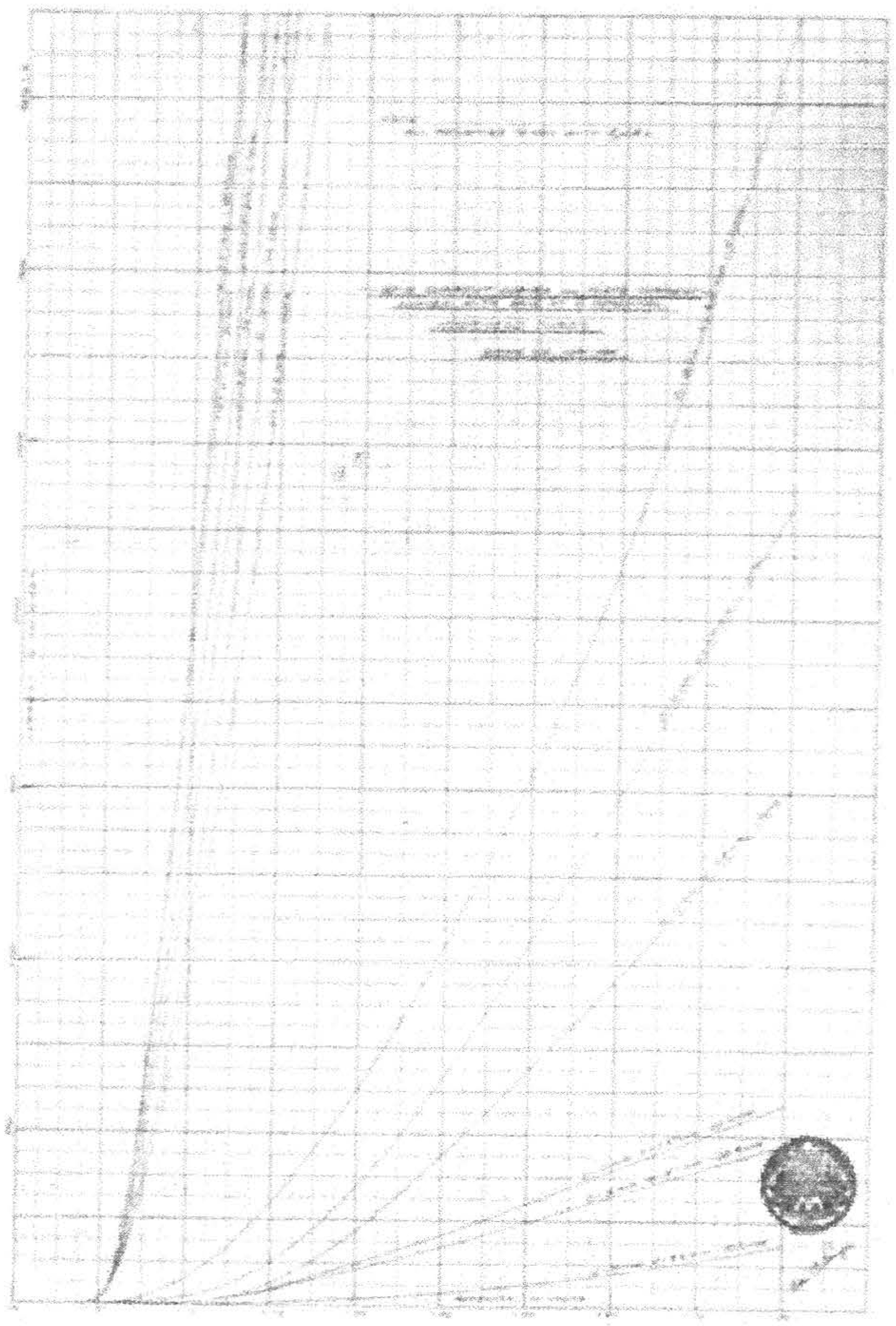


FIGURE 9

Studying the curves we will find that the plate-current curve of the gridless tubes runs together with grid current curves. All other curves represent the plots of readings of plate-filament current, with grid kept at zero potential by grounding it; when taking grid-filament current readings the plate was grounded. (No difference in readings was noted when grid or plate were not grounded). Each curve on this drawing very closely follows the equation

$$Y = A X^3$$

This equation appears to express the law governing the operation of any two-element valve, within the limits of saturation, The saturation point of the valve depends on the filament temperature and the potential difference between the filament and the anode. The difference between the results as given by the "thermionic" equation (1), and equation (2), is evidently due to acceleration of emission due to applied potential. This may also explain the difference between the slopes of the calculated curves and those plotted from actual tests.

It will be noted that checking the curves from point to point, the rise of the curves is not exactly in the ratio of $\frac{V_2^{\frac{3}{2}}}{V_1^{\frac{3}{2}}}$, but is more correctly in ratio of $\frac{V_2^{\frac{3}{2}}}{V_1^{\frac{3}{2}}}k$, where $k < 1$, and may be taken as a factor giving the difference of total potential applied minus the potential required to force the emission of electrons in excess of natural emission, or emission which would take place if the filament were removed from the influence of a charged body.

Figure 10 gives the plots of tests of the grid-filament current characteristics. The sketches of Figures 11 to 14 inclusive show the same curves to the smaller scale. From the curves, it is evident that the same law of the flow of current applies in this case also. Three different sizes of grids were tested, in each case the plate was grounded and thus kept at zero potential.

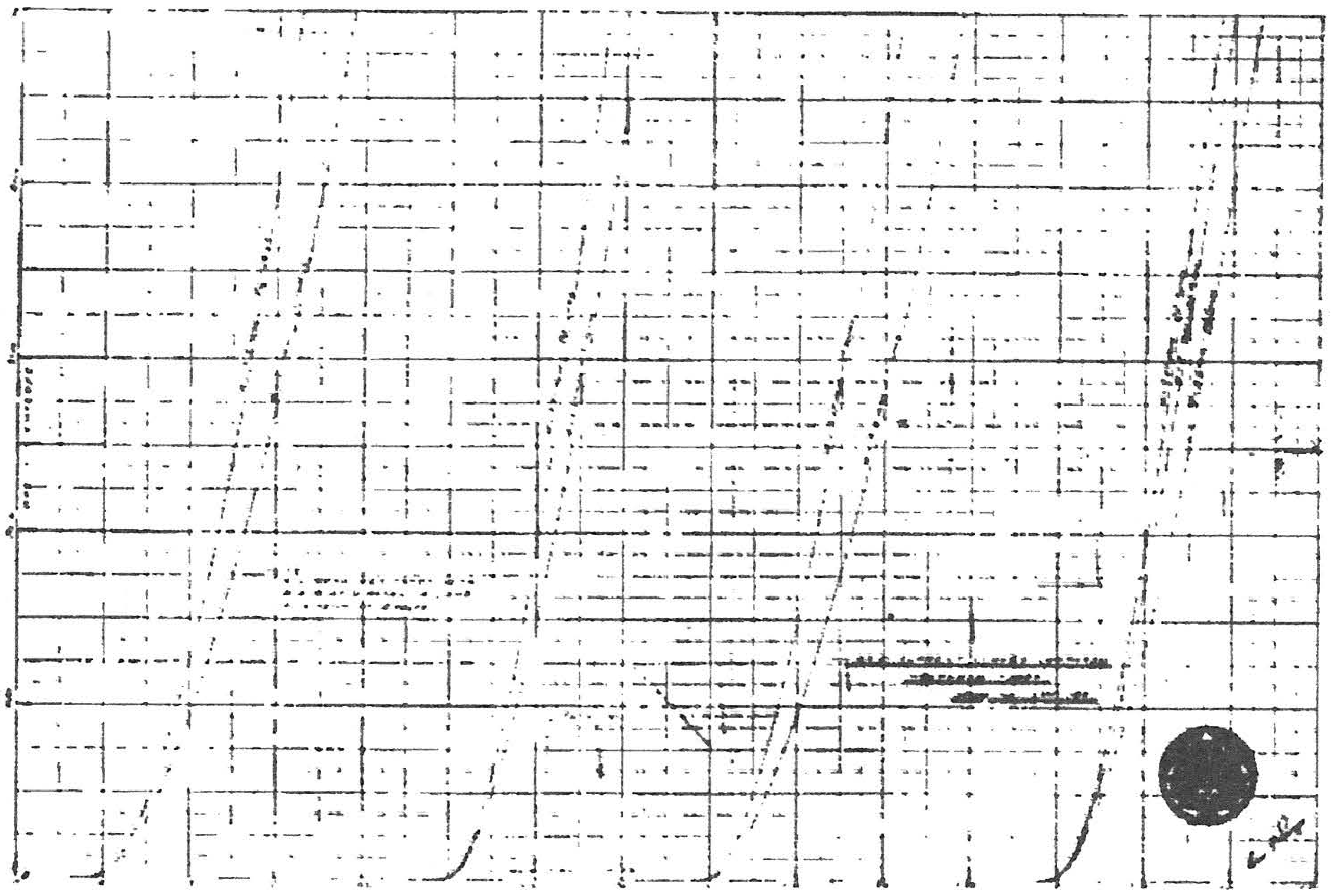
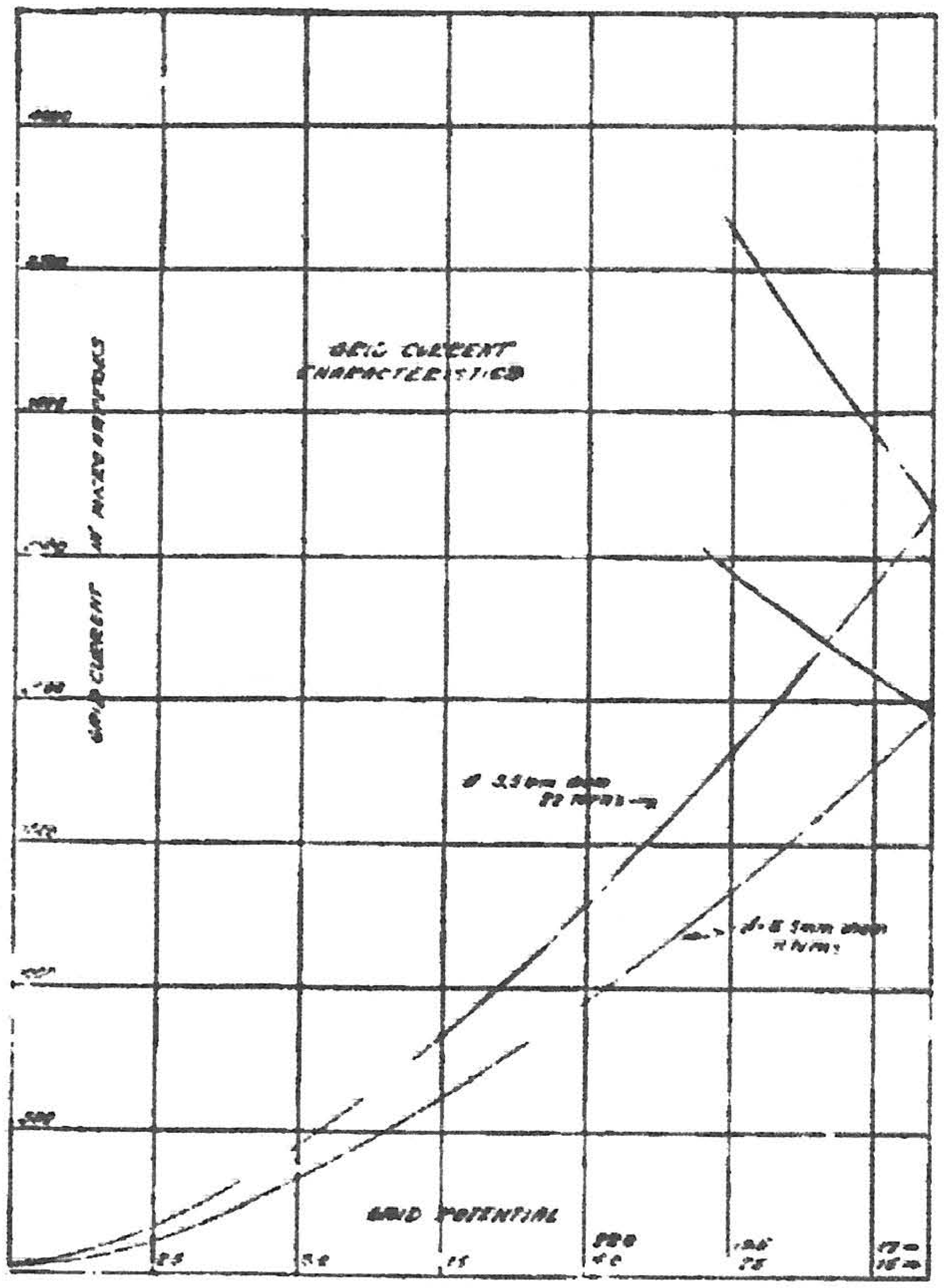


FIGURE 10

Figures 11 thru 14 represent the grid potential-grid current curves. The tests were taken with grids 11 and 22 complete turns, 3.37, 4.1, and 5.5 mm. (0.133, 0.162, and 0.217 inch) diameters respectively (these diameters are the diameter of mandrels used in the winding of the grids and, therefore, represent the inside diameter of the grid spiral). The wire used was 0.010″=0.254 mm. diameter The pitch of winding for the 11-turn grid was 1.5 mm. (0.059 inch), that for 22-turn grid was 0.75 mm. (0.0295 inch).

Figure 15 gives grid potential-grid current characteristic of a tube having grid and filament only. The same drawing shows three computed curves for plates of length equal to the length of grids and of the same internal diameter. It will be noted that the ratio of values of plate current to that of the grid of the same diameter and length, depends on the number of turns of the grid and its distance from the filament.

Figures 11 and 12 (Curves 1 and 2 in Figures 13) show two sets of grid current curves; Figure 7 shows curves for 5.5 mm. (0.217 inch) inside diameter grid, Figure 11 for 3.37 mm. (0.133 inch)



FIGURES 11

diameter grid. These two sets of curves give the variation of current as a function of number of turns, and show that by doubling the number of turns of the grid we do not double the current. The difference between the values of current for the same size of grid but different number of turns appears to be not only a function

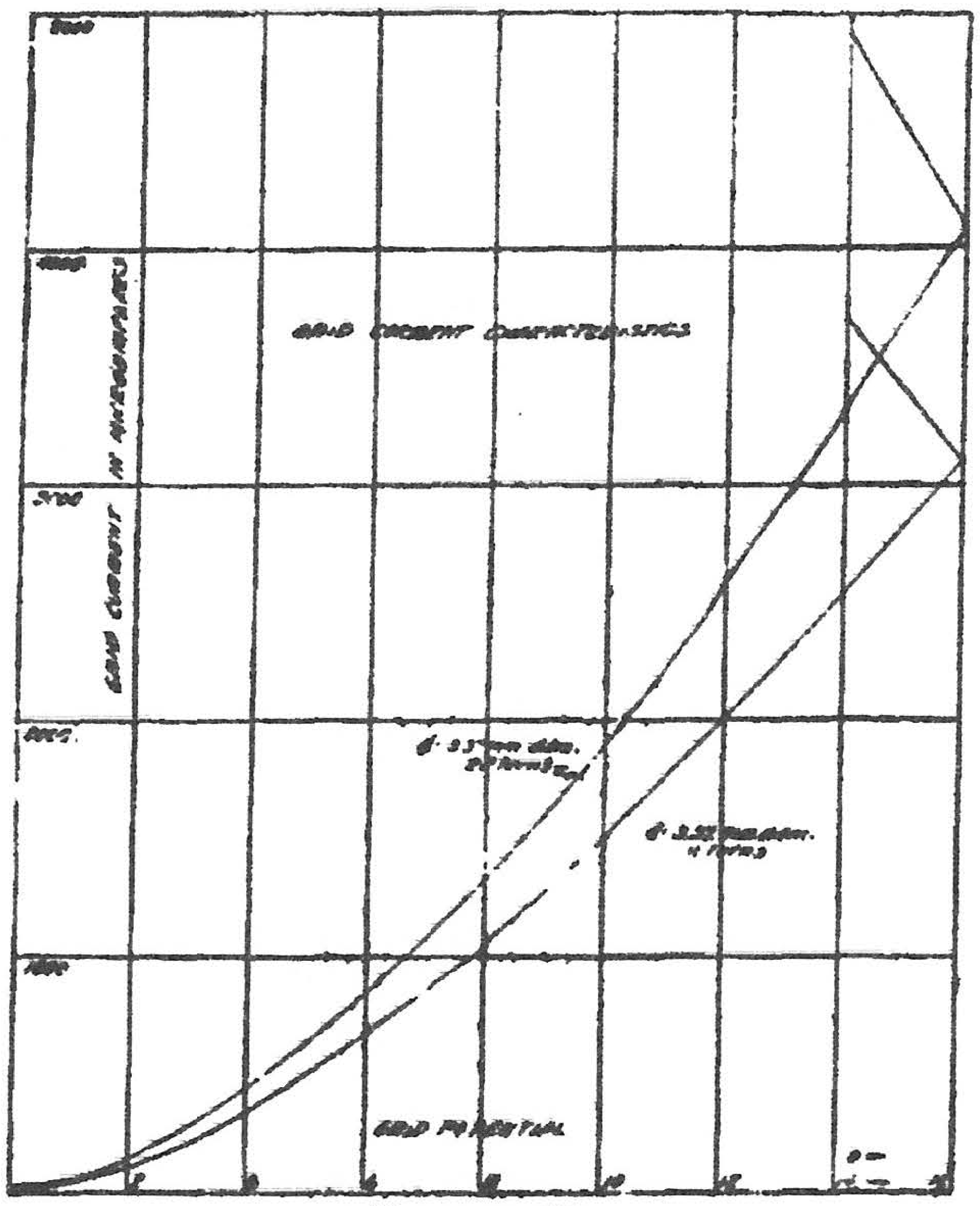


FIGURE 12

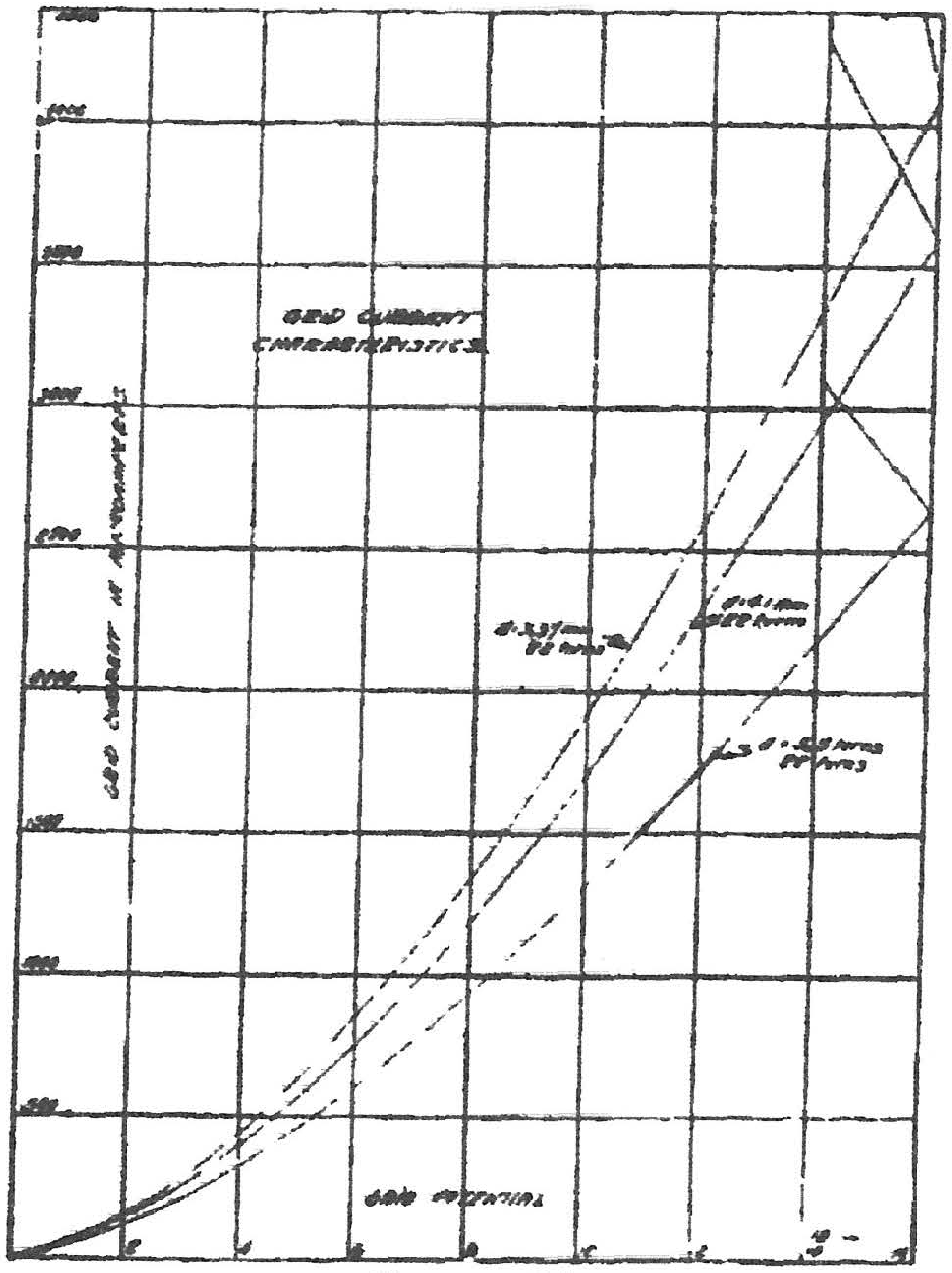


FIGURE 13

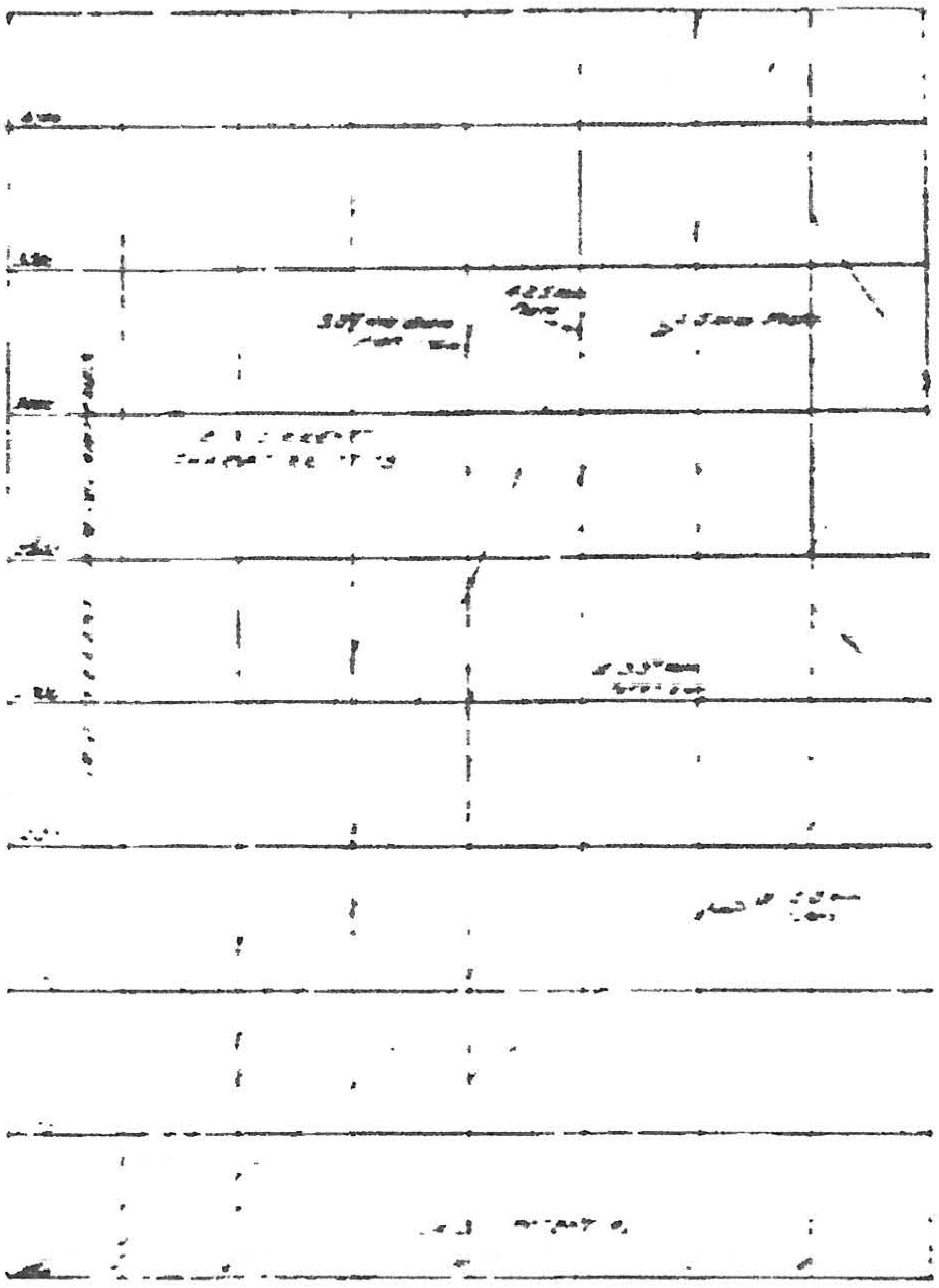


FIGURE 14

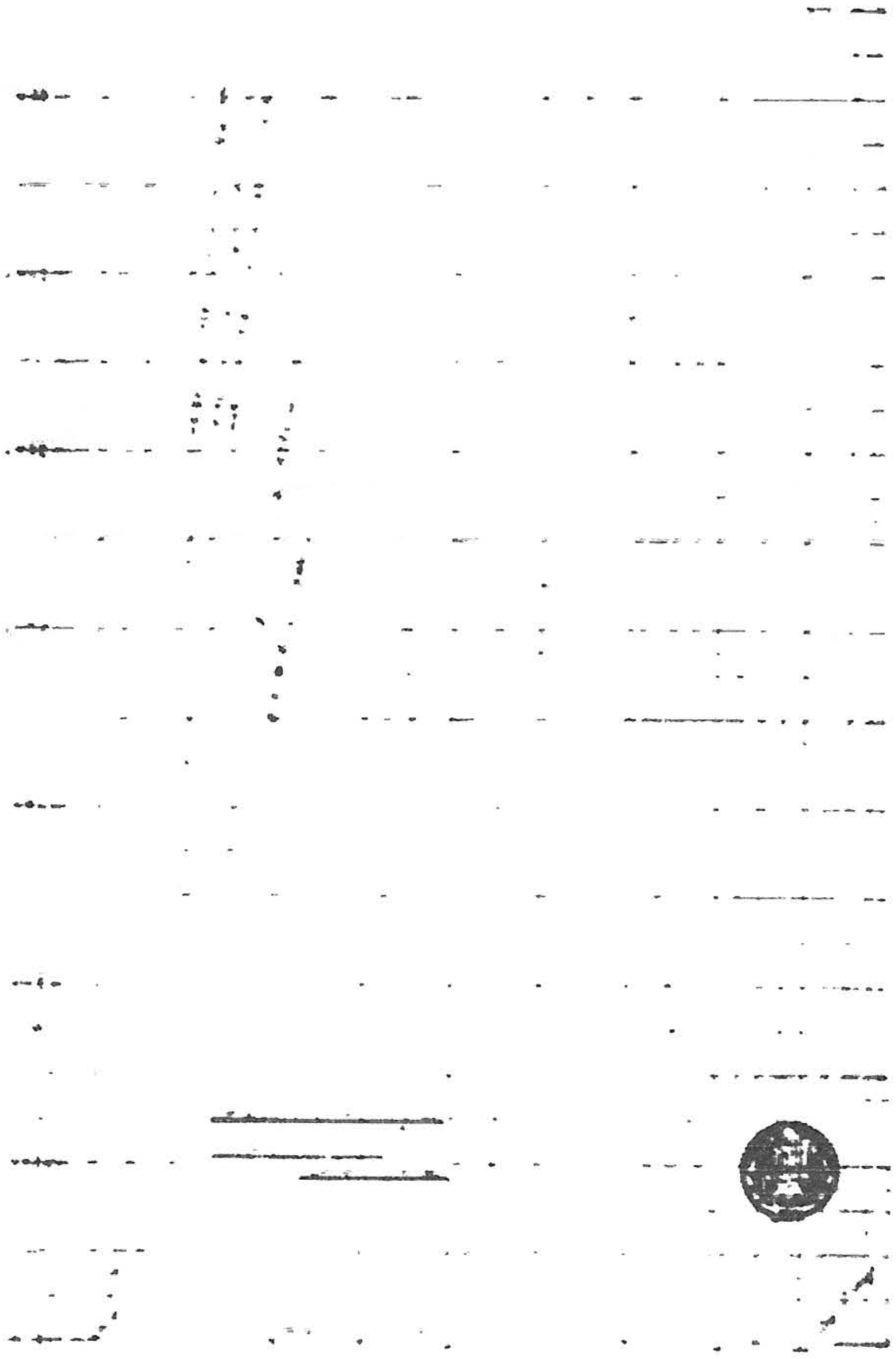


FIGURE 15

of the number of turns but also a function of its distance from the filament and the potential applied. The determination of this function, we believe, will completely solve the problem of mathematical predetermination of characteristics. Two curves in Figure 16 show the variation of current difference with varied potential for 11- and 22- turn grids, and it will be noted that the slope of the curve 3.37 mm. (0.133 inch) grid is considerably greater than that of 5.5 mm. (0.217 inch) grids. The variation of grid current as a function of the diameter turns is clearly shown in Figure 13, representing the current curves for 3.37, 4.1, and 5.5. mm. (0.133, 0.162, and 0.217 inch) diameter grids. The curves show a certain consistency, but do not follow exactly the ratios of their diameters.

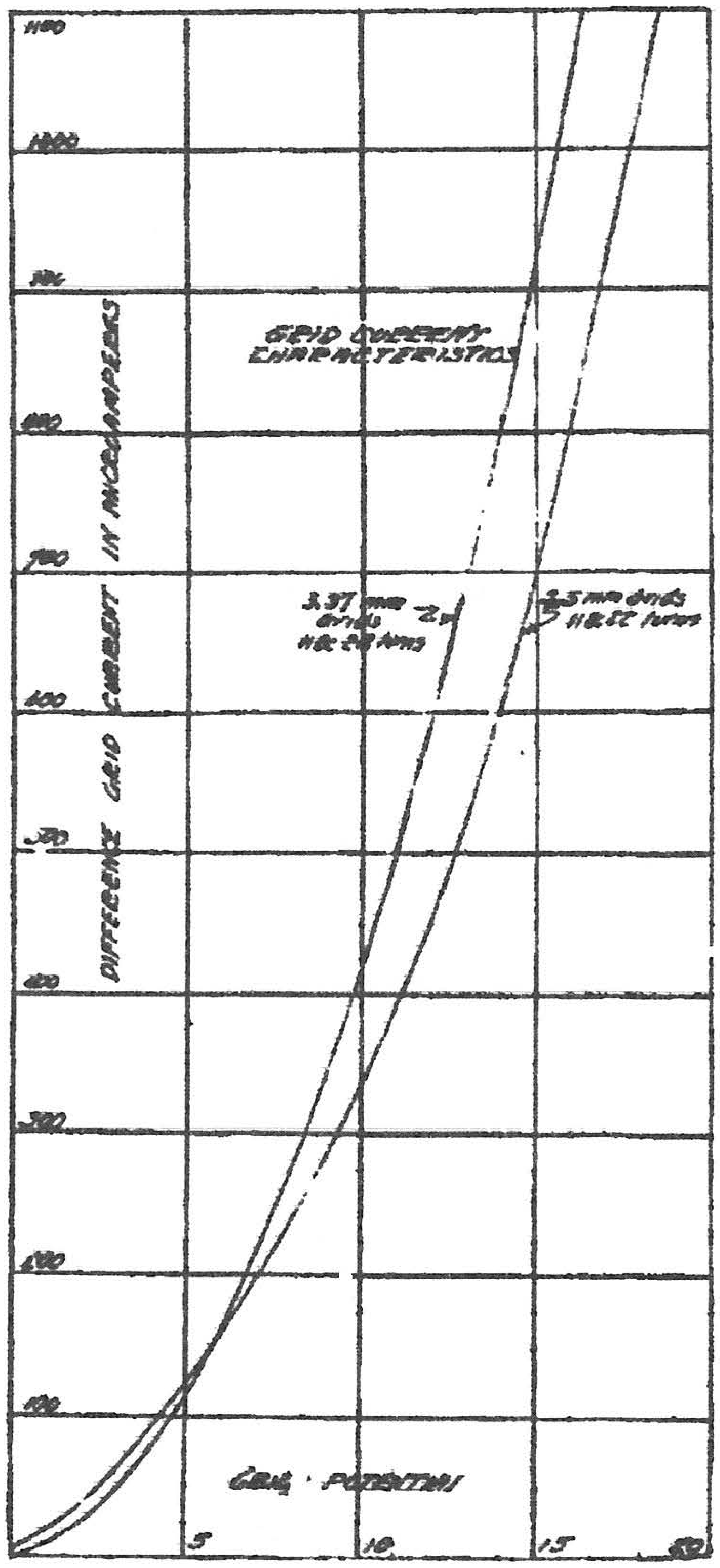


FIGURE 16

Figure 17 gives the curves of grid current differences as function of diameters of the grid and the potential applied. Here the curve for 22-turn grid shows a greater slope than that of 11-turn grid. It is impossible for the authors to present at present

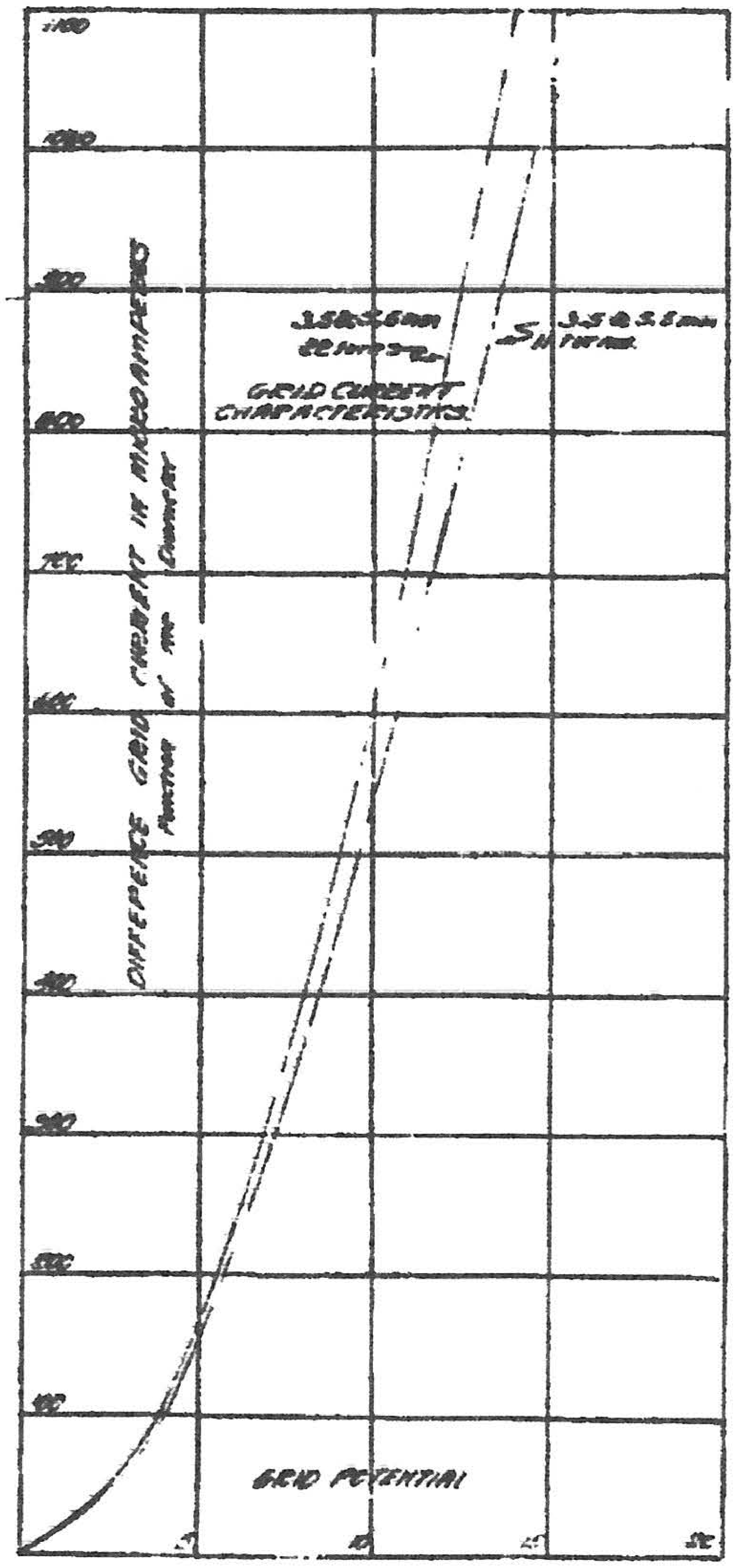


FIGURE 17

a complete analysis of grid action, as the observations and experiments are not complete. Several special tubes will have to be made and carefully tested before conclusive interpretation of the grid action may be given.

It is the writers' opinion that the action of the grid is dependent upon the distribution of the charge on the grid; due to its non-uniform distribution, the path taken by the elementary charge diverges from a straight line, as it would if no charged body were present near the filament. The grid consisting actually of a number of rings will produce a field as indicated on the attached force diagrams, Figures, 18, 19, and 20. These force

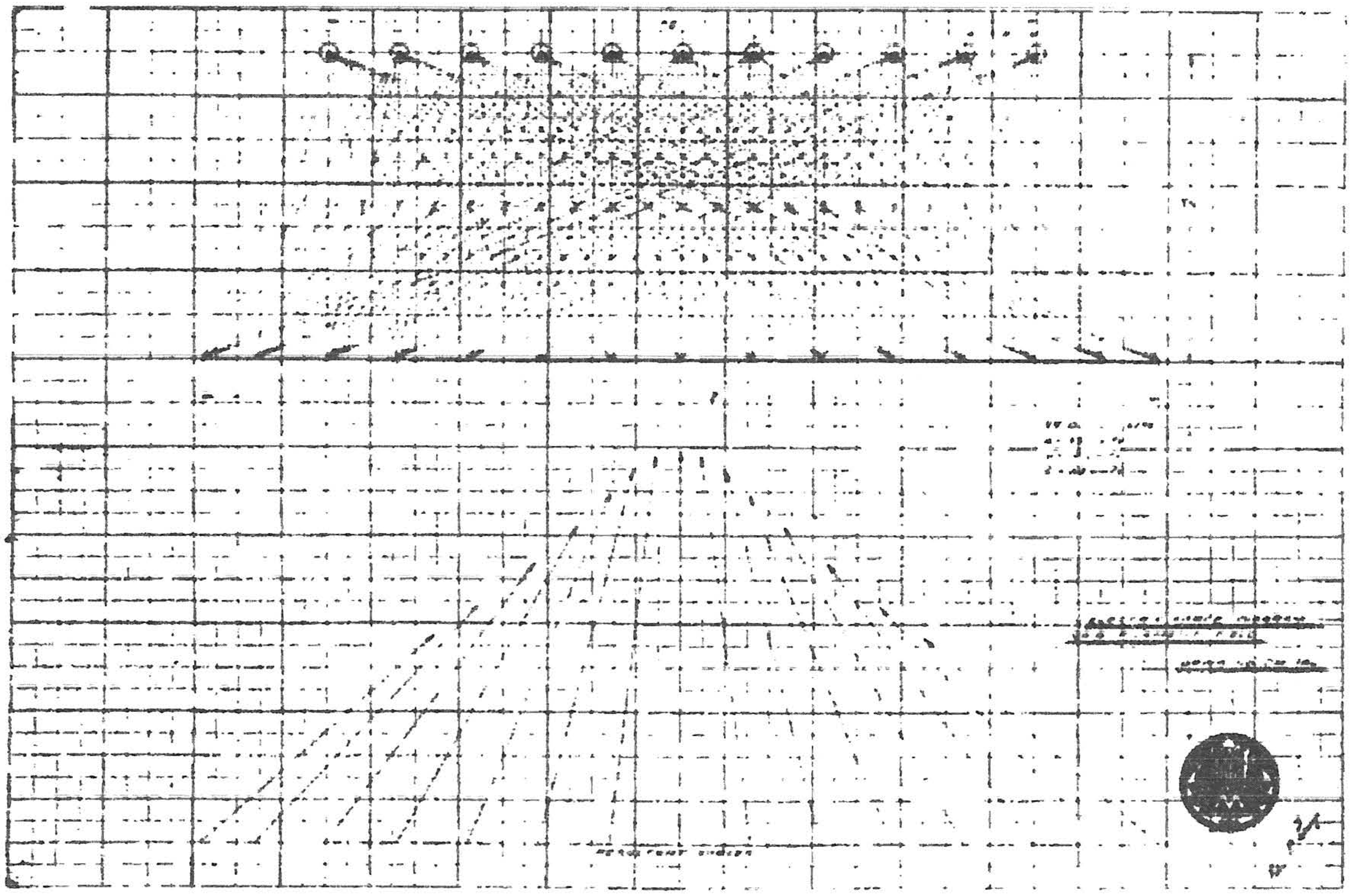


FIGURE 18

diagrams indicate that the moving charge, purely under the action of grid, without the action of any body placed outside the grid, will be crowded toward the center turns of the grid, this action becoming more and more apparent as the diameter of the grid decreases. The diagrams were drawn for arbitrarily assumed values for the diameter, spacing, and so on, with the sole intention of studying the resultant action of a number of rings, or turns, placed concentrically with regard to the filament. The curves on Figure 21 represent the values of forces from point to point extending thru the whole length of the filament; the values of the resultant forces were taken disregarding their direction, for 1, 3, 5, and so on turns of the grid. The curves are self-explanatory and show very clearly that with increasing number of turns and increasing diameter of the grid, its action on the filament (or, rather, its action in the space between fila-

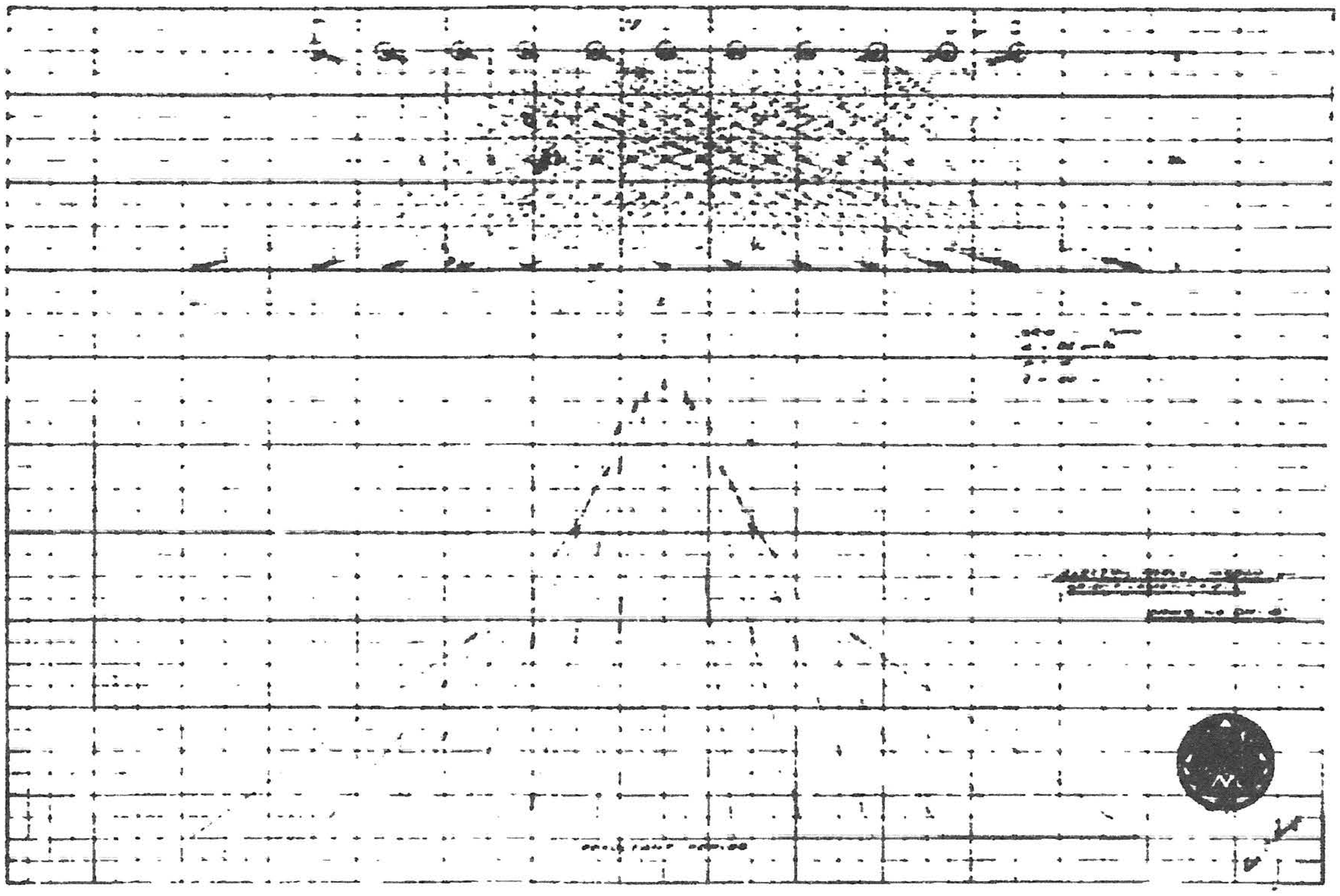


FIGURE 19

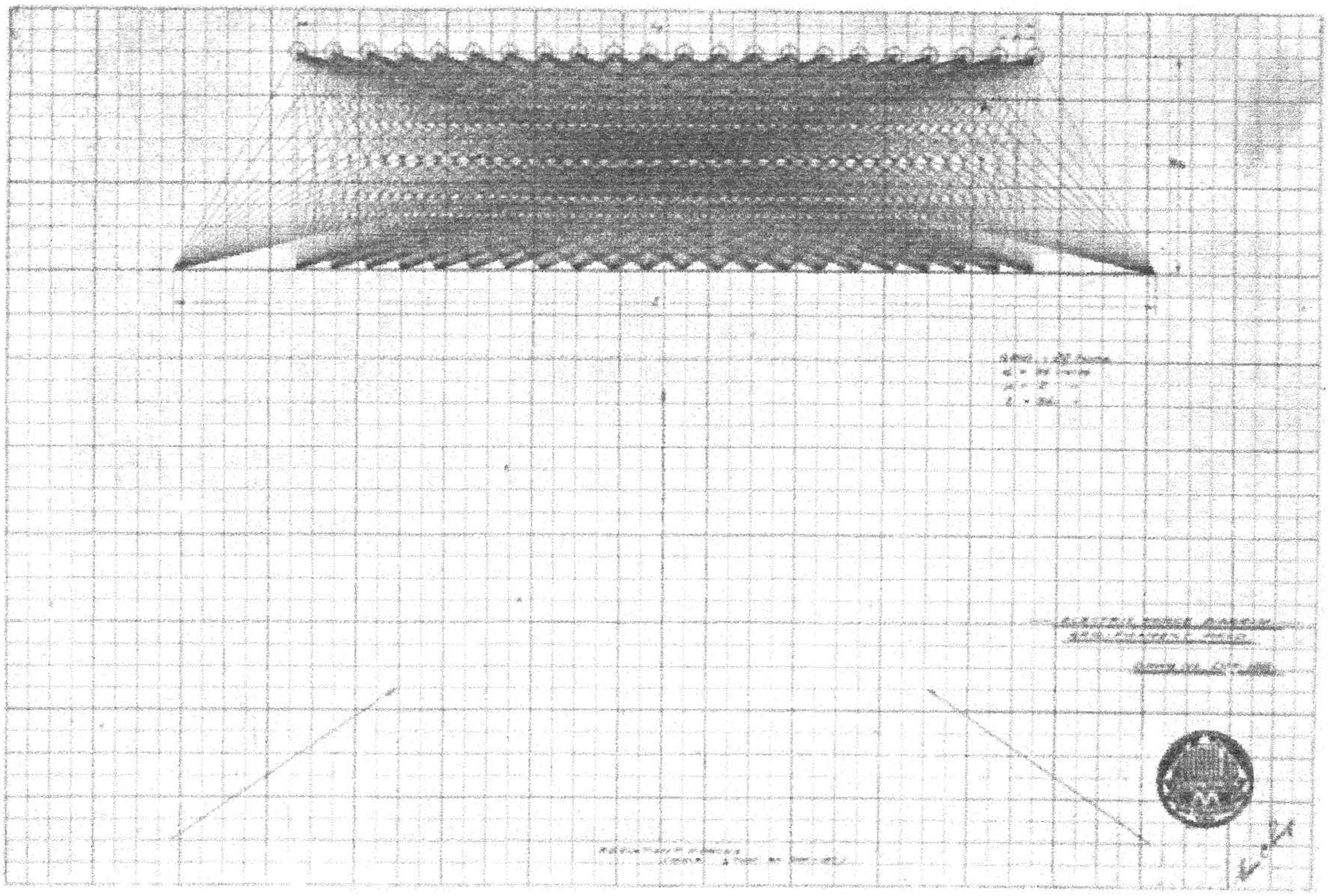


FIGURE 20

ment and grid) becomes more and more uniform. In general, the number of turns, their spacing, and the diameter of the grid and also length of the filament and its diameter, all have to be considered in an analysis of grid characteristics.

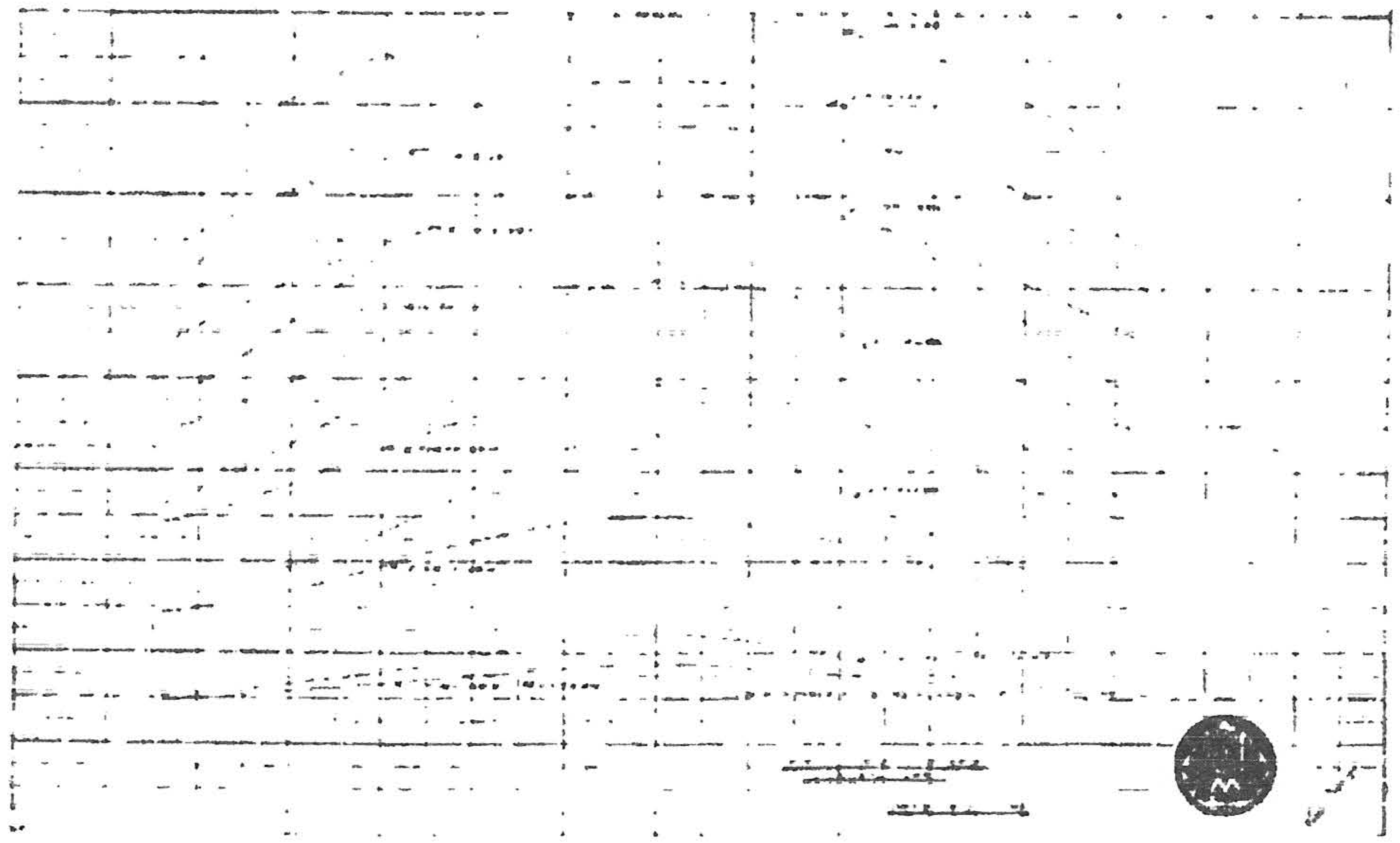


Figure 21

The equation (2), according to the above statement, can not be applied in the case of grid. Studying the characteristics of two-element tubes consisting of the filament and plate only (so-called gridless tubes,) it was observed that in each case the value of current as given by the formula was too high. This fact is very clearly shown by the curves of Figures 8 and 22, and Figure 8 gives comparisons of the plate-filament current of a hard vacuum tube with that of a soft tube at different temperatures of the filament, and also calculated curves for 8 and 10 mm. (0.315 and 0.394 inch) diameter plates. Figure 22 shows tests of 3 tubes with plates 8 mm. (0.315 inch) diameter. (It must be noted that the specified diameter of 8 mm. is not correct by a wide margin for these tubes; the plates were formed by means of a pair of pliers and then very poorly. The curves are shown solely for the purpose of demonstrating how small mechanical defects will alter the characteristics of a tube). All of the three tubes were exhausted at the same time and with the same precaution, yet they show considerable variation as regards the limits of saturation, indicating some condition practically beyond control.

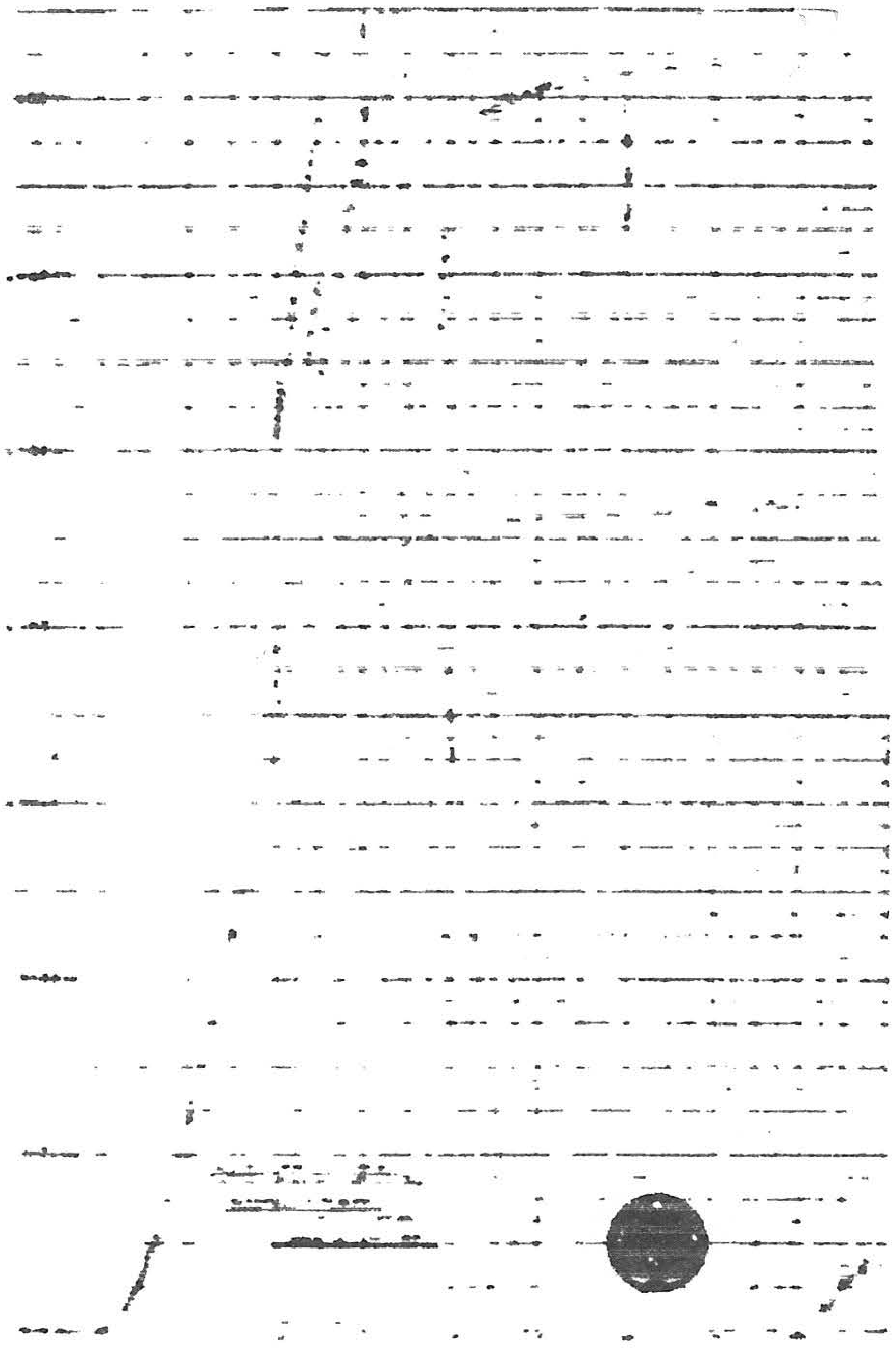


FIGURE 22

In general, it may be said that the plate-filament current at a given temperature of the filament in a two-element tube, consisting of a cylindrical plate and a filament, is a function of the plate diameter, and the diameter of the filament and its length.

Figures 23 thru 27 give the curves representing the values of plate-filament current of hard vacuum tubes, all tubes having the three elements completely assembled in accordance with standard practice. The readings were taken with the grid entirely disconnected (grounding of the grid did not affect the readings at all). Thus the action of the grid was confined to a purely screening action and the results obtained were rather startling. The tubes tested had diameters of the plates varying from 8 mm. to 10 mm. (0.315 to 0.395 inch) and three sizes of grids were used, 3.37 mm., 4.1 and 5.5 mm. (0.132, 0.162, and 0.217 inch) and varying the number of turns from 11 to 22. Due to lack of time, no valves were tested with grid turns between 11 and 22 but it is expected to complete the tests before final mathematical analysis is completed. The determination of exact relations between the geometrical dimensions of the grid and its action on the plate is more difficult than may appear at first, but, in the opinion of the authors, a few more tests will definitely indicate the laws governing said action. Figure 9

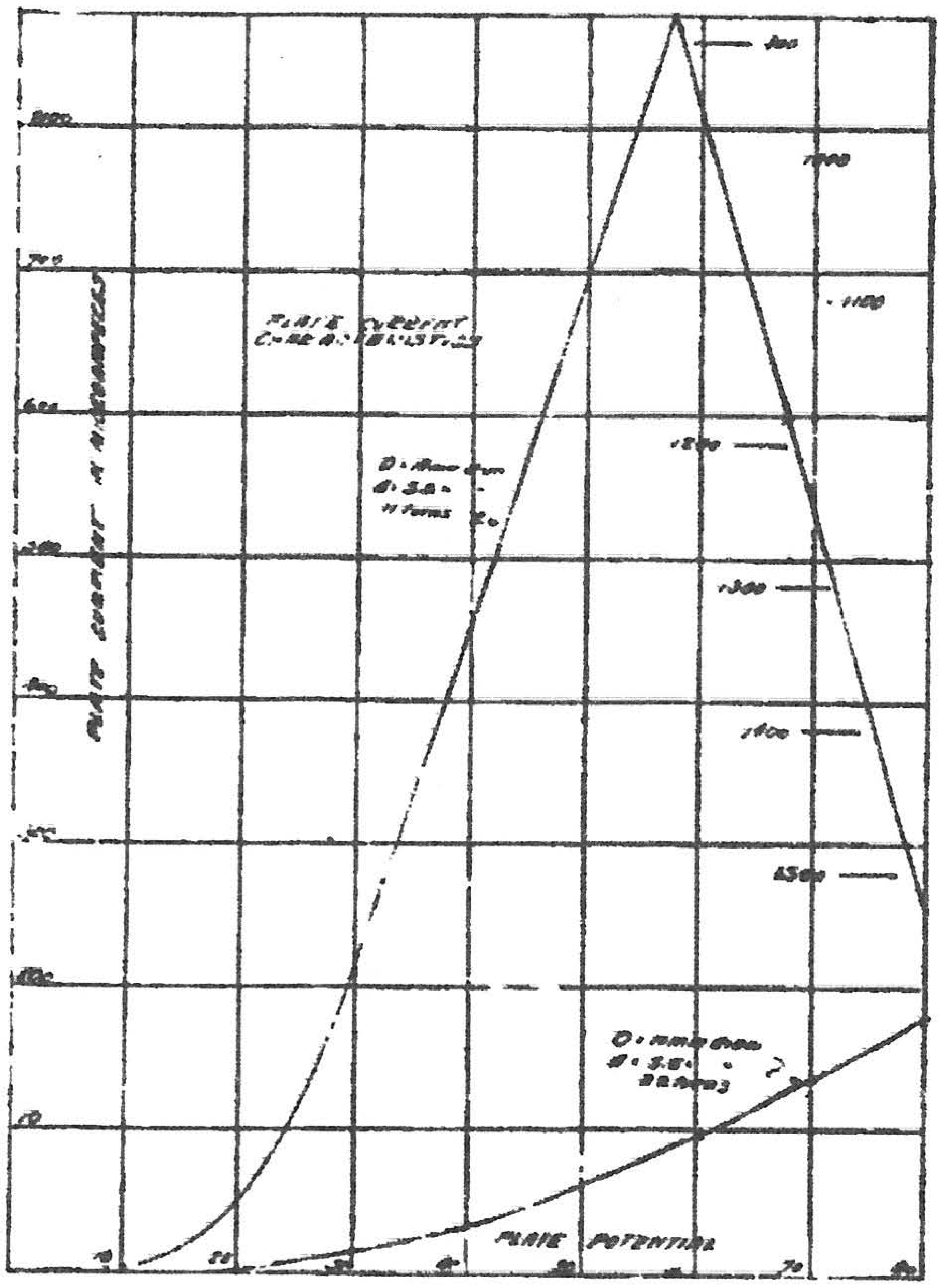


Figure 23

shows the plate-filament and the grid-filament current curves; the plate-filament curves were taken with grid disconnected, and are the same as shown on sketches, Figures 23 thru 27, and are plotted here to the same scale in order to bring out more clearly the action of the grid as a screen; the grid-filament current curves were plotted on the same sheet to demonstrate that one and the same law governs the flow of the current for both plate and grid. It is of interest to note that the plate-filament curve of a gridless tube (D = 10 mm. or 0.394 inch) takes its place in this family of curves among the current curves for grids.

A careful study of the curves will reveal several interesting points. Examining the grid-filament current curves, we note that for the same diameter and the same overall length of grid, the current will be greater the greater the number of turns. The difference in current between two grids of same diameter but of different number of turns seem to be a function of the number of turns only, and is independent of the diameter of the grid. As expected, the larger the diameter of the grid, the smaller the current.

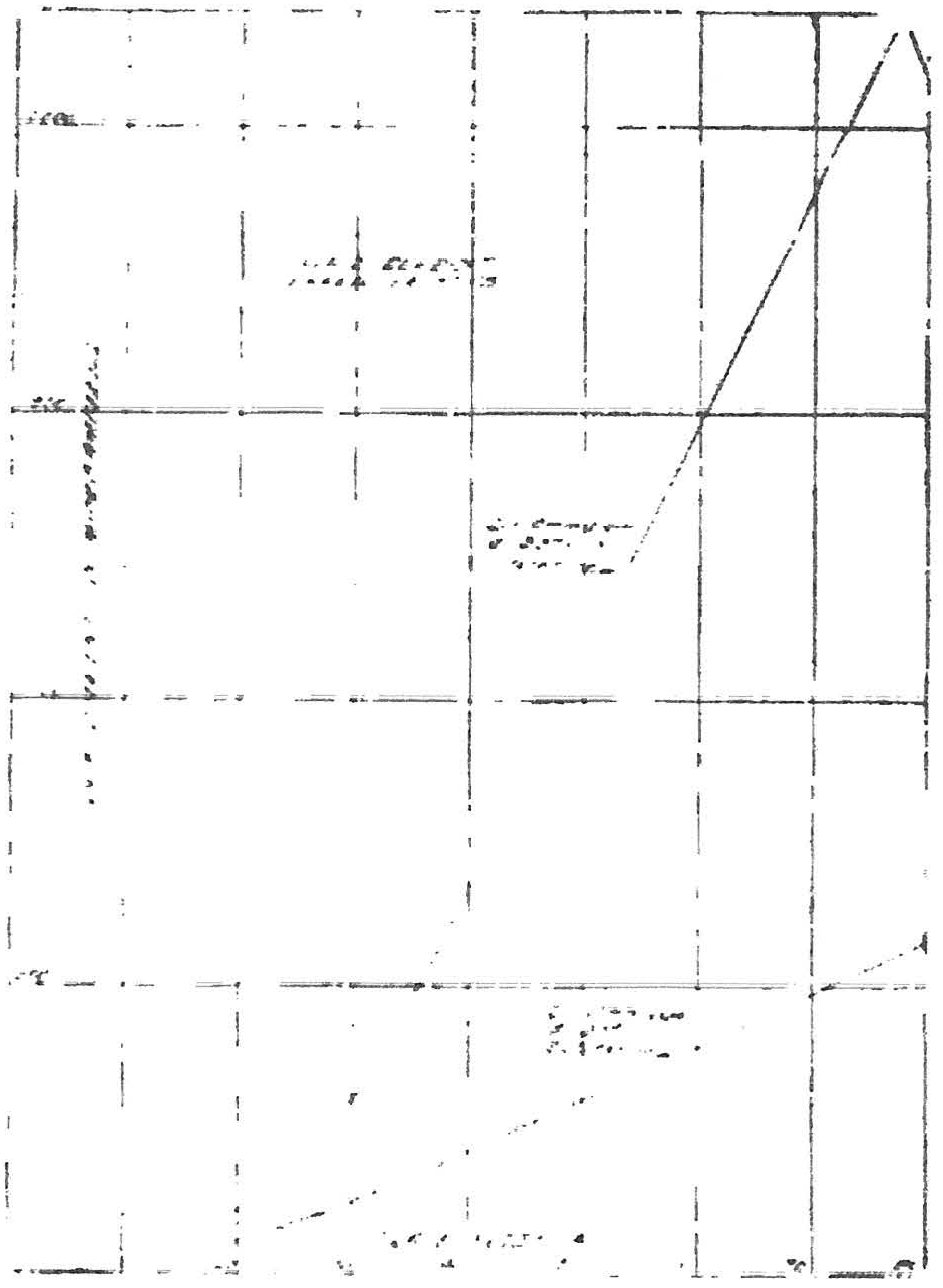


FIGURE 24

We will now compare the plate-filament current curves screened by the grid (grid at zero potential) in greater detail and refer to Figures 23 thru 27. Figure 23 represents current curves of a tube having 10 mm. (0.394 inch) diameter by 15.2 mm. (0.6 inch) long plate ($D = 10$ mm). The diameter (inside diameter) of the grid is $d = 5.5$ mm. (0.217 inch), the pitch of winding for 11-turns grid being 1.5 mm. (0.059 inch), and that for 22-turns grid 0.75 mm. (0.029 inch). These curves show that a slight difference in values at lower potentials of the plate increases very rapidly as the potential increases, the difference varying approximately as the cube of the potential. The same approximate relation is brought out by the curves of Figure 24, which curves were compiled from readings of tubes of same dimensions as those of Figure 17 except that the diameter of the grid was made 3.37 mm. (0.133 inch). Both of the above sets of curves show the plate-filament current, with grid interposed, but at zero potential, as a function of the number of turns in the grid, when overall dimension of the grid and its relative position with respect to other elements were kept the same.

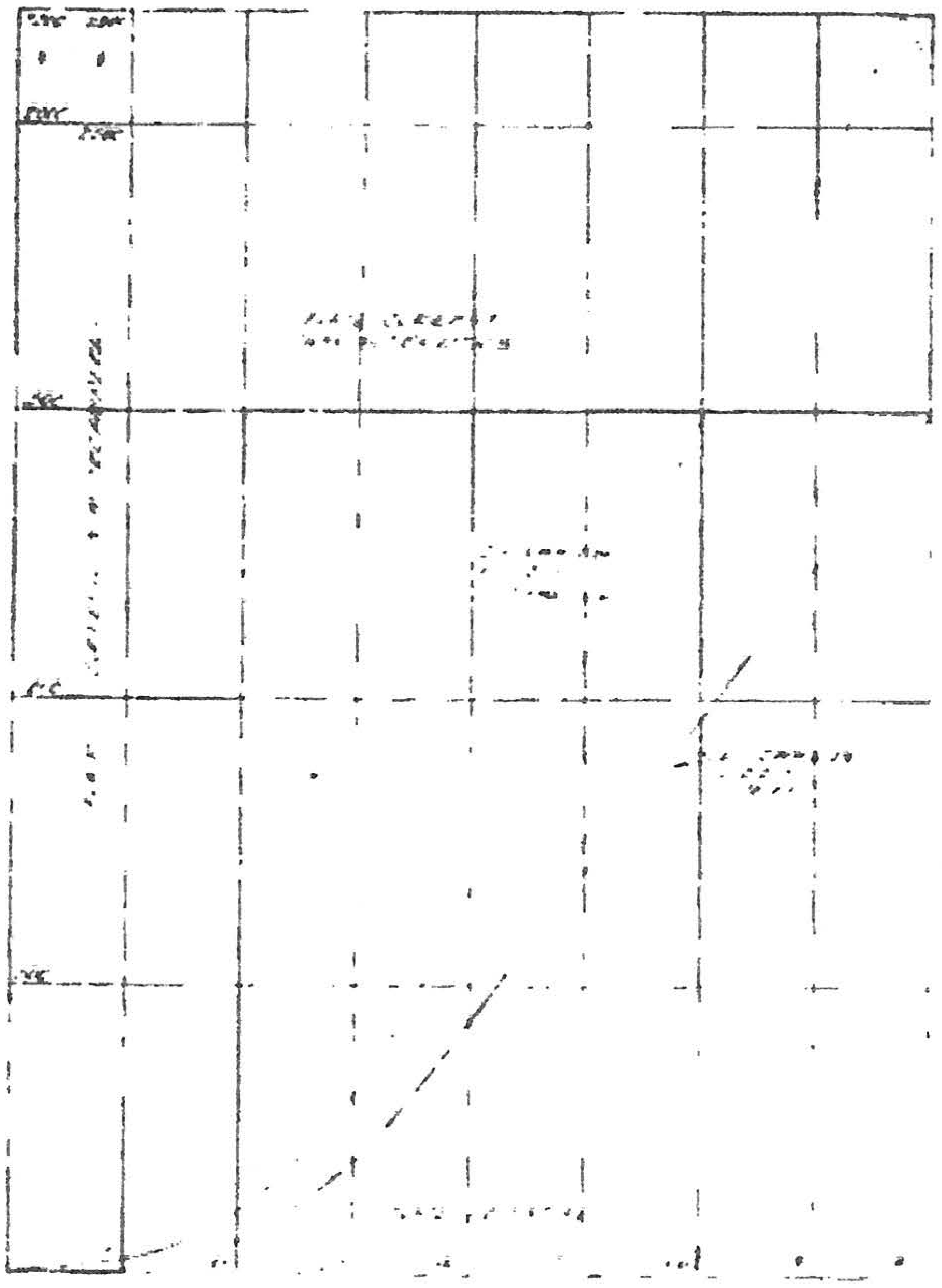


FIGURE 25

To compare now the difference of the flow of plate-filament current, keeping the number of turns of the grid the same but varying its diameter, the curves of Figures 25 and 26 were plotted. The rate of variation of the current as a function of the diameter in this case is not as apparent as in the above case, but no doubt careful investigations and a detailed analysis will permit arriving at the establishing of relations between the flow of the current and the diameter of the grid.

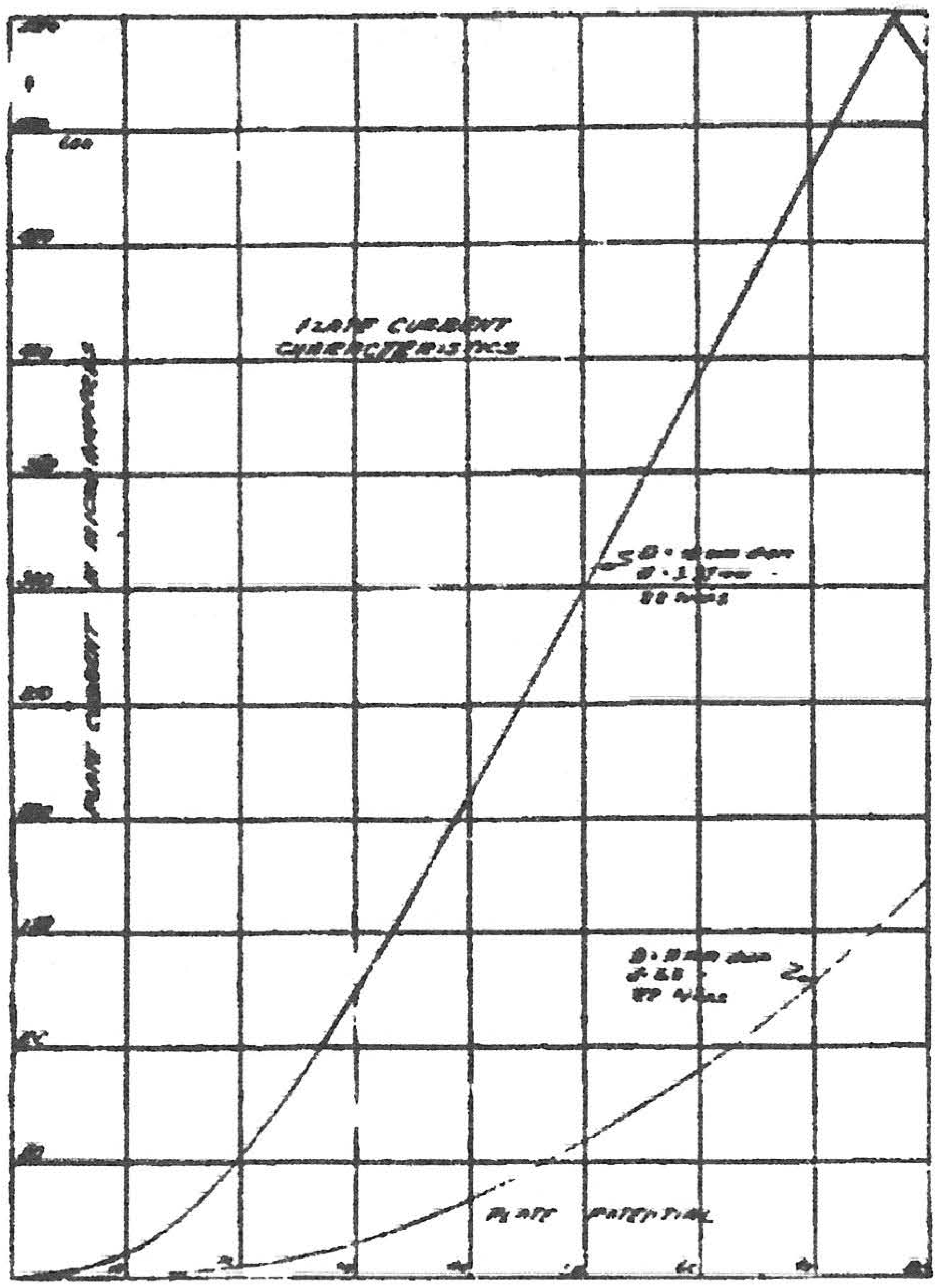


FIGURE 26

Figure 27 shows two curves of tubes having grids and filaments alike in every respect (as near as is possible in their manufacture), but the plate diameters were 8 mm. and 10 mm. (0.316 and 0.394 inch) approximately. In other words, these curves furnish us with information as regards the changes of current as a function of grid-plate distance. With regard to this grid-plate distance, we can state that it appears to have a great influence on the operating characteristics of a tube. As we shall see later, it is this distance that governs the quality of a tube as an amplifier.

We can now take up the study of simultaneous action of all of the three elements of a vacuum tube. Three sets of curves in Figure 4 illustrate completely why it is imperative to duplicate almost all of the foregoing tests. It will be noted from the curves that the three tubes, which, by the way, were taken at random from a large lot, show widely different characteristics. As stated at the very beginning of this article, the causes for such variations are many, and to determine conclusively such causes for the purpose of their elimination, if this be within possibility, it is necessary to carry out series of tests with as many possible variations of dimensions of elements as will be necessary to complete the mathematical analysis. With the aid of such an analysis the various causes tending to distort the characteristics of a tube could be studied with more precision, as could also the possibilities of determining the best which can be expected of a tube.

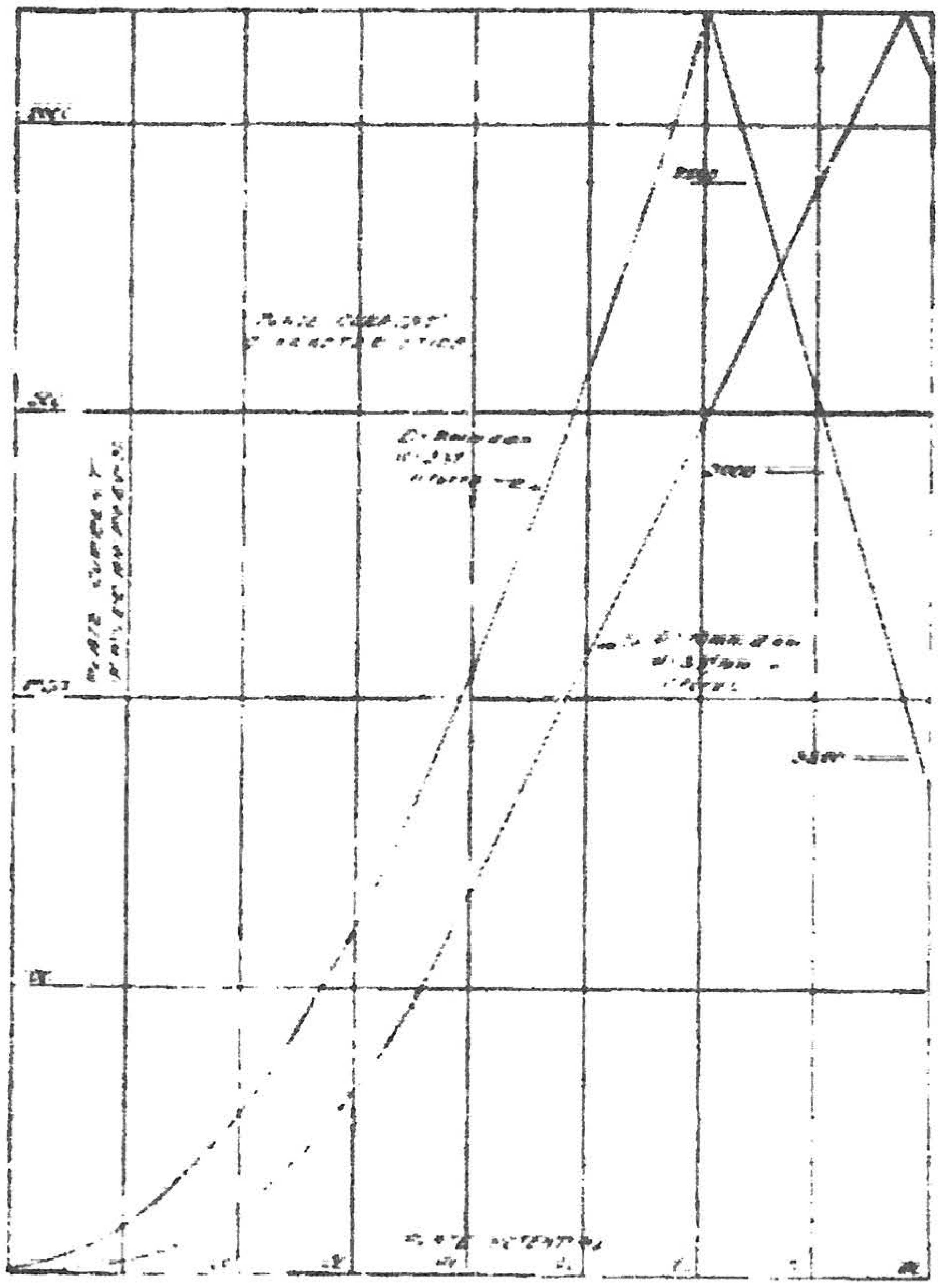


FIGURE 27

Figure 28 shows a complete set of curves of a tube, which by reason of its constancy in action, its characteristics as medium plate-potential amplifier, may be considered a representative type of the vacuum tube. This tube was built for transmitting and amplifying purposes only, and as such has given excellent results. It is the "British B" tube, or Moorhead Type C. These excellent amplifying characteristics were secured by using a 22-turn grid. Comparing with that tube the tube known as "British R" and its duplicate the "SE-1444," we find that by changing the grid from 22 turns to 11 turns, keeping the other elements of the same size, we get a tube which is a fair amplifier and also a fair detector. The characteristic curves of this type tube are given in Figure 2. The tests of the above tubes, together with series of tests carried out on tubes of various dimensions, bring out the fact that to secure best results in the action of a tube as amplifier a certain location of the grid is required, but that, at the same time, this location of the grid is very unfavorable for detector action.

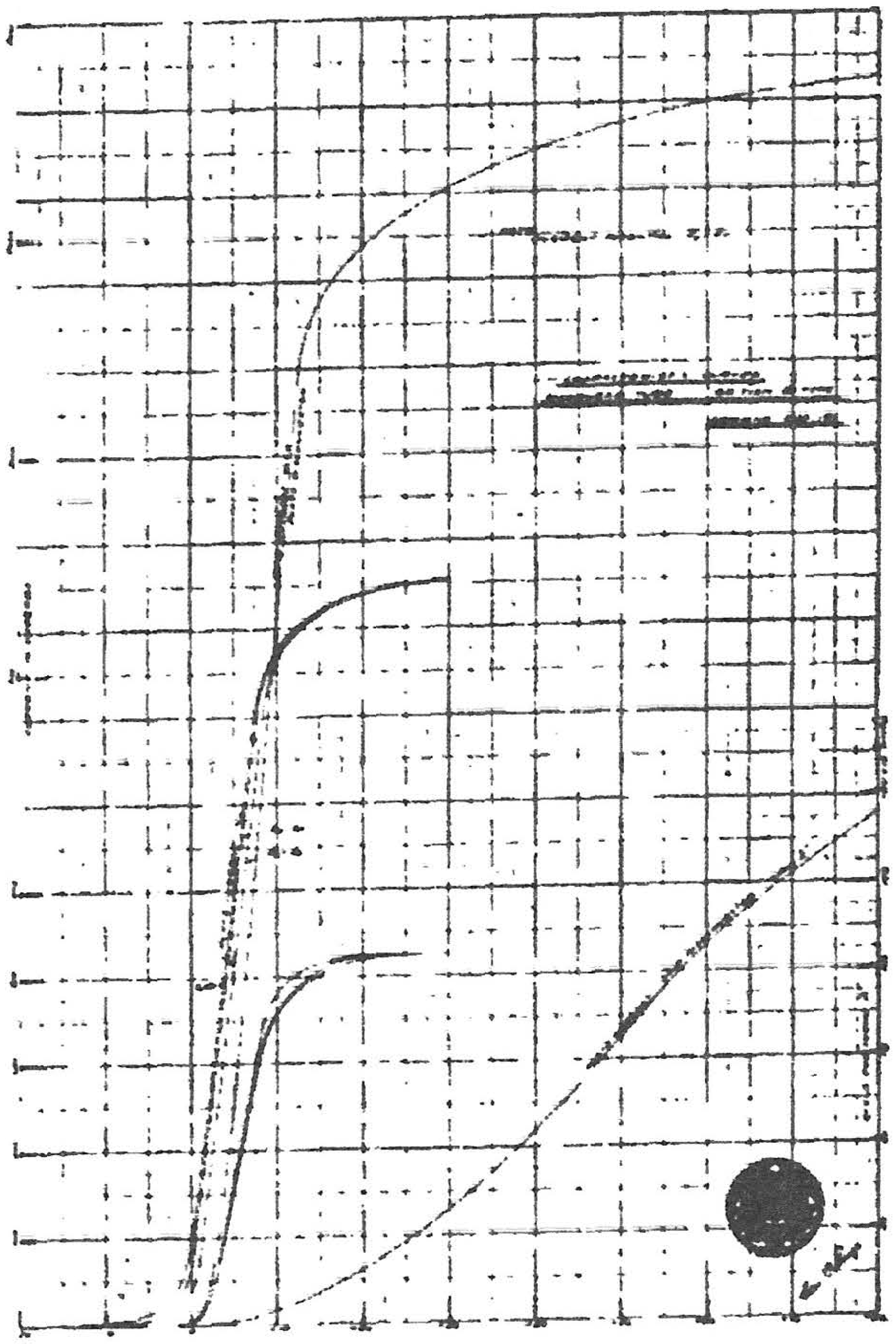


FIGURE 28

The question arises, which conditions must be fulfilled to produce a good detector, and which disposition of elements of the tube is necessary to make the tube a good amplifier. The requirements of a tube as a detector are low internal resistance and that this resistance shall change suddenly, that is, within very narrow limits of grid potential variation. The amplification characteristic of a tube depending on the ratio of the change in plate potential to the corresponding change in grid potential, the maximum action will be obtained when for a given change of the grid potential the increase in plate potential required to maintain the same current will be a maximum.

Thus we find that in a detector the resistance must drop suddenly, for a small change in grid potential, from a maximum to a minimum; whereas in an amplifier a small change in grid potential should tend to increase the resistance to a maximum. This represents the fundamental difference between the two classes of tubes, and conclusively confirms the statement made by the authors at the beginning of this paper.

Figure 29 gives 4 sets of curves of tubes built specially for determining the action of tubes as detectors and amplifiers. The plates and the filaments of these tubes were made as nearly as possible alike, but the grids were varied; the dimensions chosen were approximately the maximum and minimum considering the diameter of the plate. The exact dimensions and the number of turns of the grid are given in the figure; the standard length of filament and plate, and also the standard pitch of grid windings, were maintained for all four tubes. The results obtained confirmed the theory in every respect.

Inspection of the curves will immediately show that the tubes having 22-turn grids were good amplifiers but poor detectors; the rise of the curves is gradual and the radius of curvature at the knee of the curve, or in the region of operating grid potentials, is comparatively large—on the whole, both tubes proving of inferior value as detectors. Further comparison will show that of the tubes (numbers 13 and 17) number 17 is a better detector than the 13; on the other hand, tube 13 is by far the better amplifier. In other words, the farther the grid is from the filament, and the closer the grid is to the plate, the better are the amplifying qualities of the tube. Referring to the sketch of arrangement of elements in the tube, we may state that for the same number of turns in the grid the smaller is the ratio of $\frac{a}{b}$, the better is the amplification; thus, increasing this ratio will tend to bring out detector qualities at the expense of amplification. This statement holds equally well for the tubes 14 and 15, which are duplicates of 13 and 17 respectively, except for the number of grid turns, which in this case was 11 instead of 22.

Comparing now in pairs tubes 14 and 13, and 15 and 17, we will note that the larger the number of turns in the grid, the higher the resistance, the better the amplification quality, and conversely.

Picking out of the four tubes the best detector, or tube 15, we find that this tube has the grid of small diameter and small number of turns, or is the opposite extreme of tube 13, which is the best amplifier.

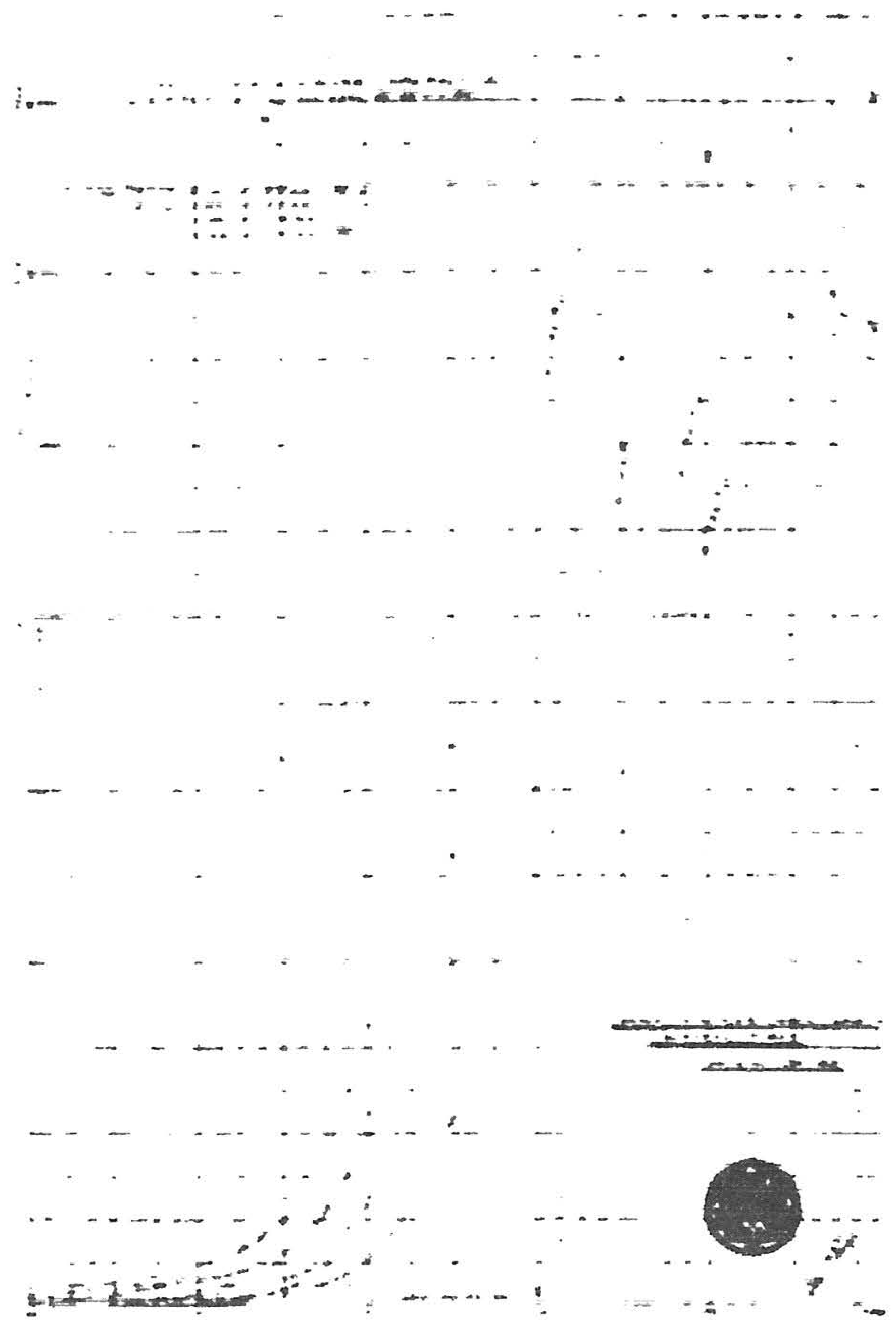


FIGURE 29

Further examination of the tube will reveal an interesting fact, namely that the curves of tubes 13 and 14, or the tubes with grids of larger diameter, do not show saturation within the limits of tests, while the tubes with grids of small diameter, numbers 15 and 17, indicate rather low saturation.

These and many other tests, in the authors' opinion, have proven conclusively that to obtain the best results in the use of tubes in radio, or any other work, at least two different types of tubes should be employed, selecting proper tubes designed for the purposes intended.

The mathematical formulas expressing the laws of action of tubes, as given to date, do not exactly explain the action, giving one or more constants in their general expression, which constants as indicated by the experiments, are not constants at all, but are variable functions of geometrical dimensions of the tube elements.

SUMMARY: A number of types of Moorhead tubes are described, together with the mode of testing them and the specifications to be met.

The tubes obtained are classified as detectors or amplifiers, which types the authors regard as separate and generally non-inclusive.

The effects of small variations of a number of the tube dimensions are exhaustively studied, and conclusions are drawn as to the effect of varying the various tube dimensions.