

Dec. 30, 1941.

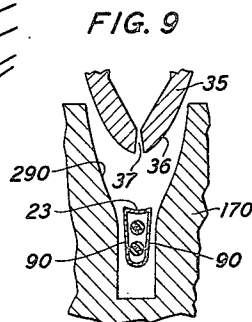
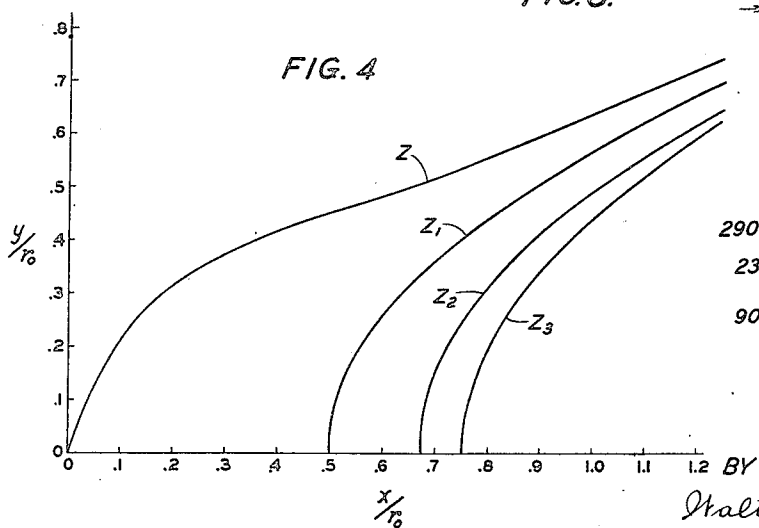
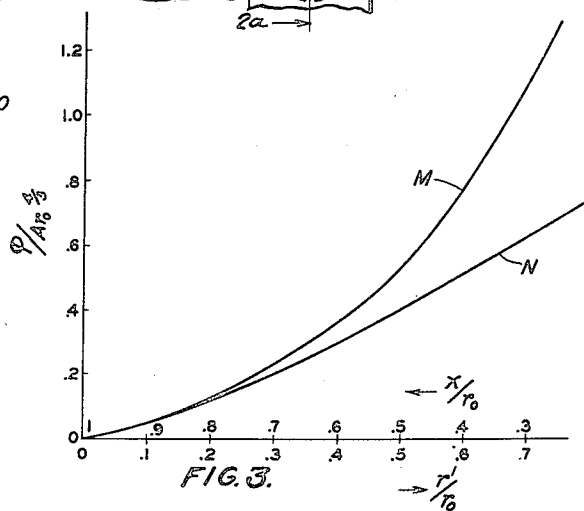
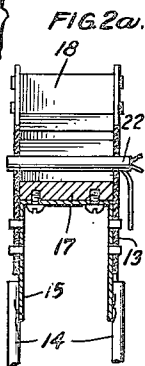
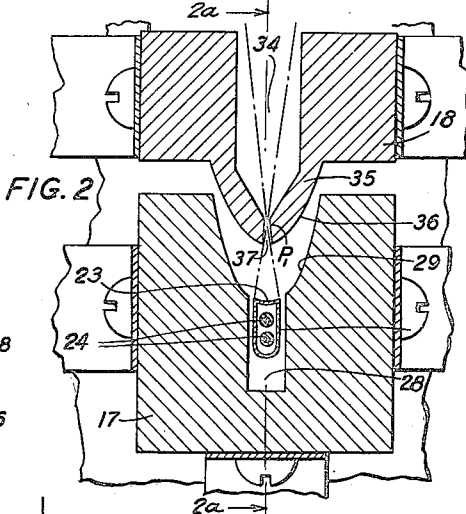
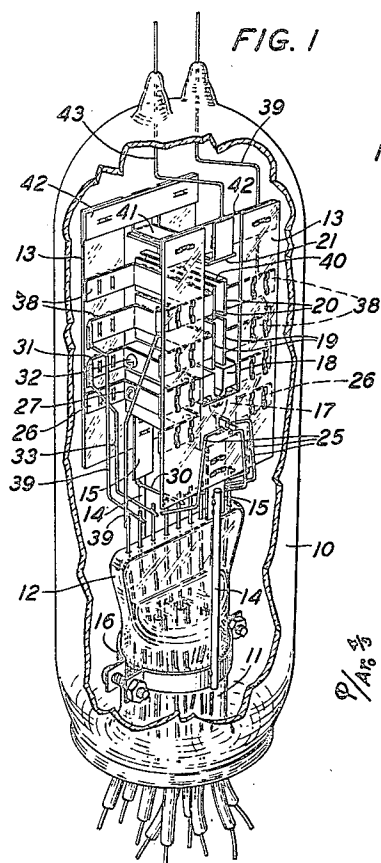
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2,268,196

ELECTRON DISCHARGE DEVICE

Filed Dec. 2, 1939

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 5

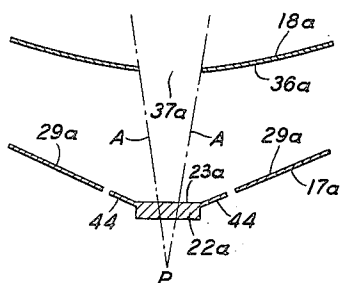


FIG. 6

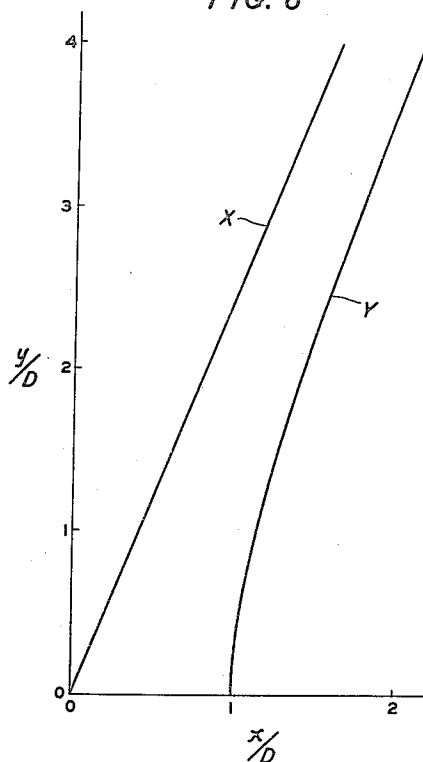


FIG. 7

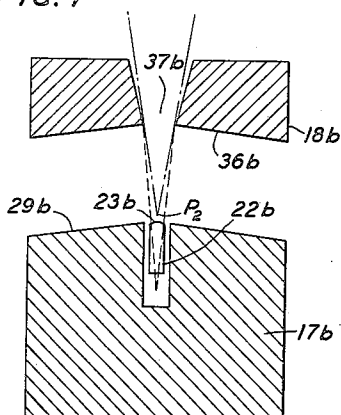
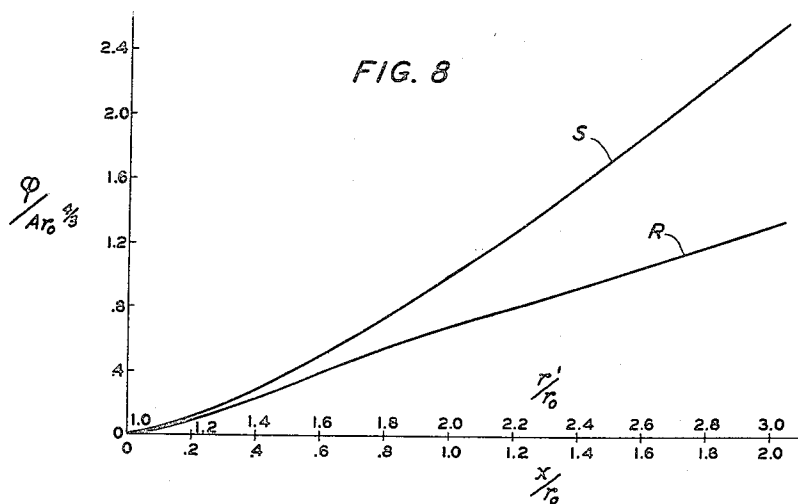


FIG. 8



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2,268,196

ELECTRON DISCHARGE DEVICE

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Application December 2, 1939, Serial No. 307,233

10 Claims. (Cl. 250-162)

This invention relates to electron discharge devices and more particularly to electrode systems, such as disclosed in the applications Serial No. 307,232, filed December 2, 1939, of Myron S. Glass and Serial No. 307,255, filed December 2, 1939, of Robert C. Winans, for producing a concentrated stream of electrons in electron beam discharge devices.

Electron beam discharge devices comprise in general an electron source, such as a cathode, an electron receiving element, such as a fluorescent screen or one or more targets, an electrode system for concentrating the electrons into a stream of desired cross-section, and means for controlling the intensity or direction, or both, of the electron beam.

Satisfactory and efficient operation of such devices requires that a large proportion of the electrons emanating from the electron source be concentrated into the electron beam and that these electrons traverse similar paths so that the beam may be focussed, deflected or otherwise controlled. The design of electrode systems which will effectuate these and other desiderata with reasonable accuracy has been an extremely complicated and cumbersome problem approached principally upon the basis of experience and upon restricted and only approximately accurate theoretical analyses.

One of the major complications introduced into the design of electrodes for beam discharge devices is that presented by space charge. In general, heretofore, in designing electron optical systems, the effect of space charge has been either neglected or treated as a simple diverging effect. Such assumption may be reasonably accurate, for practical purposes, in regions wherein the potential is high and space charge fields are small. However, in many cases, such as in an electron gun for electron beam discharge devices, in the region of the electron source, such as a cathode, space charge plays a major role. Any electron optical system designed in such instances upon analyses which neglect space charge or treat it as a simple effect may not produce optimum results and the results obtained may vary considerably from those predicted and expected upon the basis of calculations.

One general object of this invention is to enable the construction of electron guns having predetermined desired characteristics. More specifically, objects of this invention are:

To enable the design of electron guns having calculable performance;

To obtain a uniform cathode current density in electron beam discharge devices;

To assure a high current efficiency in electron guns; and

To simplify the structure, from both mechanical and electrical standpoints, of electron guns.

In one illustrative embodiment of this invention, an electron beam discharge device comprises a cathode, an electron receiving element such as an output electrode, and an electrode system between the cathode and anode for concentrating the electrons emanating from the cathode into a beam of desired configuration and cross-sectional area.

In accordance with one feature of this invention, the electrode system comprises electrodes having surfaces of such configuration that throughout the system and in the presence of complete space charge the field perpendicular to a line extending normal to the emissive surface of the cathode is zero.

In accordance with a more specific feature of this invention, the electrode system comprises a pair of apertured electrodes aligned with the emissive surface of the cathode and juxtaposed surfaces of these electrodes are so constructed and arranged that, in the presence of complete space charge, the potential along any line normal to the emissive surface varies with distance from the cathode surface, over a substantial portion of the distance between the cathode and the electrode furthest removed therefrom, essentially in a predetermined manner. For example, this potential may vary essentially as the potential varies between infinite parallel planes, one a cathode, or between concentric cylindrical electrodes, one a cathode.

The invention and the foregoing and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings in which:

Fig. 1 is a perspective view of an electron beam discharge device illustrative of one embodiment of this invention, a portion of the enclosing vessel being broken away to show the electrode structure more clearly;

Fig. 2 is an enlarged detail view in section of the cathode and the beam forming electrodes in cooperative relation therewith in the device shown in Fig. 1;

Fig. 2a is a view in section along line 2a-2a of Fig. 2 of a portion of the electrode assembly in the device shown in Fig. 1;

Fig. 3 is a graph illustrating a suitable poten-

tial distribution for producing a converging electron beam;

Fig. 4 is a diagram illustrating the configurations of opposed surfaces of the beam forming electrodes to produce a converging electron beam;

Fig. 5 is an enlarged detail view in section of a modification of the electrode system shown in Fig. 2, for producing a beam wherein the electrons traverse parallel paths;

Fig. 6 is a diagram illustrating the configuration of the electrodes in the system shown in Fig. 5;

Fig. 7 is an enlarged detail view in section of another modification of the electrode system illustrated in Fig. 2, for producing a diverging stream of electrons;

Fig. 8 is a diagram illustrating a suitable potential distribution for producing a diverging electron stream, from which distribution the configuration of the electrodes in the system shown in Fig. 7 is determined; and

Fig. 9 is a detail view mainly in section illustrative of another embodiment of this invention.

Referring now to the drawings, the electron discharge device shown in Fig. 1 comprises an evacuated enclosing vessel 10 having at one end thereof an inwardly extending stem 11, from which a unitary electrode assembly is supported, the stem 11 terminating in a press 12 in which leading-in conductors for the various electrodes are sealed.

The electrode assembly comprises a pair of parallel insulating uprights or frames 13, for example, U-shaped mica sheets, affixed to rigid wires or supports 14 by a U-shaped fastening strip 15, the supports 14 being affixed to a metallic collar or band 16 clamped about the stem 11. Supported in axial alignment by and between the insulating uprights 13 are a cathode, a modulating electrode 17, an anode 18, pairs of deflector plates 19 and 20, and a target or output electrode 21.

As shown clearly in Fig. 2, the cathode may be of the indirectly heated equipotential type and comprise a metallic sleeve 22 having a dish or circular arcuate portion 23 thereof coated with a thermionic material, and a heater filament 24 within the sleeve 22. The cathode sleeve 22 may be fitted in apertures in the insulating uprights 14 and the cathode and heater filament may be connected to the leading-in conductors therefor by the wires or conductors 25.

The modulating electrode 17 may be a metallic block, for example of copper, which is affixed to a pair of U-shaped metallic bands 26 as by screws 27, the arms of the bands 26 being affixed to the insulating uprights 13. As shown clearly in Fig. 2, the modulating electrode 17 is provided with a channel or recess 28 in which the cathode is positioned and with a surface 29 in axial alignment with the surface 23 of the cathode and of a configuration to be described hereinafter. The modulating electrode may be affixed also to the U-shaped fastening strip 15 and electrical connection thereto may be established through a tie wire 30 connected to one of the leading-in conductors in the press 12 and to one of the uprights 14.

The anode 18 similarly may be a metallic block, for example of copper, supported by a pair of U-shaped strips 31 to which it is affixed, as by screws 32, and which are secured to the insulating uprights 13, one of the strips 31 having connected thereto a tie wire 33 connected to one

of the leading-in conductors in the press 12. As shown clearly in Fig. 2, the anode 18 has therein a channel or recess 34 and is provided with a portion 35 extending into the channel bounded by the surface 29, and in axial alignment therewith. The portion 35 has a surface 36 of a configuration described hereinafter and is provided with a tapered aperture 37 in parallel alignment with the surface 23 of the cathode.

The deflector plates 19 and 20 may be metallic plates, for example, of nickel, supported by U-shaped strips 38 secured to the uprights 13, and are mounted on opposite sides of and equally spaced from a plane passing through the aperture 37 and cathode surface 23. Suitable potentials may be applied to the deflector plates 19 and 20 through connections including tie wires 39 affixed to the strips 38. As shown in Fig. 1, one of the deflector plates 20 may be provided with a flange or lip 40 extending toward and terminating short of the plane of the other deflector plate 19.

The target or output electrode 21 may be a metallic plate, in alignment with the aperture 37 and cathode surface 23, supported by a metallic U-shaped strip 41 affixed to bands 42 secured to the uprights 13. Leading-in connection to the target may be established through a conductor 43.

During operation of the device, the electrons emanating from the cathode surface 23 are concentrated into a beam and accelerated toward the target or output electrode 21. The beam may be deflected through potentials impressed upon the deflector plates and may be so deflected to such an extent that it impinges upon the flange or lip 40 so that the space or beam current to the target 21 is cut off. The intensity of the beam may be controlled through the application of a modulating potential upon the electrode 17.

The efficiency and operating characteristics of the device will be dependent upon the proportion of the electrons emanating from the cathode surface 23 which form the beam and upon the character of the paths traversed by the individual electrons. Satisfactory and efficient operation require that a large proportion of the electrons emanating from the surface 23 go into the electron beam and that these electrons follow rectilinear paths which may be parallel or converging toward or diverging from a common focus. These factors, of course, are dependent largely upon the character of the fields through which the electrons pass and the accurate determination of these fields is complicated, as noted heretofore, by space charge effects.

The design of electrodes for an electron gun to produce fields of the character necessary for the attainment of uniform cathode current density and travel of the electrons in rectilinear paths whereby a large proportion of the cathode current is utilized and an intense beam of electrons is produced in accordance with this invention will be clear from the following description.

In general, in the method employed, electrons are assumed to move in a beam according to known solutions of the space charge equations. Outside of the beam, electrodes are provided of such shape that the boundary conditions are consistent with the electron motion assumed.

As a specific illustration, the case of a two dimensional beam of infinite width and constant thickness, i. e., a beam composed of electrons traversing parallel rectilinear paths, may be considered. Although, of course, in actual devices, beams are of finite width, in devices such as

illustrated in Fig. 1 wherein the width of the beam is large as compared with the electrode spacings, the assumption in the analysis of the fields between the electrodes, of a beam of infinite width leads to conclusions truly accurate, for all practical purposes, inasmuch as, in an actual beam, the conditions are identical with those in a beam of infinite width except for small regions at the sides of the beam. Hence, only two coordinates of the beam need be taken into account, i. e., the dimension normal to the cathode surface, identified hereinafter as the X coordinate, and the dimension normal to the Y coordinate and to the width of the beam, identified hereinafter as the Y coordinate. It will be assumed that the electrons have zero initial velocity, the off cathode field is zero and the field perpendicular to the direction of electron motion is zero everywhere in the beam.

The potential at any point in the beam, then, in accordance with Child's law, is given by the relation

$$\phi = Ax^{4/3} \quad (1)$$

where ϕ is the potential in volts, x is the distance from the cathode in centimeters, and

$$A = \left(\frac{j}{2.33 \times 10^{-6}} \right)^{2/3}$$

j being the current density in amperes/cm.².

Thus, having the electron motion and the potential distribution in the beam, the problem is to determine what the field outside of the beam must be in order that the electrons move as desired in the beam. At any small region on the boundary of the beam at a distance x from the cathode, consider a point just inside the beam, at a potential ϕ . From the foregoing, it will be noted that

$$\frac{\partial \phi}{\partial y} \text{ and } \frac{\partial^2 \phi}{\partial y^2}$$

are zero throughout the beam so that at the point in question, according to Poisson's equation

$$\frac{\partial^2 \phi}{\partial x^2} = \frac{-\rho}{p_0} \quad (2)$$

where ρ is the charge density inside the beam at a distance x from the cathode and p_0 is the permittivity of free space where ϕ is in volts, x is in centimeters, ρ is in coulombs per cubic centimeter and p_0 is 8.85×10^{-14} .

At a neighboring point just outside of the beam, the potential is ϕ' and its derivatives are

$$\frac{\partial \phi'}{\partial y}, \frac{\partial^2 \phi'}{\partial y^2}$$

and

$$\frac{\partial^2 \phi'}{\partial x^2}$$

In order that there will not be a dipole layer at the boundary of the beam, ϕ' must equal ϕ and in order that there will not be a surface charge at the boundary of the beam,

$$\frac{\partial \phi'}{\partial y} = \frac{\partial \phi}{\partial y} = 0$$

Hence, the potential and field must be continuous in passing through the boundary of the beam.

At the point outside of the beam

$$\frac{\partial^2 \phi'}{\partial \phi^2} + \frac{\partial^2 \phi'}{\partial x^2} = 0 \quad (3)$$

Inasmuch as, as pointed out above, for any

value of x the potential just outside of the beam is the same as the potential just inside the beam,

$$\frac{\partial^2 \phi'}{\partial x^2} = \frac{\partial^2 \phi}{\partial x^2} \text{ and } \frac{\partial^2 \phi'}{\partial y^2} = \frac{\partial^2 \phi}{\partial x^2} = \frac{\rho}{p_0} \quad (4)$$

Thus, the second derivative of the potential is discontinuous at the boundary of the beam, changing by an amount proportional to the discontinuity in charge density in passing through the boundary.

The nature of the field outside of the beam is determined by the fact that the potential outside of the beam must match the potential of the beam and must have zero gradient normal to the beam boundary.

The determination of a field consistent with the assumed motion of the electrons in the beam reduces, thus, to the determination of a field satisfying Laplace's equation for which the potential along the x axis varies in a prescribed manner, according to a real function of x , and for which

$$\frac{\partial \phi}{\partial x}$$

is zero at the beam boundary, $y=0$. It is known that Laplace's equation is satisfied by the potential given by the relation

$$w = \phi + i\mu = f(x + iy) \quad (5)$$

where μ is real, $i = \sqrt{-1}$, x and y are the rectangular coordinates, and ϕ is the potential. For this relation, the potential at the boundary of the beam, $y=0$, is $f(x)$ and at $y=0$,

$$\frac{\partial \phi}{\partial y}$$

is the real part of

$$\frac{\partial w}{\partial y}$$

Now

$$\frac{\partial w}{\partial y} = if'(x + iy) \quad (6)$$

so that at $y=0$,

$$\frac{\partial w}{\partial y}$$

is imaginary and

$$\frac{\partial \phi}{\partial y}$$

is zero.

Along the boundary of the beam, $y=0$, for the case under consideration

$$\phi = f(x) = Ax^{4/3} \quad (7)$$

and the potential outside of the beam will be

$$\phi = A(x + iy)^{4/3}, \text{ real} \quad (8)$$

In polar coordinates, the potential may be expressed as

$$\phi = Ar^{4/3} \cos 4/3 \theta \quad (9)$$

The electrodes employed, then, should be such that the potential distributions satisfy Equation 9. Various combinations of electrodes may be employed. For practical purposes the combination involving the smallest number of electrodes is, of course, preferable. Two electrodes are sufficient to determine the field, namely, an electrode at cathode potential and an electrode at a positive potential with respect to the cathode.

At the cathode or zero potential, it will be seen from Equation 9 that

$$\cos 4/3 \theta = 0 \text{ and } \theta = 67.5 \text{ degrees}$$

Thus, the zero potential electrode should be planar and meet the edge of the cathode at an

angle of 67.5 degrees to the normal to the cathode surface.

The potential at the positive electrode should be such that

$$\phi = AD^{4/3} \text{ or } \frac{AD^{4/3}}{\phi} = 1$$

where D is the distance between the cathode and the positive electrode. The shape of the anode for all distances may then be given by the relation

$$\frac{r}{D} = (\cos^{1/2} \theta)^{-3/4} \quad (10)$$

where r and θ are polar coordinates and D is the distance between the cathode and any point on the surface of the positive electrode.

A structure illustrative of the case under discussion is shown in Fig. 5 and the shape of the surfaces of the two field determining electrodes is illustrated in Fig. 6. In Fig. 5, the electron gun illustrated comprises a cathode 22a having a plane rectangular emissive surface 23a, an electrode 17a, having plane portions 29a making an angle of 67.5 degrees with the normal to the surface 23a, and a positive electrode or anode 18a having a central slit 37a in alignment with the cathode surface 23a and a surface 36a as determined by Equation 10. The configuration of surfaces 29a and 36a may be obtained conveniently by plotting Equation 10 in rectangular coordinates as shown in Fig. 6 where curve X corresponds to the configuration of the surface 29a and curve Y corresponds to the configuration of the surface 36a. As shown in Fig. 5, the cathode may have plane extensions 44 extending at the same angle as the surfaces 29a and coplanar therewith.

The slit or aperture 37a will have, of course, an effect upon the configuration and direction of the beam emerging therefrom. If the spacing between the cathode 22a and anode 18a is several times as great as the width of the slit, the slit can be considered as acting simply as a diverging lens and the beam then will appear to diverge, as indicated by the broken lines A in Fig. 5 from a point P a distance substantially 3/2 times the distance between the cathode and anode. This diverging effect of the slit can be eliminated by placing a grid, not shown, over the slit.

Electrodes for producing rectilinear motion of electrons in converging paths may be designed by following the procedure outlined for the case discussed hereinabove. Thus in Fig. 3, curve M is a plot of $\phi/Ar_0^{4/3}$ versus distance from the cathode,

$$\frac{x}{r_0}$$

for concentric circular cylindrical electrodes with an external cathode, r_0 being the radius of the cathode emissive surface and r' the distance from its center of curvature, and N is a plot of

$$\left(\frac{x}{r_0}\right)^{4/3}$$

As noted heretofore, the potential near the cathode surface must vary as given by Equation 7 so that

$$\frac{\phi}{Ar_0^{4/3}} = \left(\frac{x}{r_0}\right)^{4/3} \quad (11)$$

It can be shown that curve M approaches very closely to the relation

$$\frac{\phi}{Ar_0^{4/3}} = \left(\frac{x}{r_0}\right)^{4/3} \left[1 + 1.63 \left(\frac{x}{r_0}\right)^2\right] \quad (12)$$

which, it will be seen is a very close approximation to the potential for the range

$$\frac{x}{r_0} = 0 \text{ to } \frac{x}{r_0} = 0.75$$

5 or

$$\frac{r^1}{r_0} = 1 \text{ to } \frac{r^1}{r_0} = 0.25$$

10 It approaches the true value for small values of

$$\frac{x}{r_0}$$

For practical purposes, Equation 12 may be considered as specifying the boundary potential of the beam when the radius of the anode surface is greater than 1/4 the cathode emissive surface radius.

Using Equation 12 as a basis, the configuration for the surfaces of the electrodes for the converging case may be calculated. A plot in rectangular coordinates illustrative of these surfaces is shown in Fig. 4 for several values of

$$\frac{\phi}{Ar_0^{4/3}}$$

Specifically for curve Z,

$$\frac{\phi}{Ar_0^{4/3}} = 0$$

for curve Z₁, it equals 0.559, for curve Z₂ it equals 1.0 and for curve Z₃, it equals 1.31.

The curve Z, it may be noted, makes an angle of 67.5 degrees with the line

$$\frac{x}{r_0}$$

which corresponds to the normal to the cathode surface at the edge thereof, as in the case for parallel paths previously discussed.

In constructing an actual electron gun, one form of which is illustrated in Fig. 2, the electrode 17 is shaped so that the surface 29 conforms to the curve Z of Fig. 4 and is fitted together with the circular arcuate surface 23, and the electrode 18 is shaped to conform to one of the curves Z₁, Z₂ or Z₃. Which of the curves Z₁, Z₂, Z₃ or other similar curves is used in one particular case as the basis for forming surface 36 is a matter of choice dependent upon the results desired. The results obtainable with surfaces corresponding to the various curves will be clear from the following considerations. Between the cathode surface 23 and electrode 36, the beam converges along radii of the surface 23 to a center r_0 . At a distance x from the cathode, the beam is a distance r' ($r' = r_0 - x$) from the center. If W_0 is the width of the beam at the cathode, the width of the beam W_x at a distance x will be

$$W_x \frac{r}{r_0} = W_0 \frac{r' - x}{r_0}$$

Hence, if curve Z₃ is used as the basis for the surface 36, the beam will be 1/4 as wide at the electrode 36 as at the cathode. For a surface conforming to curve Z₁, the beam will be 1/2 as wide at the electrode 36 as at the cathode.

The aperture 37 will have, of course, a diverging lens effect the focal length, f, of which may be determined from the relation.

$$\frac{f}{r_0} = -3/2 \frac{D}{r_0} \left[\frac{1 + 1.63 \left(\frac{D}{r_0}\right)^2}{1 + 4.07 \left(\frac{D}{r_0}\right)^2} \right] \quad (13)$$

75 where D is the distance between the cathode and

the anode, measured from the mid-point of surface 23 to the end of aperture 37 nearest this surface, the end of the aperture 37 being taken at the line where the surface 36 would intersect the plane of symmetry of the electrode surfaces if the surface 36 were continuous and not apertured.

It can be shown that when the aperture 37 is small in comparison with the cathode-to-anode spacing, for cases where

$$\frac{r'}{r_0}$$

is greater than about 1/2, the beam emerging from the slit or aperture 37 will be diverging and when

$$\frac{r'}{r_0}$$

is equal to 1/2 the emerging beam will be substantially parallel. The cross-over point P₁ for a diverging beam in a particular structure,

$$\frac{r'}{r_0} = \frac{1}{4}$$

is shown in Fig. 2.

Another case of some interest is that wherein the electrons traverse rectilinear diverging paths as illustrated by the electron gun shown in Fig. 7. The method of determining the configuration of the surfaces 29b and 36b is the same as that described in connection with the two cases considered above. Thus in Fig. 8, curve R is a plot of

$$\frac{\phi}{Ar_0^{4/3}} \text{ versus } \frac{x}{r_0}$$

and curve S is a plot of

$$\left(\frac{x}{r_0}\right)^{4/3}$$

From these curves it will be seen that throughout the range from

$$\frac{x}{r_0} = 0 \text{ to } \frac{x}{r_0} = 2$$

or

$$\frac{r'}{r_0} = 1 \text{ to } \frac{r'}{r_0} = 3$$

a straight line through the origin is a very close approximation of the curves, sufficiently close for most practical purposes. Thus, as shown in Fig. 7, the surfaces 29b and 36b may be planar and substantially parallel, the surface 29b making an angle of somewhat more than 67.5 degrees, for example, approximately 90 degrees, with the normal to the edge of the cathode surface 23b.

Because of the diverging effect of the slit or aperture 37b, the electron stream will appear to diverge from a point P₂ as shown in Fig. 7, which may be in front of or behind the anode depending upon the value of

$$\frac{x}{r_0}$$

It may be noted that in all cases, if the electrode 17 is not used for modulation, the surface 29 preferably is made an integral part of the cathode, only a portion 23, of course, of the structure being made electron emissive. When the electrode 17 is used for modulation, the spacing between the boundary of the surface 23 and the inner edges of the surface 29 should be as small as practicably possible in order to minimize divergence of the electrons emanating from the surface 23.

In connection with the matter of modulation, it will be clear that in an electron gun constructed as described heretofore, the beam will be focussed upon the slit or aperture 37 when the electrode 17 is at zero potential and for this potential the current through the slit is a maximum. If the electrode 17 is made negative with respect to the cathode, the cathode current will be reduced and the focussing of the beam will be reduced so that the current through the slit or aperture 37 will be reduced by two factors.

Preferably, if the electrode 17 is used for modulating, the voltage of the electrode 17 should be zero for maximum current. Hence, the electrode should have a bias sufficiently negative with respect to the cathode so that at peak signal intensity, the potential of electrode 17 is just zero.

It may be noted also that in all cases the electron beam current density may be determined fairly accurately. Thus, for converging beam guns, the current density may be obtained from the curves shown in Figs. 8 and 10, respectively or may be calculated from the following approximate expression for the potential.

$$j = \frac{2.33 \times 10^{-6} \phi^{3/2}}{D^2 \left[1 + 1.63 \left(\frac{D}{r_0} \right)^2 \right]^{3/2}} \quad (14)$$

where j is the current density in amperes per square centimeter, ϕ is in volts, and D and r_0 are in centimeters. The actual current density may differ somewhat from the calculated value due to deviations from exact alignment of the electrodes encountered in actual electron guns.

However, the difference, if care is exercised in constructing the gun, is well within the limits permissible for practical purposes.

Furthermore, it may be remarked that in electron guns constructed in accordance with this invention, the current density will be substantially uniform over the entire emissive surface of the cathode so that the entire surface of the cathode may be operated at the allowable limit of current density. Moreover, in such guns, electrons emanating from the edge portions of the cathode emissive surface are conserved and constitute a part of the electron beam inasmuch as the electrode 17 prevents such electrons suffering an undue space charge divergence in leaving this surface. These features, it will be appreciated, may be realized in accordance with this invention, in electron guns wherein the electron motion is other than rectilinear.

Although the invention has been described thus far with particular reference to devices wherein two electrodes, one at zero potential and one at a positive potential, are utilized to produce fields of the desired configuration and strength, it may be practiced also in devices wherein an electrode at a negative potential with respect to the cathode is employed in place of the zero potential electrode. One such construction is illustrated in Fig. 9 wherein the surface 36 is of the same form as in Fig. 2, and the surface 290 of the modulating electrode 170 conforms to an equipotential boundary of the same field to which the surface 36 conforms and passes through the axis of alignment of the electrodes at a point behind the cathode surface 23, i. e., below the surface 23 in Fig. 9. In cases where such a negative electrode is employed, it has been found that the sides 90 of the cathode should make an angle of 67.5 degrees with the edges of the cathode surface 23, for parallel, diverging and converging beams.

Finally, although specific embodiments of this invention have been shown and described, it will be understood that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electron discharge device comprising an electron emissive surface, an electron receiving element spaced from said surface, and means for concentrating the electrons emanating from said surface into a beam, said means comprising a pair of electrodes in alignment with said cathode and having opposed centrally apertured dished surfaces of such configuration and so spaced that in the presence of complete space charge, at all points in said beam and between said electrodes the component of the electric field perpendicular to a normal to the cathode surface is substantially zero.

2. An electron gun for electron discharge devices comprising a cathode, and means including a pair of spaced electrodes in alignment with said cathode and having opposed dished surfaces for producing a field between said cathode and the electrode furthest removed therefrom the potential at any point in which is $Ax^{4/3}$, where

$$A = \left(\frac{j}{2.33 \times 10^{-6}} \right)^{2/3}$$

j is the current density in amperes per square centimeter, and x is distance from the cathode in centimeters.

3. An electron gun for electron discharge devices comprising a cathode, an electrode having a dished surface extending from immediately adjacent the cathode, the elements of said surface making an angle of substantially 67.5 degrees with the normal to the emissive surface of said cathode at the edge thereof, and an anode spaced from and in alignment with said first electrode and having a dished surface facing said first surface and conforming to the relation

$$\frac{r}{D} = (\cos 4/3 \theta)^{-3/4}$$

where D is the distance between said cathode and anode and r and θ are polar coordinates.

4. An electron gun in accordance with claim 3 wherein the emissive surface of said cathode is substantially plane, and said cathode includes an integral extension projecting from the edge of the emissive surface and at an angle of substantially 67.5 degrees to said surface.

5. An electron gun for electron discharge devices comprising a cathode having a curved electron emissive surface, and a pair of spaced electrodes having central apertures in alignment with each other and said cathode, said electrodes having opposed dished surfaces, the dished surface of one electrode extending from immediately adjacent the electron emissive portion of said cathode, and said dished surfaces conforming to equipotential boundaries of a field corresponding to a potential varying according to the relation

$$\frac{\phi}{Ar_0^{4/3}} = \left(\frac{x}{r_0} \right)^{4/3} \left[1 + 1.63 \left(\frac{x}{r_0} \right)^2 \right]$$

where ϕ is the potential, r_0 is the radius of cur-

vature of said emissive surface, x is distance from said emissive surface,

$$A = \left(\frac{j}{2.33 \times 10^{-6}} \right)^{2/3}$$

and j is the current density.

6. An electron gun for electron discharge devices comprising a cathode having an emissive surface, and a pair of spaced electrodes having opposed centrally apertured surfaces in alignment with said cathode, one of said surfaces having a portion extending from immediately adjacent said cathode, and said portion of said one surface having all elements thereof defining an angle of substantially 67.5 degrees with normals to said emissive surface at the edges thereof.

7. An electron discharge device comprising a cathode having an elongated concave electron emissive surface, an electron receiving element spaced from said emissive surface, an electrode system between said surface and said element for concentrating the electrons emanating from said surface into a converging beam of rectangular cross-section, said system comprising a pair of spaced electrodes each having an elongated central aperture, the apertures in said electrodes being in alignment with each other and said emissive surface, and said electrodes having opposed dished surfaces conforming to equipotential boundaries of a field corresponding to a potential increasing away from said emissive surface according to the relation

$$\frac{\phi}{Ar_0^{4/3}} = \left(\frac{x}{r_0} \right)^{4/3} \left[1 + 1.63 \left(\frac{x}{r_0} \right)^2 \right]$$

where ϕ is the potential, r_0 is the radius of said emissive surface, x is distance from said emissive surface,

$$A = \left(\frac{j}{2.33 \times 10^{-6}} \right)^{2/3}$$

and j is the current density.

8. An electron gun for electron discharge devices comprising an electron emissive surface, and a pair of electrodes having central apertures and mounted in spaced relation opposite said emissive surface and in alignment with said surface and with one another, said electrodes having opposed surfaces corresponding to equipotential boundaries of a field which satisfies Laplace's equation between said opposed surfaces, for which

$$\frac{\partial \phi}{\partial y} = 0$$

over a boundary normal to said emissive surface at the edges thereof and for which, in said normal boundary, $\phi = f(x)$, where ϕ is potential, y is distance normal to said normal boundary, x is distance from said emissive surface, and $f(x)$ is a known solution of the space charge equation for rectilinear motion of electrons.

9. An electron gun in accordance with claim 8 wherein said emissive surface is plane and $f(x)$ is a known solution of the space charge equation between parallel planes.

10. An electron gun in accordance with claim 8 wherein said surface is arcuate and $f(x)$ is a known solution of the space charge equation between concentric cylinders.

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