May 10, 1960 G. R. BREWER 2,936,394

ELECTRON GUN

Filed July 18, 1955 2 Sheets-Sheet 1

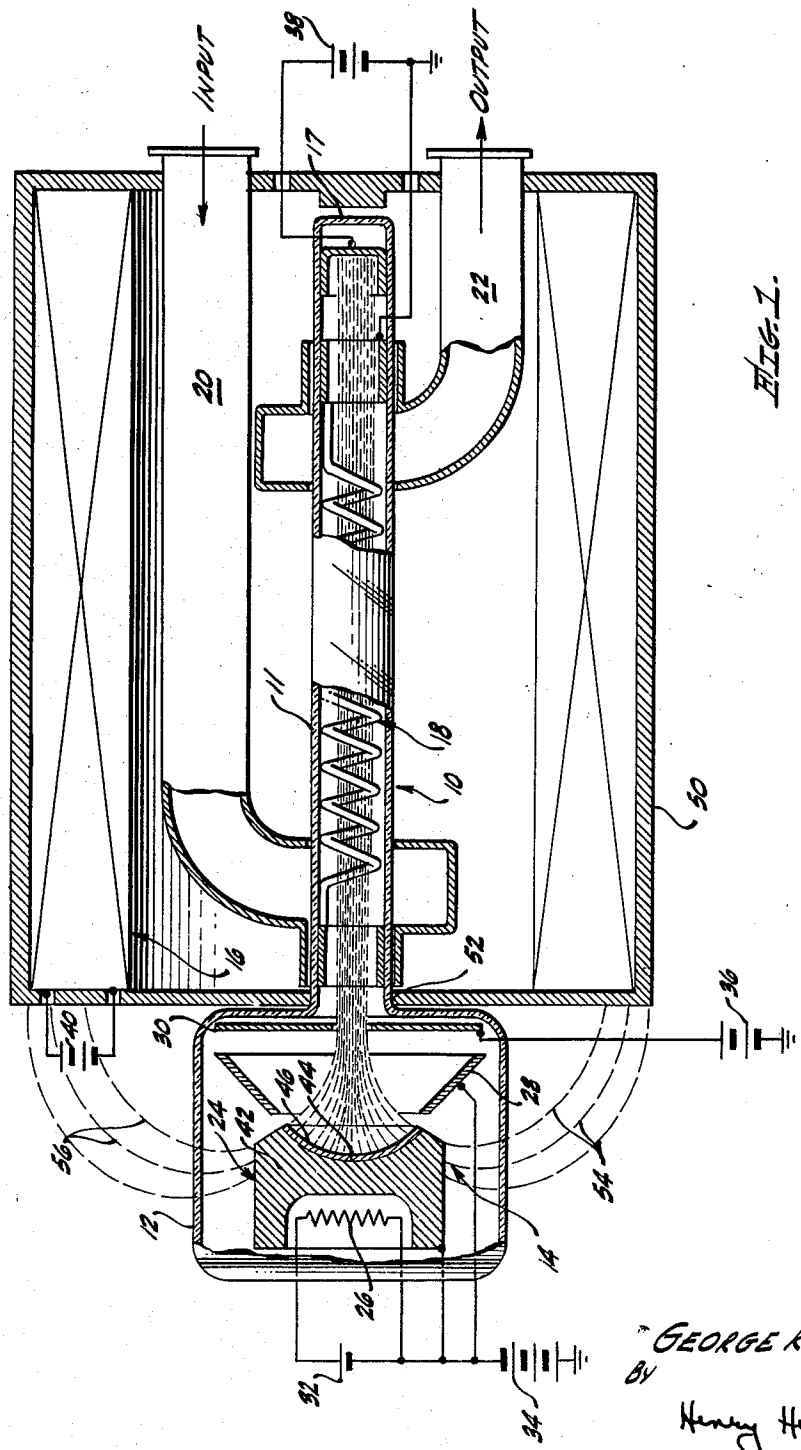


FIG. 1.

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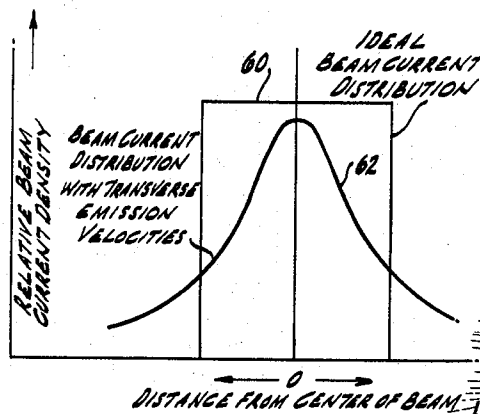


FIG. 2.

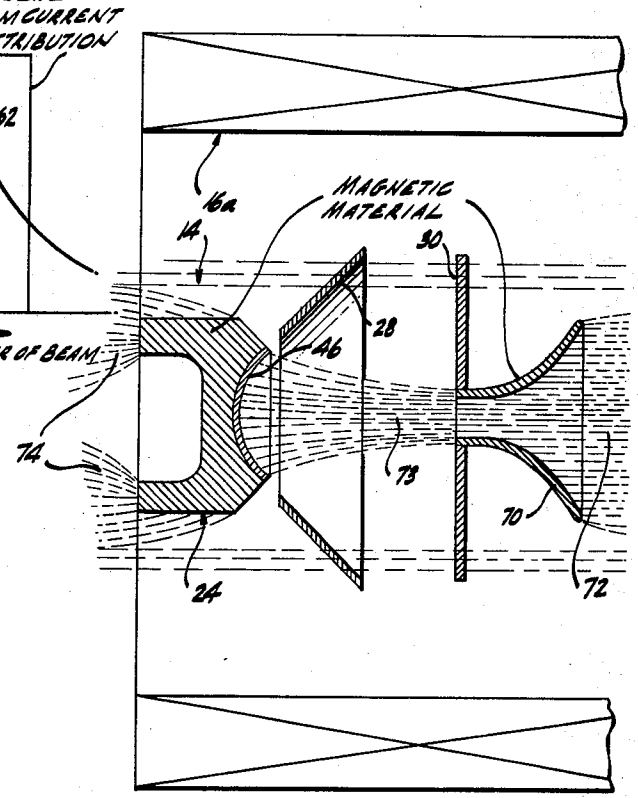


FIG. 3.

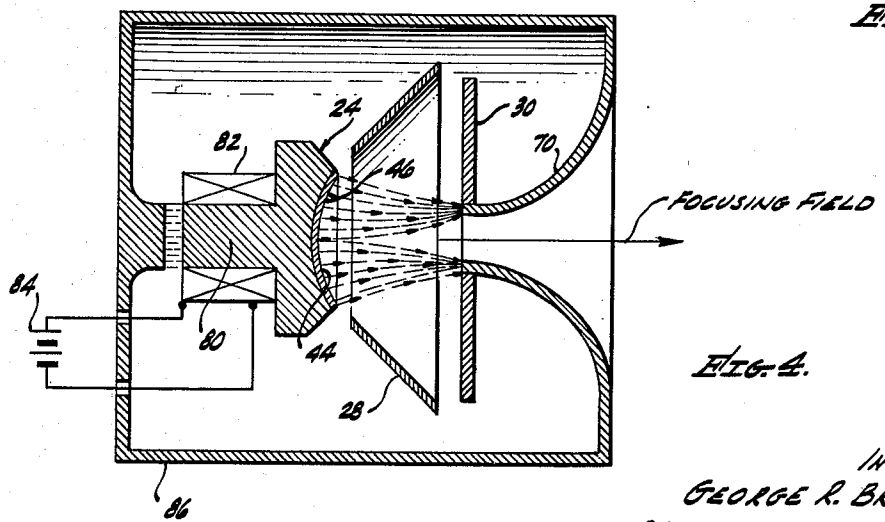


FIG. 4.

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ELECTRON GUN

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3 Claims. (Cl. 315—3.5)

This invention relates to electron guns for use in traveling-wave tubes and more particularly to converging beam electron guns incorporating a magnetic field arrangement to aid in converging and confining the electron beam.

As is generally known, the power available from a traveling-wave tube is partially dependent on the current of the electron beam of the tube. Thus, for certain applications it becomes desirable to increase the available power output by increasing the current of the electron beam of the tube. Because of the limited transverse area suitable for accommodating current flow in the slow-wave structures employed in tubes of this type, however, it is generally necessary that an increase in the current flow be accomplished by increasing the current density of the electron beam. As the current that can be emitted from a unit area of cathode emitting surface soon reaches saturation, it is the present practice to employ what is known as a converging beam electron gun. This type of electron gun incorporates a cathode having a large electron emitting surface. In operation, the electrons emitted from this large emitter surface are converged into an electron beam of sufficiently small cross-sectional area to be accommodated by the slow-wave structures.

The collimated magnetic field generally used for focusing and constraining the electron beam in the traveling-wave tube, may, however, tend to limit the effectiveness of a converging beam electron gun. That is, a portion of the electrons emitted from the cathode have transverse components of emission velocity due to the effect of the magnetic lines of force of the focusing field on the emitted electrons, particularly in the regions about the outer periphery of cathode emitter surface. These transverse velocity components of the electrons produce a variation in current density in the electron beam which is undesirable.

In accordance with the present invention, a converging beam electron gun is provided wherein a converging magnetic field is produced between the cathode and the commencement of the slow-wave structure thereby to substantially eliminate transverse velocity components of the emitted electrons. More particularly, a magnetic field is produced that preferably is approximately normal to the cathode emitter surface. In one embodiment of the invention, the solenoid for producing the focusing field is enclosed within a cylinder of ferromagnetic material which is coextensive with the active length of the tube and does not enclose the electron gun. One extremity of the cylinder enclosing the focusing solenoid has an opening which is adapted to receive the elongated portion of the tube envelope. A converging beam electron gun incorporating a cathode composed of a ferromagnetic material is employed so that leakage flux is attracted from this opening to the ferromagnetic cathode to produce the converging magnetic field necessary for eliminating the transverse velocity components in the stream electrons.

In another embodiment of the device of the present invention, the entire length of the tube is immersed in a

magnetic focusing field that would normally be collimated throughout the length of the tube. According to the present invention, however, a ferromagnetic cathode together with apparatus for intercepting and converging the focusing field inwards toward the anode aperture of the electron gun is provided to produce a converging magnetic field between the cathode and the anode of the electron gun. In still another embodiment of the invention, a converging magnetic field from a ferromagnetic cathode to the anode aperture of a converging beam electron gun is produced by magnetomotive force developed by a winding on the cathode which can also serve to heat the cathode to its proper temperature for electron emission.

It is therefore an object of the invention to provide an improved electron gun for use in traveling-wave tubes.

Another object of the invention is to provide apparatus for minimizing the transverse velocity components of electrons emitted from the cathode of an electron gun.

Still another object of the invention is to provide apparatus for producing a magnetic field through the electron emitting surface of the cathode in a converging beam electron gun that is normal to said electron emitting surface.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only, and are not intended as a definition of the limits of the invention.

Fig. 1 is a cross-sectional schematic view of one embodiment of the device of the present invention together with associated circuitry;

Fig. 2 is a graph showing the current density distribution in an ideal electron beam and in an electron beam having transverse emission velocities; and

Figs. 3 and 4 are cross-sectional schematic views of two additional embodiments of the device of the present invention.

Referring now to Fig. 1 there is illustrated a first embodiment of the device of the present invention comprising an evacuated envelope **10** which has an elongated portion **11** and an enlarged portion **12**. The enlarged portion **12** of envelope **10** disposed at the left extremity, as viewed in the drawing, houses an electron gun **14** for producing an electron beam. A solenoid **16** directs the electron beam along a predetermined path through the elongated portion **11** and a collector electrode **17** is disposed at the extremity of the path farthest from the electron gun **14** to intercept and collect the electron beam. A helix **18** is disposed about the predetermined electron path to propagate an electromagnetic wave therealong, and input and output waveguide sections **20**, **22** are coupled to the helix **18**.

More particularly, electron gun **14** comprises a cathode **24** with a heater **26**, a focusing electrode **28**, and an accelerating electrode **30**. Heater **26** is connected across a battery **32**, one terminal of which is referenced to the cathode **24**. The cathode **24** together with the focusing electrode **28** is maintained at a potential of several thousand volts negative with respect to ground by means of connections therefrom to the negative terminal of a battery **34**, the positive terminal of which is connected to ground. The accelerating anode **30**, on the other hand, is maintained at a potential of the order of 200 volts positive with respect to ground by means of a connection therefrom to the positive terminal of a

battery 36, the negative terminal of which is referenced to ground. In addition to the above, the collector electrode 17 and the helix 18 are maintained at potentials of the order of 200 volts positive and ground, respectively, by means of suitable connections to a battery 38 and ground. The solenoid 16 is energized with a direct-current to produce a magnetic field of from 600 to 1000 gauss along the longitudinal axis of the tube by means of a connection across a battery 40.

In accordance with the invention, the cathode 24 comprises a member 42 composed of a ferromagnetic material and having a circular concave surface 44 of a substantially larger area than the cross-sectional area of the electron beam. The member 42 is disposed in such a manner that the surface 44 faces helix 18 and is concentric with respect to the longitudinal axis of the tube. The edges of the member 42 adjacent the concave surface 44 are beveled so that the angle between a radial tangent to the outer periphery of the surface 44 and the beveled surface is of the order of 90°. In addition, the member 42 is made sufficiently thick so as to substantially decrease the reluctance of any magnetic path along the longitudinal axis of the tube. A layer 46 of emitter material is disposed over the concave surface 44 to provide a source of electrons. The layer 46 may, for example, be composed of sintered nickel powder and alkaline earth carbonates, or other equivalent material. In that it is necessary to heat the layer 46 to temperatures of the order of 800° centigrade to produce electron emission, it is necessary that the Curie temperature of the ferromagnetic material out of which member 42 is composed be sufficiently high so that it retains its magnetic properties at an appropriate operating temperature. A Curie temperature of the order of 900° centigrade would be suitable for a cathode operating at 800° centigrade. A material out of which member 42 may be composed is, for example, cobalt as it has a sufficiently high Curie temperature and a vapor pressure that is less than that of nickel at the same temperature. Nickel is a metal commonly used for making cathodes.

Operating in conjunction with the cathode 24 to produce a converging magnetic field commencing from the layer 46 of emitter material, is a cylindrical magnetic shield 50 which encloses the solenoid 16 and the elongated portion 11 of the envelope 10. The end portion of shield 50 nearest the electron gun 14 has an aperture 52 disposed in the center thereof of sufficient diameter to accommodate the elongated portion 11 of the envelope 10. During operation, a magnetic field is produced along the longitudinal axis of the tube coextensive with the elongated portion 11 of the envelope 10 to focus and constrain the electron beam along its path in this region. The path of the magnetic flux constituting this field has a toroidal shape. That is, the field extends lengthwise along the tube within the solenoid 16 between the end portions of the shield 50. Upon reaching the end portions, it proceeds in a radial direction to the outer wall of the shield 50 whence it follows the low reluctance path offered by this wall to form a closed path about the solenoid 16.

There is, however, some leakage flux which penetrates through the aperture 52 in the end portion of the shield 50 nearest the electron gun 14. Due to the low reluctance presented by the ferromagnetic member 42 of cathode 24, this leakage flux threads the cathode 24 prior to closing upon its path about the solenoid in a manner shown by dashed lines 54, 56. In that the bevel about the outer periphery of concave surface 44 does not present a shorter path to the leakage flux, a maximum of the leakage flux threads the cathode 24. Thus the leakage flux constitutes a converging magnetic field commencing from the emitter surface of the cathode which considerably decreases the transverse velocity components of electrons emitted from the cathode 24.

The effect of producing a converging magnetic field commencing from the emitter surface is to bring electrons emitted from each elemental area of the emitter surface of cathode 24 uniformly together to form an electron beam that has a current distribution that approaches an ideal beam current distribution as represented by line 60 of Fig. 2. The effect of transverse emission velocities on current distribution is represented by line 62 of Fig. 2. It is generally desirable to avoid large variations in current density across the electron beam so as to improve the focusing characteristics or collimation of the electron stream. In the device of the present invention, it is apparent that the trajectory of an electron is influenced strongly by forces acting on it while it is near the cathode surface and thus moving relatively slowly. For this reason, if the transverse velocities of emission are to be reduced, it is preferable that the magnetic flux at the cathode surface be normal to this surface. By the use of the member 42 which is composed of a material which exhibits ferromagnetic properties at the operating temperature of the cathode, a magnetic field may be produced which is normal to the emitter surface of the cathode 24 irrespective of its size.

In an alternative embodiment of the present invention, the electron gun portion of which is shown in Fig. 3, no magnetic shield 50 is employed and a focusing solenoid 16*a* is made coextensive with the complete length of the tube including the enlarged portion thereof. The cathode 24, focusing electrode 28 and accelerating anode 30 of the electron gun 14 are the same as those employed in the device of Fig. 1. However, an additional horn 70 of ferromagnetic material has a throat portion which is inserted in the aperture of accelerating anode 30 and expands radially outwards from the electron beam along the direction of electron flow to a diameter substantially equal to or greater than the diameter of the cathode 24. The ferromagnetic horn 70 presents a low reluctance path to the magnetic flux of the focusing field which causes a substantial portion of the flux to thread the horn 70. In this manner, a portion of the magnetic flux of the focusing field is concentrated about the aperture of the accelerating anode.

The cathode 24, as before, presents a low reluctance path to the flux of a magnetic field. Thus the magnetic flux leaving the aperture of the accelerating anode is attracted towards the nearest surface of cathode 24. A typical flux distribution into the ferromagnetic horn 70, from the horn 70 to the cathode 24, and leaving the cathode 24 is represented by lines 72, 73, and 74, respectively. Thus a converging magnetic field commencing from the emitter surface 96 of the cathode 24 is produced. It is to be noted however, that in this case it is necessary to focus the electrons radially inwards electrostatically by means of a suitable potential applied to the focusing electrode 28 so as to minimize the number of electrons that are intercepted by the horn 70 and accelerating electrode 30. Otherwise the converging magnetic field represented by the lines 73 direct the beam electrons towards the throat end of the horn 70.

In still another embodiment of the present invention illustrated in Fig. 4, the cathode 24, focusing electrode 28, accelerating anode 30, and ferromagnetic horn 70 similar to the device of Fig. 3 are employed. In addition, the cathode 24 is fitted with an armature 80 about which is disposed a solenoid 82 which serves to heat the cathode 24 to its proper emission temperature and to generate a magnetomotive force. Accordingly, the solenoid is energized with a direct current by means of a connection across a battery 84. A low reluctance magnetic path is provided from the extremity of the armature 80 farthest from the emitter surface of cathode 24 to the outer periphery of the ferromagnetic horn 70 by a cylinder 86 composed of ferromagnetic material. A gap is left between

the end portion of the cylinder **86** and the armature **80** as the cathode **24** must be maintained at a potential that is different from that of accelerating anode **30**. The generation of a converging magnetic field commencing from the emitter surface of the cathode **24** to the throat of the horn **70** is similar to that of the device of Fig. 3. Should this device be used in conjunction with a magnetic focusing field, however, the polarity of the current energizing the solenoid **82** should be such that the magnetic field between the cathode **24** and horn **70** aids that of the focusing field.

What is claimed is:

1. An electron gun capable of producing a high density electron beam of predetermnied cross-sectional area, said electron gun comprising a cathode including a support member composed of a ferromagnetic material for providing a concave support surface having beveled edges adjacent to said support surface, said beleved edges being approximately at an angle of 90° to said support surface at its junction therewith, a layer of emitter material disposed on said support surface having beveled edges, means for heating said member to a temperature less than the Curie temperature of said ferromagnetic material and sufficiently high to provide a source of electrons, and means for producing a magnetic field through said cathode, said magnetic field being substantially perpendicular to said support surface at each elemental area thereon.

2. An electron gun capable of producing a high density electron beam of predetermined cross-sectional area, said electron gun comprising a cathode including a support member comprised of a ferromagnetic material for providing a support surface, said support surface being concave along the axis of the electron beam and having a beveled edge around the concave area, said beveled edge being at an angle approximately 90° with respect to said support surface at its junction therewith, a layer of emitter material disposed on the concave area of said support surface, means of heating said ferromagnetic material to a temperature less than the Curie temperature of said ferromagnetic material and sufficiently high to provide a source of electrons, and means for producing a magnetic field having a central axis along the path of the electron beam, said magnetic field extending through said support member and converging from lines substantially perpendicular to the concave area of said support surface into substantially parallel lines having the desired cross-sectional area for the electron beam.

3. In a traveling-wave tube, apparatus for producing an electron beam of predetermined cross-sectional area comprising: a ferromagnetic cylinder encompassing a slow-wave structure of the traveling-wave tube and including an aperture at an electron gun end thereof; a solenoid disposed concentrically about and coextensive with the length of the electron beam path to provide a constraining field along the electron beam path, some of the field from the solenoid emerging in a leakage flux extending outside said ferromagnetic cylinder at the electron gun end thereof; a cathode structure spaced apart from said ferromagnetic cylinder at the electron gun end thereof, said cathode including a member composed of ferromagnetic material providing an emitter support surface having a concave central surface along the axis of said beam and beveled edges surrounding the periphery of said concave surface, said beveled edges being at an angle of approximately 90° with respect to said concave surface at its junction therewith said ferromagnetic material converging the leakage flux extending outside said ferromagnetic cylinder into the constraining field within said cylinder; and a layer of emitter material disposed on said support surface for emitting electrons to be converged by said leakage flux into the electron beam of predetermined cross-sectional area prior to entering the ferromagnetic cylinder through the aperture therein.

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