Dec. 18, 1956 D. CHARLES 2,774,913

ELECTRON DISCHARGE TUBE WITH CROSSED ELECTRIC AND MAGNETIC FIELDS

Filed May 28, 1952 2 Sheets-Sheet 1

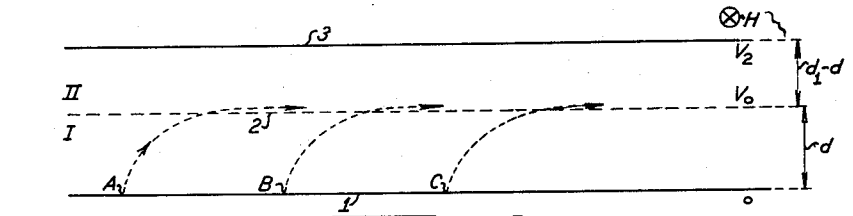


FIG. 2

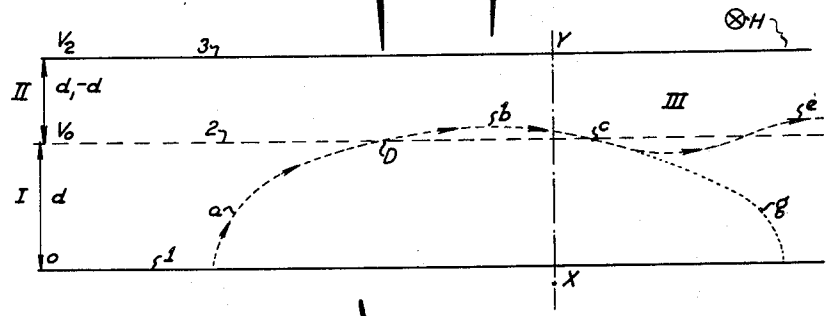


FIG. 3

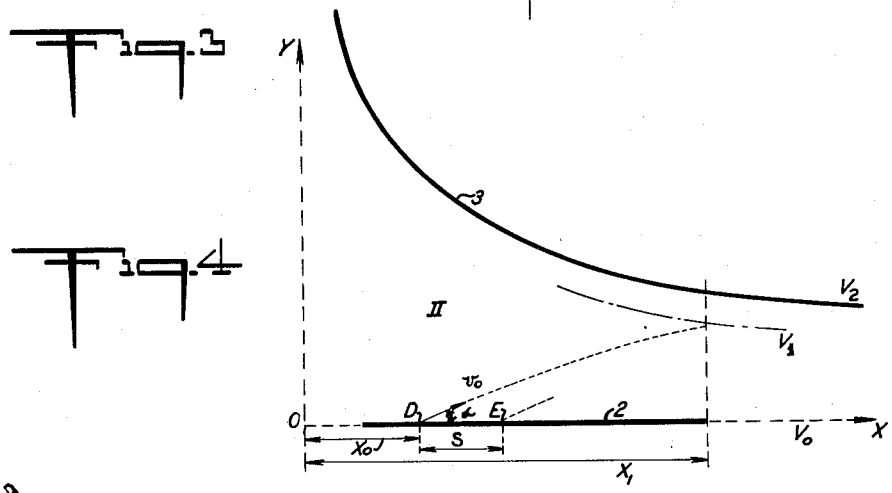


FIG. 4

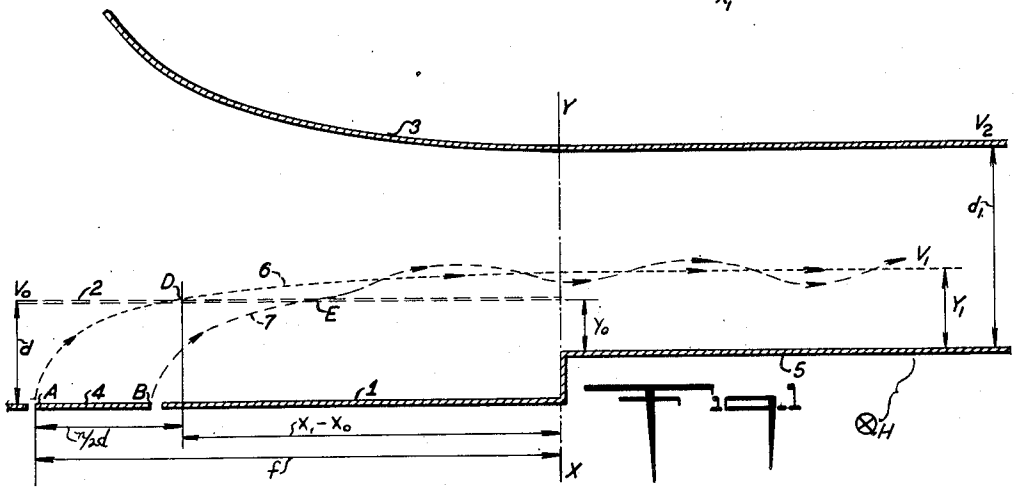
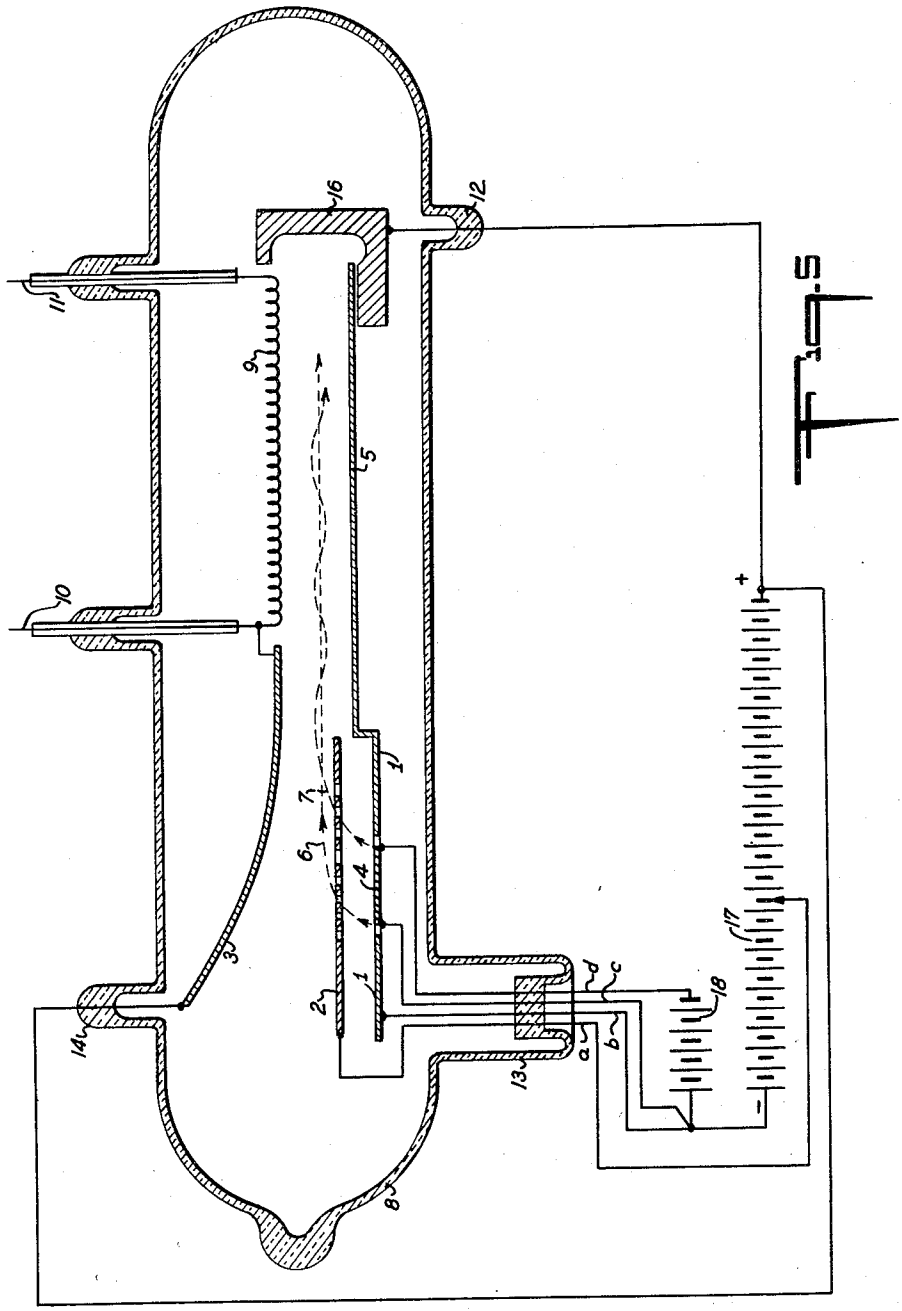


FIG. 5

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ELECTRON DISCHARGE TUBE WITH CROSSED ELECTRIC AND MAGNETIC FIELDS

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2 Claims. (Cl. 315—39.3)

The present invention relates to electronic discharge tubes having crossed electric and magnetic fields, and more particularly to a new and improved electron gun for use in such tubes.

The general object of the invention is to provide a tube of this type wherein a stream of electrons is caused to follow a substantially rectilinear path between two electrodes across which an electric potential is maintained. One of the prerequisites for such operating conditions is generally that the cathode emitting the electrons be quite small in the direction of travel of the electrons, a plurality of cathodes of similar size being used as an alternative to enlarging the cathode, when it is desired to increase the emission.

The amount of current which may be applied to the cathode or cathodes is, however, limited by the sensitivity of the cathode to currents of high density, the life of the cathode being inversely proportional to the strength of the current, and the latter being further limited by other considerations even for a short life of the cathode.

It is, therefore, a further object of this invention to provide an electron gun in a tube of the type described wherein the cathode may be of substantially greater size than heretofore without thereby impairing the operation of the tube.

With these and other objects in view, the invention may be defined as comprising an electron gun for electron discharge tubes having crossed electric and magnetic fields including a cathode of large dimension in the direction of movement of the electrons.

More specifically, the emissive cathode is situated in the plane of a substantially flat electrode, and it emits electrons into a space bounded on the one side by the flat electrode and on the other side by an electrode having a hyperbolic profile decreasing in the desired direction of movement of the electrons, the latter electrode being raised to a positive potential relatively to the flat electrode. The space between the electrodes is traversed by a magnetic field perpendicular to the plane in which the electrons are emitted, with a view to imparting curvature to the path of the electrons in the desired direction. Furthermore, this space is divided into two zones by a grid raised to an electric potential intermediate the potentials of the two electrodes, the extent of the grid being limited to a predetermined distance lengthwise of the cathode in the direction of movement of the electrons. At the forward edge of the grid, the hyperbolic electrode is continued by a substantially flat electrode co-extensive of a further flat electrode raised to the potential of the first flat electrode and defining therewith a further space which is not divided into two zones by the grid. The potentials to which the electrodes and the grid are raised, the magnitude of the magnetic field, the transverse distances between various electrodes and the longitudinal distance between the forward edge of the grid and the cathode are suitably selected so that the electric field in the undivided space is equal to the field between the grid and the hyperbolic electrode at the level of the

forward edge of the grid, and so that the electrons pass through the grid at a very small angle relatively thereto, for example about 1°–3°, and, thereafter, pass into the undivided space without again contacting the grid.

In the accompanying drawings:

Figures 1–4 are diagrammatic illustrations of the operating conditions and the dimensions of an electron gun according to the present invention and

Figure 5 is a longitudinal section through a travelling wave tube, including an electron gun constructed and arranged in accordance with Figures 1–4.

The invention will be more readily understood with reference to Figure 1, which illustrates diagrammatically a section of the gun in a plane perpendicular to the direction of the magnetic field. In Figure 1 the flat electrode 1 is raised, for example to a potential O and it contains an electron emissive cathode 4. A grid 2, which is permeable to the electrons is located at a transverse distance d from the electrode 1 and it is raised to a potential V. In the direction of movement of the electrons, the extent of the grid is limited to a distance f measured from the rear edge of the cathode 4. An electrode 3, raised to a potential V_2 comprises a first portion of hyperbolic profile merging into a second portion of rectilinear profile positioned at a distance d_1 from a further flat electrode 5 which is at the same potential as the electrode 1, the electrode 5 being at a distance y_1 from the equipotential V_1 along which the path 6 of the electrons issuing from the rearward edge of the cathode 4 becomes substantially rectilinear and the same electrode 5 being at a distance y_0 from the grid 2. A magnetic field is applied in a direction perpendicular to the plane of Figure 1 as indicated at H, and the effect of this field is to bend the path of the electrons toward the right if the potentials V_0 and V_2 of the grid 2 and of the electrode 3 are positive.

The operation of the electron gun constructed according to Figure 1 will be readily understood from a step by step description of Figures 2–4.

Figure 2 shows an electrode 1 at a potential O positioned at a distance d from an electrode 2 permeable to the electrons i. e. a grid, raised to a potential V_0, and at a distance d_1-d from the electrode 2 there is an electrode 3 raised to a potential V_2, the three electrodes constituting a plane parallel system.

The cycloidal movement of an electron issuing from the plane of the electrode 1 in a uniform electric field E and in a magnetic field h is such that the field, at the highest point of the trajectory is:

$$v=\frac{2E}{H} \tag{1}$$

If the electron passes at this point into a zone where the electric field is still uniform but has twice the magnitude of the former field, the trajectory of the electron is rectilinear and parallel to the equipotentials. In order that the trajectory may be rectilinear in a space governed by a uniform electrical field and a uniform orthogonal magnetic field, the following condition must prevail:

$$v=\frac{E'}{H} \text{ whence } E'=2E \tag{2}$$

If in the system according to Figure 2, the relationship is

$$\frac{V_0}{d}=\frac{1}{2}\frac{V_2-V_0}{d_1-d} \tag{3}$$

the condition is fulfilled, and the electrons issuing from the points A, B, or C will follow cycloidal paths in the zone I, and rectilinear paths parallel to the equipotential V_0 in the zone II.

If the arrangement according to Figure 2 could be materialized in physical terms, it would enable the use of

a cathode of infinite length, the width being the dimension of the cathode parallel to the direction of movement of the electron beam.

In order that the electrons may pass effectively through the grid, however, and enter the zone II, they must approach the grid at an inclination of a few degrees. In such circumstances the movement of the electrons in the zone II will no longer be along a rectilinear path. The path will be trochoidal on the contrary, and the electrons will fall back onto the grid.

Figure 3 illustrates the same elements as Figure 1. In the zone I, the electron will follow a first path *a* of cycloidal shape, and in the zone II it will follow a second path *b* of elongated trochoidal shape, passing again through the grid at *c*, and following a further cycloidal path *g* identical to *a*.

If the separation into two zones I and II is suppressed slightly before the point *c* in the plane XY, and if the further zone III to the right of the plane XY is governed by an electric field equal to the field in the zone II, the trochoidal path will extend along the line *e*, the amplitude of the oscillations being proportional to the angle of incidence of the electrons passing through the grid **2** at the point D.

In order that the electrons as they pass through the grid may form with the plane of the grid an angle other than zero, and in order to prevent the electron from falling back onto the grid, the electric field in the zone II must increase slightly in the direction of movement of the electron. This field must be so selected, however, that the amplitude of transverse movement remains relatively low.

It has been found that the field defined by the electrode **3** in Figure 1, which comprises hyperbolic equipotentials, is characterized by particular properties perfectly suited for carrying out the present invention.

In the system shown in Figure 4, an electrode **2** corresponding to a grid of the previous figures is maintained at a potential V_0, and an electrode **3** of hyperbolic shape having an equation $xy=h^2$ is maintained at a potential V_2. The electrode **2** extends along an asymptote Ox of the hyperbola **3**.

If an electron enters into the system of Figure 4 at a velocity v_0 expressed in electron volts by the value V_0 and at an angle α, it will be found that there is a dimension x_0 measured from the intersection O of the asymptotes of the hyperbola **3**, according to which the electron entering the zone II at that point follows a hyperbolic path.

The distance x_0 is defined by the following formula:

$$x_0=3{,}37\sqrt{\frac{V_0}{H.\tan\alpha}} \tag{4}$$

At a distance x_1 measured from the same origin O, the electron will be situated on an equipotential V_1, such that

$$V_1=V_0\left(\frac{x_1}{x_0}\right)^2 \tag{5}$$

If an electron enters the system of Figure 4 at a distance x_0+s from the origin O at the same velocity v_0 and at the same angle α, the path of this electron will oscillate on either side of the preceding path, namely, along the path **7** of Figure 1, the total amplitude in the transverse direction being

$$\delta=2.\tan\alpha\ .s \tag{6}$$

This path will no longer contact the grid which does not extend beyond a distance x_1 measured from the origin O.

The hyperbolic electrode at a potential V_2 is defined by its constant h^2 as follows:

$$\frac{V_2-V_0}{h^2}=0{,}177.H^2.\tan\alpha \tag{7}$$

Since α is small it is known from Formula 6 that the amplitude remains small even for a cathode of large surface.

In order to adapt the space between the electrodes **2** and **3** to the discharge space, it is assumed that in the discharge space constituted by two parallel planes between which there is maintained a constant electrical field, the electron must travel along an equipotential in such a manner that the velocity of the electron expressed in volts be exactly the potential value of this equipotential.

If the adaptation is made at a distance x_1 from the origin, the velocity of the electron in electron volts is V_1. One of the properties of the field defined as above is that at each point, if α is small, the quotient of the transverse component of the electrical field by the magnetic field H is exactly equal to the velocity of the electron expressed in electron volts as V_1, and for this reason the adaptation to the discharge space is particularly easy.

It will be understood from the foregoing explanations that the structure of the electron gun shown in Figure 1 is particularly well designed. For calculating the elements of the gun the origin data y_1, V_1 and d_1 are conventional and the first step is to calculate:

$$V_2=\frac{V_1 d_1}{y_1} \tag{8}$$

hence,

$$H=\frac{V_2}{d_1\sqrt{\frac{2e}{m}V_1}} \tag{9}$$

wherein e and m are the charge and the mass of the electron.

In practice, angle α is very small, in the neighborhood of 1–3 degrees. It is then possible to determine the values of V_0, d, h, x_1, x_0 and Y_0 from the Equations 4, 5 and 7 to which three further equations are added as follows:

$$d=3{,}37\frac{\sqrt{V_0}}{H}\cos\alpha \tag{10}$$

$$\frac{V_0}{y_0}=\frac{V_1}{y_1} \tag{11}$$

$$x_1=x_0+2s \tag{12}$$

The final Equation 12 is not compulsory but it corresponds to a particularly favorable dimensioning of the parts for carrying out the invention.

The width of the cathode s is determined from the Equation 6 in accordance with the maximum permissible thickness of the beam δ.

Finally the distances x_1 and x_2 being obtained as set forth above, and the horizontal distance between A and D, equal to the projection of a half segment of a cycloid of amplitude d being determined by

$$\frac{\pi}{2}d$$

it is possible to obtain the equation which gives the exact location of the rearward edge A of the cathode **4** relatively to the plane of adaptation XY as follows:

$$f=\frac{\pi d}{2}+x_1-x_0 \tag{13}$$

The theoretical construction and practical calculation of the electron gun according to the present invention being fully set forth, it is possible to examine an example of use of the gun in a traveling wave amplifier having crossed magnetic and electric fields. Such a tube is illustrated in Figure 5 wherein the same electrodes are shown as in Figure 1 with the same reference numerals.

An electrode **1** containing a cathode **4** at the gun end of the tube is electrically connected to an electrode **5** at the interaction space end of the tube where the beam interacts with the wave. Lead *b* connects the electrodes **1** and **5** through the envelope **8** having a socket **13**. The grid **2** is also provided with a lead *a* passing through the socket **13** in order that the grid may be raised to a posi-

tive potential relatively to the plane of the cathode, lead *a* being connected to a battery **17**. The hyperbolic electrode **3** has a lead issuing through socket **14** which raises the electrode to a positive potential through the same battery **17**.

The cathode **4** of relatively large surface is heated by an element having connections *c* and *d* passing through the socket **13** and connected to a battery **18**. The paths of two typical electrons are shown at **6** and **7**.

A delay line **9**, parallel to the electrode **5**, is provided with input and output connections **10** and **11** for supplying the electromagnetic wave and respectively extracting the amplified wave. The tube is completed by a collecting electrode **16** having a lead issuing through socket **12** for connection to the same potential source as the electrode **3**. The tube is placed in a magnetic field perpendicular to the plane of Figure 5 and oriented in the direction in which the figure is viewed.

As previously pointed out, a tube of this construction has the advantage of enabling the use of a cathode of relatively large dimension with very accurate focusing, but it is also possible to cut off or re-establish the flow of electrons through the grid **2** by a very slight variation in the amplitude of V_0. It will be seen indeed that the Equation 10 is identical with that which gives the critical field, the cosine being very close to 1. A very slight decrease of V_0 will prevent the electrons from passing through the grid and they will be reflected back to the plane of the cathode.

What is claimed is:

1. An electron discharge tube comprising a first substantially flat electrode extending parallel to the axis of the tube, a substantially flat emissive cathode situated in the same plane as the first flat electrode, means for applying a common potential to the cathode and first electrode,

a second electrode comprising a first portion of hyperbolic profile having its convex surface facing the emissive surface of said cathode and a second portion of average rectilinear profile extending from the first portion, a grid separating the space between the first and second electrodes, said grid extending from a zone of the tube adjacent the cathode to a zone of the tube adjacent the junction between the first and second portions of the second electrode, means for applying a positive potential to the second electrode relatively to the first electrode, means for applying to the grid a potential intermediate those applied to the first and second electrodes, and means for producing a magnetic field having lines of force perpendicular to the axis of the tube and to the lines of force of the electric field resulting from the difference of potential between the first and second electrodes.

2. A tube according to claim 1 wherein the second portion of the second electrode comprises a delay line having input and output extremities, means being provided for supplying a wave to the input extremity and for collecting an amplified wave from the output extremity.

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