May 17, 1960 N. F. FYLER 2,937,314

HIGH RESOLUTION CATHODE RAY TUBE APPARATUS

Original Filed March 5, 1958 6 Sheets-Sheet 1

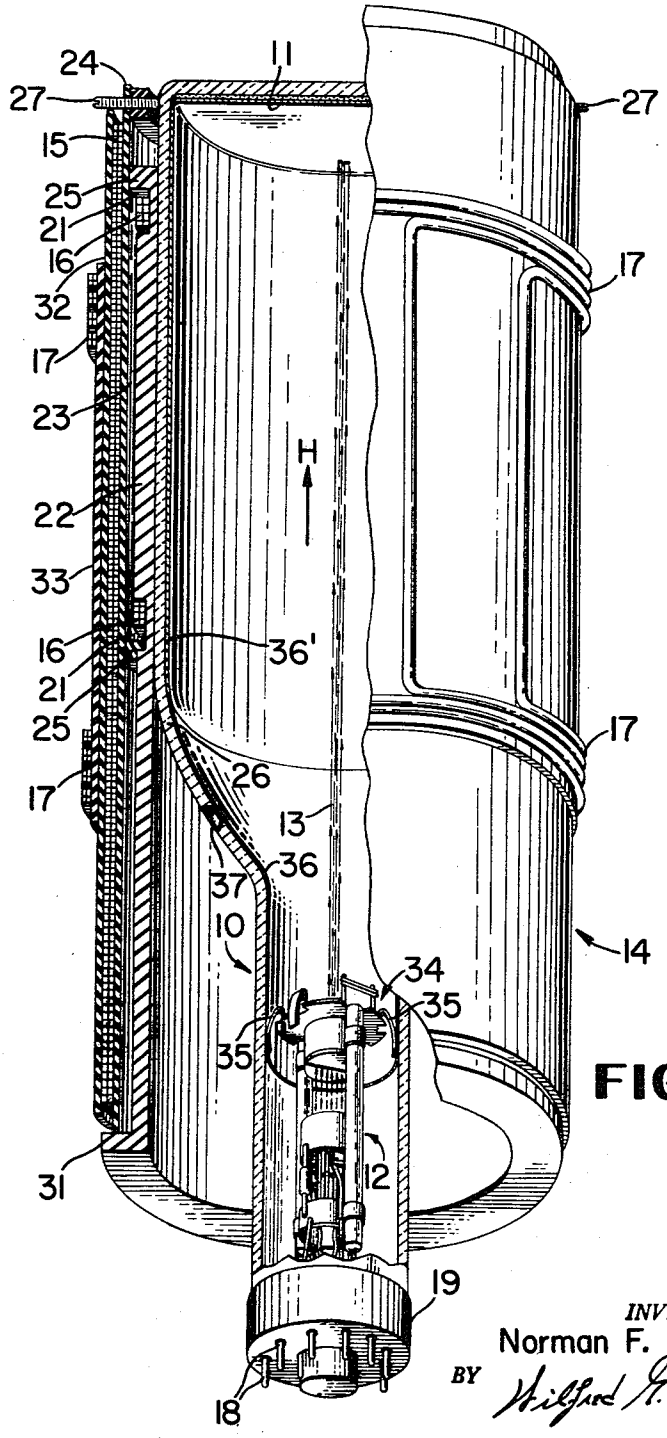


FIG. 1

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HIGH RESOLUTION CATHODE RAY TUBE APPARATUS

Original Filed March 5, 1958 6 Sheets-Sheet 2

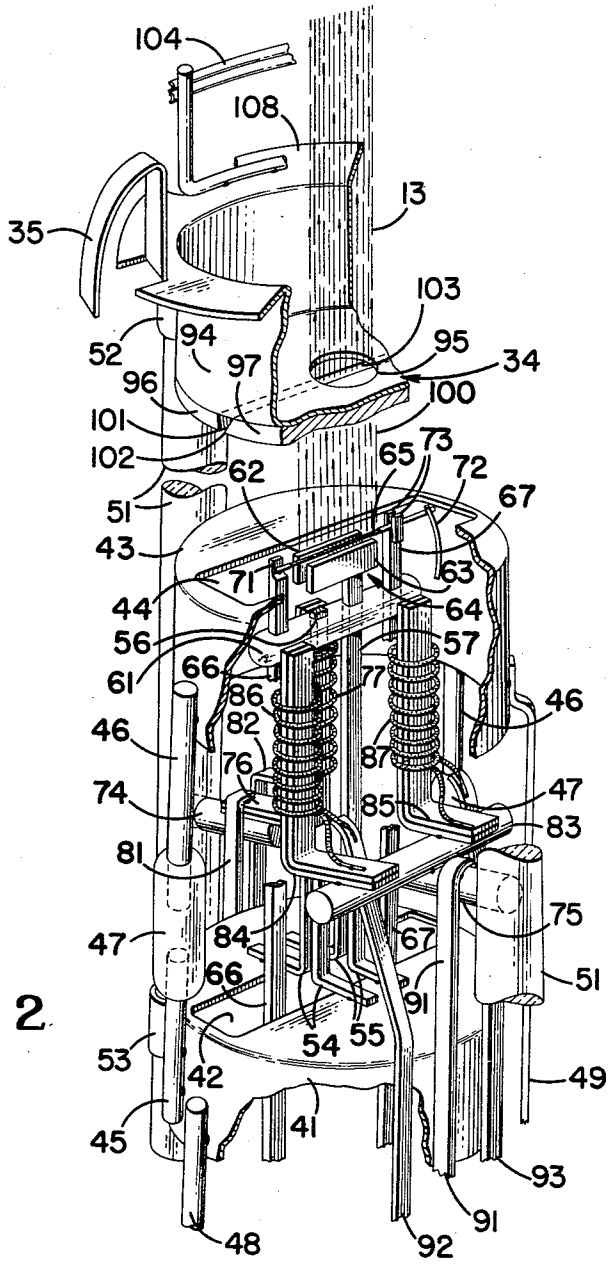


FIG. 2.

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HIGH RESOLUTION CATHODE RAY TUBE APPARATUS

Original Filed March 5, 1958 6 Sheets-Sheet 3

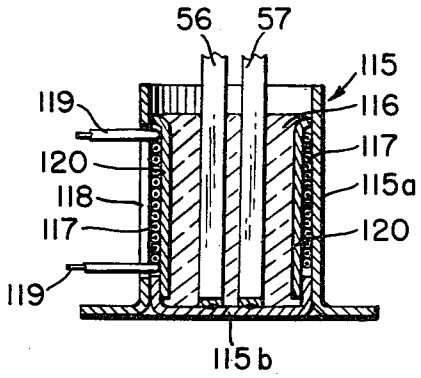


FIG. 8

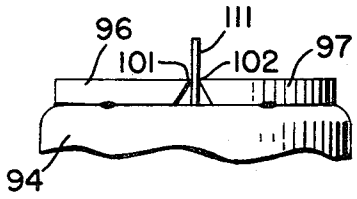


FIG. 5

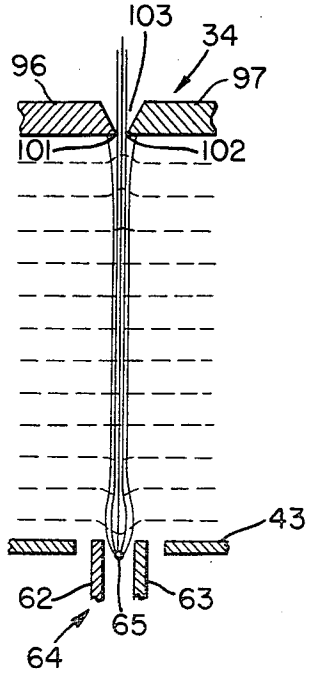


FIG. 3

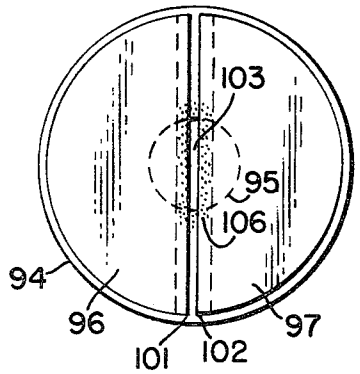


FIG. 4

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HIGH RESOLUTION CATHODE RAY TUBE APPARATUS

Original Filed March 5, 1958 6 Sheets-Sheet 4

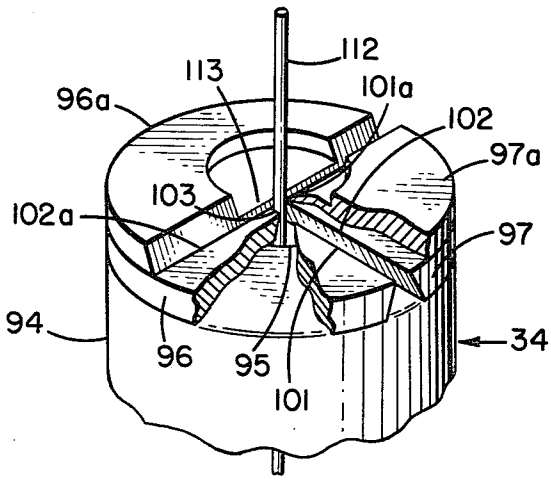


FIG. 6

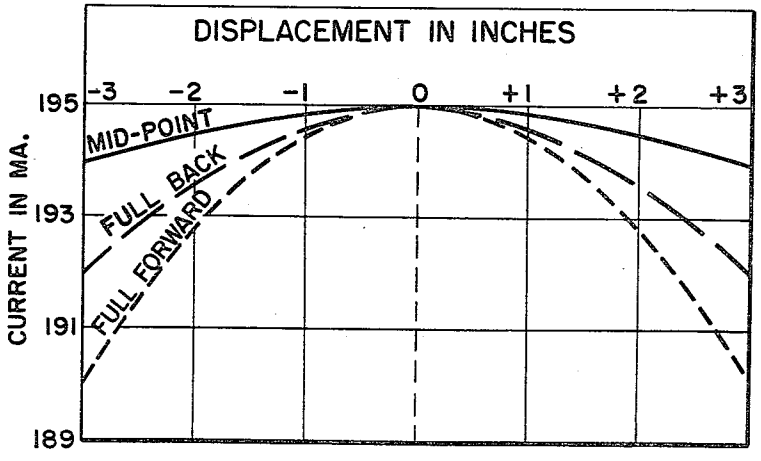


FIG. 9

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May 17, 1960 N. F. FYLER 2,937,314

HIGH RESOLUTION CATHODE RAY TUBE APPARATUS

Original Filed March 5, 1958 6 Sheets-Sheet 5

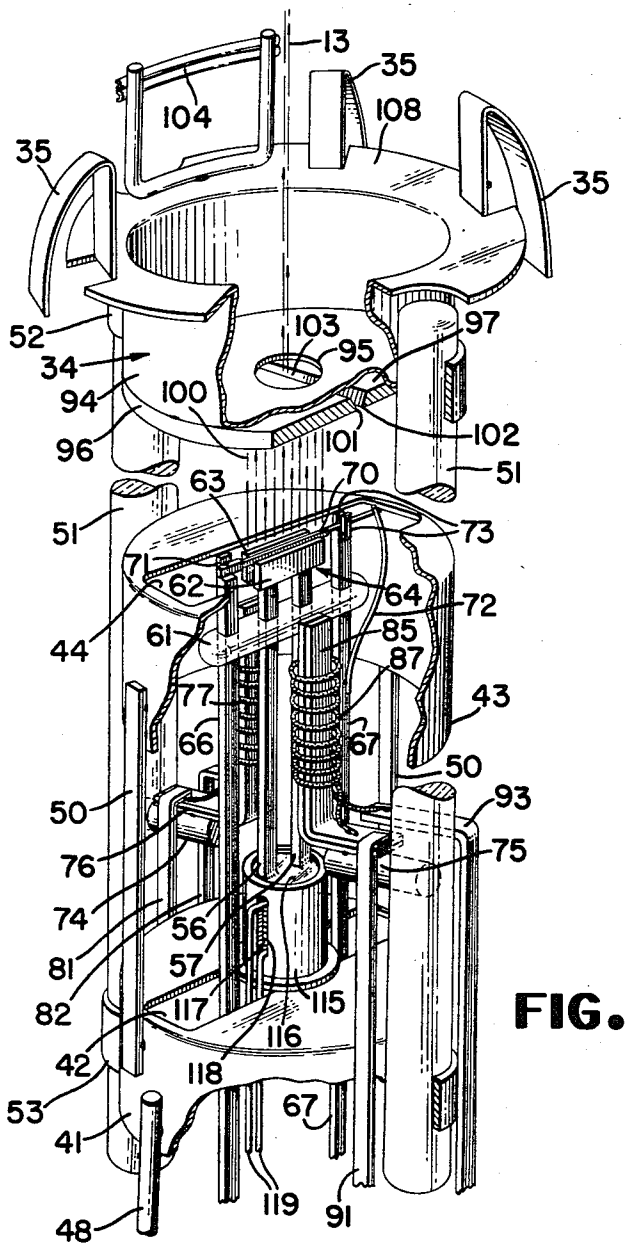


FIG. 7

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HIGH RESOLUTION CATHODE RAY TUBE APPARATUS

Original Filed March 5, 1958 6 Sheets-Sheet 6

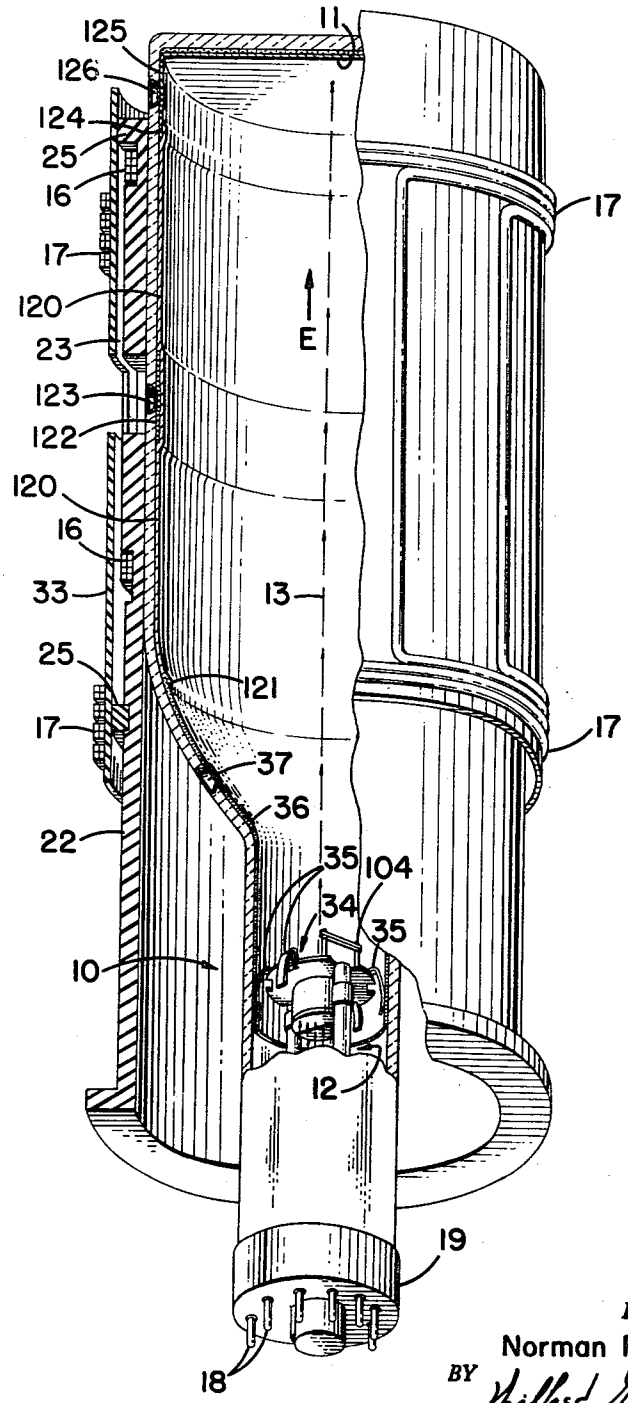


FIG. 10

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United States Patent Office 2,937,314 Patented May 17, 1960

2,937,314

HIGH RESOLUTION CATHODE RAY TUBE APPARATUS

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Continuation of application Serial No. 719,229, March 5, 1958. This application December 28, 1959, Serial No. 467

17 Claims. (Cl. 315—17)

The present invention relates in general to improved cathode ray tubes and more particularly concerns a high resolution cathode ray tube apparatus capable of producing an exceptionally fine spot of substantially uniform luminous intensity. This is a continuation of my earlier filed application Serial No. 719,229, filed March 5, 1958, entitled "High Resolution Cathode Ray Tube Apparatus," now abandoned.

From the standpoint of commercial television image generation and display, customary cathode ray techniques are readily adaptable to achieve established standards of spot size and resolution. Thus, little difficulty is experienced in presenting the required 525 line raster on the face of a home television receiving tube or on a flying spot scanner used for video signal generation. Although the emphasis on detail in specialized wideband closed-circuit television systems may require somewhat higher resolution than the 525 line raster, conventional cathode ray tubes may still be employed with little or no modification.

The present invention contemplates and has an important object the provision of a cathode ray tube apparatus offering spot definition and resolution several orders of magnitude finer than heretofore available with tubes designed primarily for television use. Through the application of the inventive concepts herein disclosed, resolution of the order of 1000 lines per inch or more may be achieved on the phosphor target or screen of a cathode ray tube, permitting image reproduction approaching photographic quality, with oscilloscope displays or flying spot scanners having the definition required to read the exceedingly small microfilm frames such as are used for data storage in a Minicard file system.

Another object of this invention is the provision of suitable structure incorporating an electron optical system for a cathode ray tube capable of providing an extremely fine luminous spot of substantially uniform light intensity.

A further object of this invention is the provision of means for developing a cathode ray tube spot in the form of an exceptionally narrow rectangle, thereby achieving high resolution in one direction and substantially constant average overall light intensity despite any variations in the emissive properties of phosphor particles on the screen, such intensity approaching that achieved in conventional cathode ray picture tubes.

Still another object of the invention is the provision of a cathode ray tube system in accordance with the preceding objects having a high degree in deflection linearity.

Still a further object of the invention is the incorporation of a deflection system for the novel cathode ray tube structure in accordance with the preceding objects capable of displacing the spot to substantially any position on the face of the tube while retaining the desired high resolution without dynamic focusing.

A feature of the invention resides in the provision of an exceptionally narrow slit controllable within precise

tolerances and suitably located within the tube for masking an electron beam from a filamentary source.

Another feature of the invention resides in the provision of means for externally controlling the orientation of an internal filamentary electron source relative to a beam masking slit in a completed tube and to maintain such orientation.

Another object of the invention is the provision of an electron gun structure arranged to minimize undesired electric field components within such structure tending to diverge the electron beam emanating from the electron source therein.

Still another object of the invention is the provision of a sensitive electron gun capable of providing marked beam current response to small, high frequency changes in grid potential.

A further object of the invention is the provision of a method for adjusting narrow beam-shaping apertures to precise tolerances.

Still further, it is an object of the subject invention to incorporate the novel gun structure source, masking and orientating means along with conventional components in a cooperative manner within a cathode ray tube type structure to achieve the foregoing objectives.

Broadly speaking, the invention comprises a cathode ray tube envelope having an electron gun which emits a narrow rectangular electron beam of substantially uniform cross-sectional density through an aperture toward a phosphor screen. A substantially uniform axial magnetic focusing field, for example, is established in the region traversed by the electron beam between the aperture and screen. The deflection yoke may comprise two pairs of coaxial deflection coils having a cosine distribution of turns in space quadrature about a section of the tube approximately midway between the electron gun aperture and the phosphor screen.

In general, the electron gun includes a filamentary source of electrons adjacent to a control grid and spaced from an accelerating anode formed with a small aperture through which the shaped beam emerges. The disposition of the source, control grid and accelerating anode is such that a substantially axial electric field exists in the region between the filamentary source and the aperture to minimize the beam divergence.

For a specific application, the filamentary source of electrons perpendicularly intersects the gun axis between closely adjacent planar control grid conducting surfaces disposed substantially parallel to both the filamentary source and the gun axis.

The accelerating anode preferably comprises a known cup-shaped electrode including a conductive surface lying perpendicular to the gun axis formed with an axially symmetric opening. A novel beam-limiting, slit-like aperture is defined by a pair of flat coplanar conductive elements secured to said anode surface and having spaced, closely adjacent, parallel knife edges symmetrically positioned over said opening. A planar electrode is positioned in the region of the edges of the grid surfaces nearest the accelerating anode in a plane perpendicular and parallel to the grid and anode surfaces, respectively. This electrode and the grid conducting surfaces are maintained at substantially the same D.-C. potential. In a preferred form, this planar electrode and grid conducting surfaces are electrically isolated with respect to A.-C. signals. Thus, the desired axial electric field pattern is obtained while the grid-cathode capacity remains relatively low, thereby facilitating the control of beam intensity with high frequency signals.

A novel feature of the invention resides in the provision of means for externally controlling lateral displacement and angular orientation of the filamentary source and control grid surfaces relative to the aperture in the accel-

erating anode. In a specific form, the legs which support the filamentary source and control grid surfaces are maintained in fixed relationship by an insulating spacer. A pair of bimetallic elements contact one side of the spacer and a third bimetallic element contacts the spacer on the opposite side in the region between the first pair of bimetallic elements. An electric heater surrounds each bimetallic element, the current through each heater being individually controllable to regulate the temperature of its own associated bimetallic element. By heating the first pair of bimetallic elements unequally, the spacer may be rotated, while lateral translation may be obtained by heating the first pair of bimetallic elements differently from the third bimetallic element. To achieve a visible indication of correct alignment, a phosphor material may be applied to the periphery of the aperture in the accelerating anode on the side thereof facing the filamentary sources. Uniform illumination about the aperture is indicative of bimetallic heater currents which have properly centered the electron beam on the aperture.

Another feature of the invention resides in the means for retaining the precise position of the filament-grid assembly after the heaters surrounding the bimetallic elements are deenergized, notwithstanding mechanical shocks imparted to the electron gun. This is accomplished by embedding the legs which support the filamentary source in any known material which has a relatively low melting point and is adapted to use in an electron tube. Any one of many well known glasses, of course, have the desired characteristics. The material is heated to its softening point, and the filament-grid assembly then precisely oriented in the manner described above. The material is then permitted to harden about the supporting legs by removing the heat therefrom so that the filament-grid assembly is firmly secured in the desired position.

Other features, objects and advantages of the invention will become apparent from the following specification when read in connection with the accompanying drawing, in which:

Fig. 1 is a perspective drawing of a first embodiment of a cathode ray tube apparatus incorporating the invention having portions of the figure cut away to show specific features;

Fig. 2 is a perspective drawing of a novel electron gun having portions removed better to expose the interior structure;

Fig. 3 is a diagrammatic representation of the electric field lines in the electron gun structure shown in Fig. 2;

Fig. 4 illustrates the anode surface of the electron gun of Fig. 2 as seen from the grid-cathode end thereof;

Fig. 5 illustrates the apparatus of the anode beam limiting aperture shown during one step in the assembly of the accelerating anode of Fig. 2;

Fig. 6 illustrates a portion similar to the one shown in the accelerating anode of Fig. 2 modified to have an aperture of precisely controlled dimensions;

Fig. 7 is a broken-away perspective view of an alternative embodiment of an electron gun according to the invention;

Fig. 8 is a vertical cross-sectional view of a portion of Fig. 7 to show details of the novel means for retaining precise alignment of components in the gun structure of Fig. 7;

Fig. 9 is a graphical representation of the focusing current for optimum focus of the electron beam as a function of the beam displacement for various deflection yoke positions of a tube made according to the invention and,

Fig. 10 is a perspective view of a further embodiment of the invention utilizing a novel electrostatic focusing arrangement.

Throughout the drawings and the description thereof, like elements referred to in the different figures are identified by the same reference numeral.

With reference now to the drawing, and more particularly Fig. 1 thereof, a perspective view of a first embodiment of the novel high resolution cathode ray tube apparatus is shown, certain portions having been deleted to disclose interior structure. A cathode ray tube is there shown consisting of an evacuated, generally cylindrical glass envelope **10** having a phosphor screen **11** deposited on an inner, substantially flat, front plate and an electron gun **12** in a neck portion of the envelope **10**. The electron gun **12**, described in detail hereinafter, emits electrons in the form of an electron beam **13** along the tube axis toward screen **11**. Leads from all the electron gun electrodes except the anode electrode are brought out to pins **18** in a conventional tube base **19**.

The beam **13** is focused and deflected by magnetic fields produced by a coil assembly **14** which surrounds the tube. The coil assembly **14** includes a solenoidal focusing coil **15** for providing an axial magnetic field H, a vertical deflection coil **16**, and a horizontal deflection coil **17**, the coils **15**, **16** and **17** being mounted upon concentrically arranged individual coil forms of Bakelite or other suitable insulating material as shown. The vertical deflection coil **16** is disposed within grooves **21** of inner cylindrical form **22** and the region **23** between form **22** and cylindrical form **24** upon which focusing coil **15** is wound. Annular ridges **25** on form **22** separate the latter from focusing coil inner form **24** to provide the region **23**.

Form **22** is in surface contact with the glass wall **26** of the envelope **10**. Several adjusting screws **27**, one being shown, are threaded through focusing coil inner form **24** so that the inner end of each adjusting screw bears against the glass wall **26** of the envelope **10**. By adjusting each screw, the focusing inner coil form **24** and the focusing coil **15** may be centered on the envelope **10**. At the opposite end, focusing coil inner form **24** contacts annular ridge **31** of inner form **22**. Focusing coil **15** is enclosed by cylindrical outer focusing coil form **32**. Horizontal deflection coil **17** is wound upon the outer cylindrical form **33** which is in surface contact with outer focusing coil form **32**.

Inner and outer forms **22** and **33**, respectively may be rotated about and moved along the tube axis to permit proper alignment of the deflection coils as discussed hereinafter.

Anode **34** of gun **12** is electrically connected to an electrically conducting coating **36**, made according to any known processes, as with Aquadag, on the inside of glass wall **26** by the resilient tabs **35**, which also serve to position and shock-mount the gun axially within the tube. A high voltage terminal **37**, embedded in the envelope **10**, contacts the Aquadag coating **36** and serves to connect accelerating anode **34** to an appropriate external biasing source of potential. The electrically conducting coating also preferably covers the forward interior of the glass wall **26** and the phosphor screen **11**, the portion **36** being Aquadag and the portion **36'** being sputtered aluminum, for example.

Referring now to Fig. 2, there is shown an enlarged perspective view of the novel electron gun with portions cut away to expose elements otherwise not visible.

A cup-shaped base electrode **41**, formed with a substantially rectangular, diametrical slot **42**, supports a similarly shaped upper electrode **43** by means of a pair of rod assemblies, each of which is formed of conductive sections **45** and **46** joined together, but electrically isolated as by glass beads **47**. The conductive rod sections **45** and **46** are preferably welded in the customary manner to the cylindrical outer surfaces of electrodes **41** and **43**. Electrode **43** is formed with a rectangular slot **44** similar to and preferably aligned with slot **42** in electrode **41**. Conductors **48** and **49** couple electrodes **41** and **43** to different pins **18** in tube base **19** (Fig. 1).

Anode **34** (Figs. 1 and 2) is supported axially within the gun by a pair of insulating rods **51**, such as glass, clamped at opposite ends by rings **52** and **53** attached

to anode 34 and base electrode 41, respectively, as through welds, for example.

Two pairs of electrically conductive L-shaped legs 54 and 55 are welded to base electrode 41 over slot 42. Flexible conductive rods 56 and 57 are secured between the upright portions of legs 54 and 55, respectively; pass through insulating bead 61, and support the small, parallel, spaced rectangular conducting plates 62 and 63, preferably being welded thereto. These plates together form the control grid 64 and lie on opposite sides of the thoriated tungsten filament 65.

Filament 65 is supported by flexible conducting members 66 and 67 which pass through insulating bead 61, extend through slot 42 of lower base electrode 41 and are electrically conducted to respective pins 18 in tube base 19 (Fig. 1). One end of filament 65 is welded to tab 71 of member 66. The other end passes freely through a yoke formed by tabs 73 at the upper end of member 67 and is attached to a tension spring 72 which maintains filament 65 under tension at all times. The filament may be fabricated from any electron-emissive material as is known in the art, but in the illustrated embodiment is made of thoriated tungsten wire.

Short rods 74 and 75 extend radially inwardly from glass rods 51, each rod being secured to one of the glass rods 51 as by metal to glass techniques. An L-shaped bimetallic 76 is secured, as by welding, along its base to rod 74 and its upright arm presses against the center of insulating bead 61. A heating element 77 encloses the upright arm of bimetallic element 78, the first end of the heating element 77, being welded directly to the base of the bimetal. A conducting rod 81 is welded to bimetallic element 76, as shown, thus connecting the first end of the heating element 77 to a pin 18 in the tube base 19 (Fig. 1). The second end of heating element 77 is welded to a conducting rod 82 which rod, in turn, is connected to another pin 18 in the tube base 19 (Fig. 1), thus completing an electrical circuit through the heating element 77.

Radial rod 75, connected to a separate glass rod 51 in the same manner as rod 74 is connected to glass rod 51, supports a tangentially disposed, short rod 83. L-shaped bimetallic elements 84 and 85 are welded to rod 83 and press against the ends of insulating bead 61 to resist the force applied on the opposite side by bimetallic element 76. Heating elements 86 and 87 surround bimetallic elements 84, 85, respectively one end of each heater being welded to its corresponding bimetallic element. These ends are electrically connected to a pin 18 in base 19 through rod 83, rod 75 and conducting member 91, as shown. The other ends of heating elements 86 and 87 are each connected to separate pins 18 through conducting members 92 and 93, respectively. It should be noted in passing, however, that the bottom ends of the heating elements 77, 86, 87 may be connected together internally of the electron gun and then connected to a single pin 18.

Anode 34 includes an inverted cup-shaped section 94 formed with spring clips 35, for high voltage connection purposes disclosed in the description of Fig. 1. The lower circular anode surface is formed with a circular opening 95 centered on the axis of the gun. A pair of thin flatplates 96 and 97 are disposed in surface contact with the lowermost surface of anode 34. The closely spaced, confronting edges of plates 96 and 97 are formed with beveled knife edges 101 and 102, respectively, to define a slitlike beam limiting aperture 103 which is parallel to the flat upper surface of electrode 43, the upper surface of control grid 64 and filament 65. Filament 65 has preferably the same width, but has a greater length than aperture 103.

To complete the gun structure, a getter 104 is fastened to an annular flange 108 extending from the upper edge of the cup-shaped section 94 of anode 34. This getter is flashed in the customary manner in completing evacation of the tube.

Certain features are to be noted with respect to the gun structure described immediately above. First, only the beam from the center portion of filament 65 passes through aperture 103, thereby enhancing the uniformity of the beam electron density. The control grid plates 62 and 63 are spaced very close to filament 65, resulting in an exceptionally high transconductance, yet, the small area of these surfaces minimizes the capacitance between the control grid and the filament. Additionally, by maintaining upper electrode 43 at substantially the same D.-C. potential as control grid 64, the electric field between the anode and control grid in the region traversed by the beam from the filament 65 to the aperture 103 remains substantially axial and relatively insensitive to signals applied to control grid 64. As a result of this relative insensitivity, variations of beam divergence due to electric field components orthogonal to the gun axis are virtually eliminated. Since variations in beam divergence are virtually eliminated, secondary defocusing effects attendant on changes in the amplitude of the grid drive signal are small enough to be disregarded in a practical gun. Moreover, since upper electrode 43 is electrically isolated from control grid 64, the interelectrode capacitance between the elements making up the gun is minimized.

The diagram of the electric field distribution in the space between the filament 65 and the anode 34 (Fig. 3) illustrates why beam divergence is virtually eliminated. Before discussing Fig. 3 in detail, it should be noted that the electrode 43, the control grid 64, the filament 65 and the anode 34 are shown in cross-section, the cut-away plane being normal to the knife edges 101, 102 of the anode 34, the longitudinal axis of the filament 65, the plane of the grid plates 62, 63 making up the control grid 64 and the slotted surface of the electrode 43. Further, spacing between the various electrodes has been changed to allow a clearer drawing to be made and the size of the various electrodes has been greatly exaggerated for the same reason. In an actual electron gun made according to the invention, the following dimensions have been used: diameter of the filament 65, .001"; width of slot between grid plates 62, 63, .003"; depth of filament 65 in slot between the grid plates 62, 63, .006"; distance from ends of grid plates 62, 63 to anode 34, .100"; size of aperture 103, .001" x .025". An accelerating potential of 25,000 volts may be applied as desired, by applying potentials to the anode 34 and the filament 65 so that the latter is negative with respect to the former. With electrodes having the foregoing dimensions and an accelerating potential of 25,000 volts, it has been found that relatively low grid drive is required to control the gun. That is, the intensity of the electron beam may be varied from saturation to cutoff with a signal of about five (5) volts amplitude applied to the control grid 64. It should be noted in this respect that the amplitude of the grid signal required for complete control of the electron beam density may be changed by changing the foregoing dimensions, particularly the depth of the filament 65 between the grid plates 62, 63. It is evident from observation of Fig. 3 that, if the filament 65 is placed farther down between the grid plates 62, 63, the grid drive required ot cut off the gun would be greater. It is also evident that the insertion of the filament 65 between the grid plates 62, 63 affords protection to the filament 65 from positive-ion bombardment, since almost all such ions are attracted to the control grid 64.

Considering now Fig. 3 in detail, the electric field existing between the electrodes is represented by dotted equipotential lines, it being understood that the illustrated equipotential lines are exemplary only. The trajectories of the electrons (shown in solid lines) emitted from the filament 65 are also exemplary. As is shown,

the equipotential lines are substantially parallel to the oppositely disposed surfaces of the anode **34** and the electrode 43, except for perturbations adjacent the aperture in the anode **34** and the apertures between the control grid **64** and filament **65**. Although the perturbations are undesirable in that their presence means that the trajectories are affected to some degree (the paraxial trajectories being curved slightly in a direction orthogonal to the desired direction) the perturbations have been found to have only a minor effect upon dispersion of the beam. It is felt that the reason the perturbations have such a small effect is that the accelerating voltage attracting the electrons toward the anode **34** is so great that the transit time of the electrons between the filament **65** and the anode **34** is very short, so the electrons are not in the perturbations for a long enough time to have their velocities changed substantially. In any event, the electron beam is clipped by the knife edges **101, 102** so that the electrons having divergent trajectories are removed from the beam. It is understood, of course, that the perturbations adjacent the filament **65** are desirable to effect normal intensity control of the electrons emitted from the filament **65**.

In passing, it should be noted that the knife edges **101, 102** are formed by bevelling the plates **96, 97** toward the sides thereof opposite the filament **65**. This type of bevel permits very close adjustment of the spacing between the knife edges **101, 102** without danger of blocking the aperture or reducing its effective width, yet allowing the plates **96, 97** to be made from thick material for mechanical considerations. The plates **96, 97** are preferably fabricated from a soft magnetic material, as, for example, material such as that known in the art by the name mu-metal. When such a material is used, the electromagnetic fields of the focus coil (**15** in Fig. 1) and the deflection coils (**16, 17** in Fig. 1) are shunted away from the space between the anode **34** and the filament **65**, leaving only the electrostatic field just described as the effective operation factor there.

While the foregoing description has been directed particularly toward an electron gun having certain recited dimensions, and potentials on the various electrodes, it is understood that such dimensions may be changed without departing from the invention. For example, if it be desired to increase the kinetic energy of the electron beam to brighten the luminescent spot on the viewing screen, the accelerating potential may be increased, say to 60,000 volts, and the spacing between the filament and anode increased to say .25" to avoid arcing between the anode and the other electrodes.

Since the electron beam in the vicinity of the aperture **103** is very well defined, it is highly desirable that provision be made to ensure centering of the electron beam on the aperture **103** to avoid excessive clipping at the aperture **103** and to keep the efficiency of the electron gun as high as possible. Both objects may be attained by moving the filament-grid structure as a unit, using the bimetallic elements **76, 84, 85** as shown in Fig. 2. After the tube is completely assembled, exhausted and energized so that the electron beam may be adjusted for optimum coincidence with the aperture **103**, the heating elements **77, 86, 87** are energized to heat each associated bimetallic element **76, 84, 85**. This heating causes the bimetallic elements **76, 84, 85** to move into contact with the insulating bead **61**, causing that part, in turn (and the filament **65** and control grid **64** attached thereto) to move. It will be appreciated that any combination of rotational and translational movement in a direction at right angles to a line between bimetallic element **84** and bimetallic element **85** may be obtained by differential energization of the heating elements **77, 86, 87**. While many types of bimetallic materials may be used to make the bimetallic elements **76, 84, 85**, it has been found advantageous to use either the bimetallic material made by the H. A. Wilson Company and known by the trade name of "Autoflex" or the bimetallic material made by the Metals and Controls Company and known by the trade name "Truflex E–5," arranged so as to bend toward the insulating bead **61** when heated. Whatever bimetallic material is used to make the bimetallic elements, it has been found to be advantageous to space the bimetallic elements **76, 84, 85** from the insulating bead **61** when the heating elements **77, 86, 87** are not energized in order that normal processing of the tube may be carried on without danger of overstressing either the bimetallic elements **78, 84, 85** or moving the supporting structure of the insulating bead **61**.

Referring to Fig. 4, anode **34** incorporating an aid to electron beam lineup is shown. The edge of the anode aperture **103** on the filament side thereof may be coated with any known phosphorescent material **106**, such as zinc sulphide, which glows when struck by electrons. Thus, when the beam is centered, the aperture edges are equally illuminated on all sides. If correct centering is not immediately obtained, the filament-grid assembly is reoriented to direct the beam toward the edge of lesser illumination as previously described. Alternatively, proper orientation may be determined by measuring the light intensity of the spot on the screen with a photocell (not shown). The position is optimum when the measured light intensity is a maximum.

Since the anode aperture **103** defines the electron beam cross-section, exceedingly close tolerances must be maintained during assembly. Fig. 5 illustrates one step in the assembly technique, by means of which the narrow dimension of the slit aperture may be closely controlled during fabrication. As shown, flat plates **96** and **97**, having knife edges **101** and **102** which define the diametrical edges of the slit, are placed upon the flat underside of anode section **94**. Knife edges **101** and **102** are pressed firmly against a shim **111**, whose thickness is the precise width of the aperture being formed. The plates **96** and **97** are then spot welded to the flat underside of anode section **94**, and the shim **111** is then removed. In the event it is found that the welding operation adversely affects the magnetic properties of the plates **98** and **97**, known annealing processes may be used to restore the plates **96** and **97** to their original state.

Referring now to Fig. 6, an alternative embodiment showing structure for forming a beam-limiting aperture **103** is shown. As may be noted, the beam-limiting aperture **103**, illustrated in Fig. 6 is square. Plates **96** and **97** are first welded to electrode **94** as described in connection with Fig. 5. A circular wire **112** having a diameter equal to the desired beam dimension along the aperture **103** is then centrally positioned between and perpendicular to the plates **96** and **97** and a second pair of plates **96***a* and **97***a* is brought into contact with the wire **112** and welded to the plates **96** and **97**. While it is possible that plates **96***a* and **97***a* be identical with plates **96** and **97**, it is preferred that the plates **96***a* and **97***a* be thinned down as shown at **113** in order that secondary emission from the bevelled portions of plates **96***a* and **97***a* be minimized and the aperture formed by the plates **96, 97** and **96***a*, **97***a* be essentially coplanar.

Referring to Fig. 7, there is illustrated an alternative embodiment of electron gun **12** with the filamentary source and aperture slit crossed to provide a beam **13** of square cross-section. Additional features, which ensure precise alignment over extended periods despite mechanical shocks, are also shown.

Since in most aspects the structure of the electron gun in Fig. 7 is like that in Fig. 2, only the differences will be described. The filament **65** of Fig. 2 is replaced by a ribbon filament **70**, preferably also of thoriated tungsten, with its narrow side facing the anode. This type of filament is characterized by ruggedness and structural rigidity. Since spring **72** maintains the already rigid ribbon filament **70** in tension, sagging is virtually non-existent.

Furthermore, the effects of vibration are absorbed by this type of filament; hence, variations in beam intensity due to filament displacement are minimized.

Aperture **103** is oriented at right angles to the length of filament **70**, thereby appreciably restricting the incident electron beam **100** along its long dimension, whereby a beam **13** having a substantially square cross-section is provided.

Rods **50** are welded to upper and base electrodes **43** and **41**, respectively. Upper electrode **43** is thereby supported and electrically connected to base electrode **41**. Since the grid **64** is electrically connected to base electrode **41**, grid **64** and upper electrode **43** are at the same potential. It has been found that such connection is quite satisfactory when high frequency modulation of the electron beam is not required.

A small metallic cup **115** is welded to lower electrode **41**. Flexible rods **56** and **57**, which support bead **61** and control grid **64**, are welded to the base of cup **115** and surrounded by a meltable solid, such as glass **116**. A heating element **117**, visible through slot **118**, is disposed between the wall of cup **115** and glass **116**. Heating element **117** is energized through conductors **119** which are connected to respective pins **18** in the tube base **19** (Fig. 1).

Details of the arrangement of elements in cup **115** are better understood by referring to Fig. 8 which shows a sectional view of the cup **115**, the cutting plane being central to the width of slot **118** and across the diameter of cup **115**. Flexible rods **56** and **57** are shown welded to the base **115*b***, the latter benig of U-shaped cross-section. The upwardly extending flange of base **115*b*** is in surface contact with the outer wall **115*a*** of cup **115** and the inner cylindrical wall **120**, the latter wall being formed with a lip extending radially outwardly into contact with outer wall **115*a***. Heating element **117** occupies the annular chamber bounded radially by inner and outer walls **120** and **115*a*** respectively, at the top by the lip of inner wall **120** and at the bottom by the top edge of base **115*b***.

Before discussing the advantages obtained from this arrangement, it is to be noted that in Fig. 7, there are only two bimetallic elements **76** and **85**, respectively. Element **85** is displaced to the left of its position in Fig. 2 and is fastened directly to rod **75**. As a result, both elements **76** and **85** are centrally located on opposite sides of bead **61**, thereby controlling only the lateral displacement of the filament-grid asesmbly in a direction normal to the filament length. Alignment in a direction along the filament length is not at all critical in this embodiment, because the cross-sectional length of beam **100** is much greater than the width of aperture **103**. It is evident, however, that the three bimetallic elements could also be used here with only design changes required.

With the arrangement of Figs. 7 and 8, alignment is obtained by energizing heating element **117** to cause the glass **116** to soften sufficiently to permit movement of rods **56** and **57**. Heating elements **77** and **87** are appropriately energized to heat bimetallic elements **76** and **85**, respectively, until they translate the filament-grid assembly to a position which results in a beam **13** of maximum current density. This position may be determined as described hereinbefore in connection with Figs. 2 and 4. When the assembly is in the optimum position, heating element **117** is deenergized. The glass **116** hardens as it cools, thereby holding the assembly in the optimum position. The heating elements **77** and **87** may then be deenergized. This adjustment is initially made when the tube is first assembled and is not usually required thereafter. However, should unusual circumstances cause the filament-grid assembly to be displaced from its optimum position, it is evident that the adjusting procedure just described may be repeated to move the filament-grid assembly.

While the metallic cup **115** is shown to be of relatively short length in Fig. 7, so as not to obscure details of the electron gun, the metallic cup **115** may extend almost into contact with the bead **61** in order to minimize the possibility of subsequent displacement of the filament-grid assembly from its optimum position. Cup **115**, inner wall **120** and rods **56** and **57** are preferably made of metal having a thermal coefficient of expansion very close to that of the glass contained therein. Many such metals are known in the art, one such being chrome-iron. Although other meltable solids may be employed, glass is preferred as the supporting substance because of the relatively low melting point of many known types. Furthermore, many glasses remain tacky at temperatures just above their softening points so that rods **56** and **57** are supported at all times, although free to move gradually in response to pressure from the bimetallic elements. Sudden changes in position are thereby avoided and the optimum position is rapidly and accurately determined.

Having considered a preferred electron gun section, the focusing and deflecting systems according to the invention will now be described.

Focusing coil **15** (Fig. 1) is a long solenoid that produces a magnetic focusing field. As may be seen in Fig. 1, focusing coil **15** overlaps both the phosphor screen **11** and the anode **34**. As a result of this overlapping, the focusing field traversed by the beam from the aperture in the anode **34** to the phosphor screen **11** is substantially uniform. Since the focusing field is substantially uniform and the lines of force therein are parallel to a line through the center of the aperture **103** and the center of the phosphor screen **11**, all electrons which pass through the aperture **103** follow trajectories formed in accordance with the laws of motion of electrons in a magnetic field in which the lines of force are aligned substantially with the direction of motion of the electrons. That is, all electrons that enter the magnetic field at an angle to the magnetic lines of force therein travel in a helical path and all electrons that enter such a field parallel to the magnetic lines of force therein are unaffected by the magnetic field. The strength of the magnetic field may be adjusted (according to the velocity of the electrons entering therein) so that all the electrons that enter the field (as by passing through the aperture **103**) are focused at the same point within the field. It is evident that the strength of the field due to the focusing coil **15** may be adjusted so that all electrons that pass through the aperture **103** in the anode **34** may be focused on the phosphor screen **11**.

It has been found possible to accomplish satisfactory focusing by using a coil, consisting of 14 layers of No. 24 wire with a total of 14,269 turns, forming an 8-ohm coil 22¾" long and 7¼" in diameter, and passing a current of about 0.2 ampere through the coil. The size of the image on the phosphor screen **11** is then the same size as the aperture **103**, when the distance between the aperture **103** and the phosphor screen is approximately 22".

The preferred embodiment of the invention shown in Fig. 1, utilizes magnetic deflection by means of a horizontal deflection coil **16** and a vertical deflection coil **17**. The field generated by each of the deflection coils is perpendicular to the field generated by the focusing coil **15** in Fig. 1. This means, of course, that the field of the deflection coils **16** and **17** is also perpendicular to the direction in which the electrons are moving toward the phosphor screen **11**. As a result, the field from each of the deflection coils would cause the electrons to travel in a substantially circular path if the fields from each were uniform. However, it has been found preferable to wind each of the deflection coils so that each has a cosine distribution of turns, so that the displacement of the luminescent spot on the phosphor screen **11** is linear with the current applied to each of the deflection coils. Specifically, the horizontal deflection coil **16** having 400

cosine distributed turns of No. 28 wire and exhibiting a deflection sensitivity of 200 milliamperes per inch for a 20,000 volt anode potential has been found to be satisfactory. The vertical deflection coil **17**, of course, may be substantially the same as the horizontal deflection coil just described or its sensitivity may be changed as desired. Although conventional bridge-null methods may be used to determine when the horizontal and the vertical deflection coils are aligned so as to be perpendicular to each other, it has been found desirable to use the electron beam itself to determine correct alignment. That is, appropriate signals are applied to both the horizontal and vertical deflection coils so as to cause the luminescent spot on the phosphor screen **11** to trace a line, inclined, say, at 45° to the horizontal. When such a line is compared to a straight edge, no curvature should be discernible. In the event some curvature is detected, rotation of either, or both, of the deflection coils will result in its elimination.

It is evident that some defocusing must occur when the deflection coils **15**, **17** are energized. However, it is a simple matter to vary the strength of the focusing field in accordance with the resultant deflection field to maintain adequate focusing. In a practical tube, the amount of this compensation has been found to be very small in view of the relatively long distance from the aperture **103** to the phosphor screen and the relatively small distance that the beam is deflected on the phosphor screen.

The screen itself has been found to have some effect on the fineness of the spot which may be obtained. Specifically, it has been found that the thickness of the screen is rather critical. A rough rule of thumb is that the thickness of the screen should not exceed one-half the size of the luminescent spot to be obtained. When a thicker screen is used, the intensity of the generated spot is decreased and refraction of light through the phosphor particles making up the screen may occur. The latter problem requires special treatment of the phosphor particles before fabrication of the phosphor screen. First, it has been found highly desirable to use phosphors having initially a very fine particle size, such as the commercially available type P–16 phosphor, which has an average particle size of about four (4) microns. Secondly, such phosphors are agitated in a ball mill for 24 to 36 hours and then used to form the phosphor screen. Conventional methods of screen settling may be followed. Even if the foregoing process is used, variations in the intensity of the spot sometimes occur because the size of the luminescent spot approaches the grain size of the phosphor. However, the structure shown in Fig. 1, wherein the aperture **103** is aligned with the filament **65**, minimizes such variations. When the aperture **103** is aligned with the filament **65**, a rectangular spot is formed on the phosphor screen **11** and the output of each phosphor particle which is energized is integrated.

Referring now to Fig. 9 it may be seen that the position of the deflection coils **16**, **17** affects deflection linearity and focusing. In Fig. 9, the ordinate represents current through the focusing coil **15** required to maintain proper focusing while the abscissa represents deflection of the luminescent spot from the mid-point of the phosphor screen **11**, the negative values representing deflection to the left and the positive values representing deflection to the right. The curves marked "mid-point," "full back," and "full forward" show the variation in the required focusing current when the deflection coils are centered (mid-point), moved toward the electron gun (full back), and moved toward the phosphor screen (full forward). It is evident from the curves that substantially less correction is required when the deflection coils are centered and, further, that the magnitude of the required correction then approaches a linear function of the deflection angle. It should be recognized that the magnitude of the focusing coil current required for optimum focusing decreases as the deflection angle increases as the deflection angle increases for the following reasons:

(1) The mean length of the paths of electrons passing through the aperture **103** to the phosphor screen **11** increases as the deflection angle increases, making it necessary for focusing to occur at a greater distance from the aperture as the deflection angle is increased; and (2) the strength of the resultant magnetic field increases as deflection increases, causing focusing to occur at a lesser distance as the deflection angle increases. The foregoing effects may be minimized by providing a curved phosphor screen so that the mean length of the paths of the electrons passing through the aperture **103** does not change with deflection and, if still necessary, providing a dynamic focusing current.

Referring to Fig. 10, an alternative embodiment of the invention is illustrated. In addition to having all the advantages of fine resolution of the system of Fig. 1, the embodiment of Fig. 10 is lighter in weight, which is especially desirable in connection with air-borne systems requiring high resolution. This is achieved by providing an axially disposed focusing electric field through the region within the tube traversed by the beam after leaving the anode aperture. It should be noted, however, if a spot of exceptional resolution is required, the solenoid focusing coil may be retained to provide a supplemental magnetic focusing field; however, fewer turns on such a coil are required than are needed when only magnetic focusing is used to attain the same degree of resolution.

The focusing field-forming structure of Fig. 10 preferably includes axially symmetric bands of a material such as is known in the art by the trade-name of "Aquadag" **36** and **122** and a band of conducting material **125** such as aluminum. A cylindrical layer **120** of semiconductor material, such as ferrous oxide, overlays band **122** and contacts bands **36** and **125** at **121** and **124**, respectively. A different potential is applied to the bands **36**, **122** and **125** through terminals **37**, **123** and **126** respectively. Highest potential is applied to terminal **126**, the next highest is applied to terminal **123**, while terminal **37** is maintained at the lowest potential of the three.

The potential values are selected so that a substantially uniform potential gradient E is established in the semiconducting cylindrical layer **120** and oriented parallel to the tube axis. Since this gradient of potential is the electric field, it follows that a uniform axial electric focusing and accelerating field is obtained. It is to be noted that in the region extending axially between the gun **12** and the junction **121**, a unipotential space exists, since the anode **34** and "Aquadag" coating **36** are at the same potential. On the other side of junction **121**, the field gradient changes to a uniform value designated in the drawing as "E." Because of circular symmetry, the field in this transition region at edge **121** is axial. Since the beam is substantially on the axis in the region, radial field components further out from the axis can introduce virtually no divergence of the beam.

It is apparent that those skilled in the art may make numerous modifications of and departures from the specific embodiments described herein without departing from the inventive concepts. Consequently, the invention is to be construed as limited only by the spirit and scope of the appended claims.

What I claim is:

1. An electron gun structure for developing a rectangular beam of electrons comprising a filamentary source of electrons, means for energizing the filamentary source of electrons, means for establishing an electric field adjacent the filamentary source of electrons consisting of the combination of a pair of control grid plates, the pair of control grid plates being spaced to form therebetween a slot having the filamentary source of electrons centrally disposed therein and means for applying a first electrical potential to the pair of control grids, an accelerating

anode and means for applying a second electrical potential to the accelerating anode, the accelerating anode having a rectangular aperture formed therethrough and aligned substantially parallel to the filamentary source of electrons.

2. An electron gun structure as in claim 1 wherein the width of the slot between the control grid plates is approximately three times the diameter of the filamentary source of electrons, the distance between the end of the slot nearest the accelerating anode is approximately one hundred times the diameter of the filamentary source of electrons and the width of the aperture in the accelerating anode is approximately the same as the diameter of the filamentary source of electrons.

3. An electron gun structure as in claim 1 having, additionally, an auxiliary electrode parallel to the accelerating anode and coplanar with the ends of the control grid plates and means for applying the first electrical potential to the auxiliary electrode.

4. An electron gun structure as in claim 1 having, additionally, adjustable supporting structure for the source of electrons consisting of flexible support means attached to the source of electrons, heat responsive means disposed adjacent the flexible support means for imparting a force to the flexible support means, and means without the envelope and connected therethrough for controlling the heat applied to the heat responsive means.

5. Adjustable supporting structure for elements in an electron gun disposed within an evacuated envelope comprising an insulating bead disposed within the envelope, at least two flexible support members secured through the insulating bead, one end of each of the flexible support members being sealed through the envelope, each element to be adjusted being secured to the other end of a separate one of each of the flexible support members, at least two bimetallic elements secured within the envelope adjacent the insulating bead, independent heating means disposed adjacent each bimetallic element, and independent control means without the envelope cooperating therethrough to control each heating element whereby each bimetallic element is moved into contact with the insulating bead to move the bead and the elements attached thereto.

6. Adjustable supporting structure as in claim 5 having, additionally, a glass sleeve disposed about the flexible support members between the insulating bead and the envelope, independent heating means surrounding the glass sleeve and cooperating with independent control means without the envelope whereby the heating means surrounding the glass sleeve may be energized to soften the glass sleeve during the period the insulating bead is being moved.

7. In an electron gun for generating a high resolution electron beam, apparatus comprising, a flexibly supported source of electrons, means for forming an electron beam from electrons emitted from the source, an electrode spaced from the source having a beam-limiting aperture formed therein, phosphor material disposed about the edge of the aperture, heat responsive means for imparting a force to the source to change the direction of the electron beam, and means for controlling the heat applied to the heat responsive means to direct the electron beam at the aperture whereby all portions of the phosphor material are equally illuminated by the electron beam when the electron beam is directed at the aperture.

8. A cathode ray tube system comprising an elongated evacuated glass envelope having in combination a phosphor screen disposed on the inner side of one end thereof, an electron gun disposed at the opposite end of the envelope, the electron gun consising of a filamentary source of electrons, a pair of control grid plates forming a narrow slot with the filamentary source of electrons disposed therein and an anode spaced from the control grid plates toward the phosphor screen, the anode consisting of a plate fabricated from a soft magnetic material and having a rectangular aperture formed therethrough, means for separately energizing the filamentary source of electrons, the control grid and the anode to cause a rectangular beam of electrons to pass through the aperture, and an electromagnetic focusing coil helically wound about the envelope and extending from the anode to the phosphor screen, and means for energizing the electromagnetic focusing coil whereby a uniform axial magnetic field is provided within the envelope between the anode and the phosphor screen.

9. A cathode ray tube system as in claim 8 having, additionally, flexible support means for the filamentary source of electrons and the control grid, heat responsive means for moving the flexible support means and means operating through the envelope to control the heat applied to the heat responsive means to move the filamentary source of electrons and the control grid to center the electron beam on the aperture.

10. A cathode ray tube comprising an evacuated glass envelope, a phosphor screen disposed on the inner surface of one end of the envelope and an electron gun disposed on the other end of the envelope, the envelope between the phosphor screen and the electron gun being substantially cylindrical, focusing means consisting of a plurality of annular bands of electrically conductive material sequentially disposed on the inner surface of the cylindrical portion of the envelope, means for applying electric potential through the envelope to the annular bands to form a series of electron lenses between each annular band, and a continuous layer of semiconducting material over-laying the annular bands and the remaining surface of the cylindrical portion of the envelope to reduce the electric potential gradient between each annular band.

11. In a high resolution tube, a strip-like source of electrons having an emissive surface, means for energizing said source, a control electrode having a leading edge and symmetrically disposed relative to said source to establish a focusing field for bringing electrons emitted from said source into substantial parallelism into an electron beam of prescribed cross-section, said emissive surface being disposed rearwardly of said leading edge of said control electrode, and a further electrode arranged along the path of said beam, said further electrode having an aperture formed therein corresponding to the beam cross-section and disposed in substantial axial alignment with and parallel to said emissive surface.

12. In a high resolution tube according to claim 11, means mounting said strip-like source for adjustment in relation to said aperture in said further electrode, and means controlled externally of said tube for adjusting said strip-like source.

13. In a high resolution tube, a strip-like source of electrons having an emissive surface, means for energizing said source, a control electrode having a leading edge and symmetrically disposed relative to said source into substantial parallelism into a rectangular electron beam, said emissive surface being disposed rearwardly of said leading edge of said control electrode, means for applying a focusing potential to said control electrode, a further electrode arranged along the path of said beam, said further electrode having a rectangular beam-forming aperture therein disposed in substantial axial alignment with and parallel to said emissive surface, and means for applying a potential to said further electrode which is positive relative to the potential on said control electrode.

14. In a high resolution tube, a support, a strip-like source of electrons having an emissive surface, means mounting said strip-like source for adjustment relative to said support, means for energizing said source, a control electrode having a leading edge and symmetrically disposed relative to said source to establish a focusing field for bringing electrons emitted from said source into substantial parallelism in an electron beam of a prescribed cross-section, said emissive surface being disposed rear-

wardly of said leading edge of said control electrode, means for applying a focusing potential to said control electrode, an accelerating electrode arranged along the path of the beam, said accelerating electrode having an aperture formed therein susbtantially of said cross-section and disposed in substantial axial alignment with and parallel to said emissive surface, means for applying an accelerating potential to said accelerating electrode which is positive with respect to the focusing potential, electrically responsive positioning means for moving said strip-like source to an adjusted position, and means external to said tube for controlling said positioning means.

15. In a high resolution tube, a support, a strip-like source of electrons having an emissive surface, means mounting said strip-like source for adjustment relative to said support, means for energizing said source, a control electrode having a leading edge and symmetrically disposed relative to said source to establish a focusing field for bringing electrons emitted from said source into substantial parallelism in a rectangular electron beam, said emissive surface being disposed rearwardly of said leading edge of said control electrode, means for applying a focusing potential to said control electrode, an accelerating electrode arranged along the path of the beam, said accelerating electrode having a rectangular aperture formed therein disposed in substantial axial alignment with and parallel to said emissive surface, means for applying an accelerating potential to said accelerating electrode which is positive with respect to the focusing potential, electrically responsive positioning means for moving said strip-like source to an adjusted position, and means external to said tube for controlling said positioning means.

16. In a high resolution tube, a support, a source of electrons having an emissive surface, means mounting said source for adjustment relative to said support, means for energizing said source, a control electrode symmetrically disposed relative to said source to establish a focusing field for bringing electrons emitted from said source into substantial parallelism in an electron beam, means for applying a focusing potential to said control electrode, an accelerating electrode arranged along the path of the beam, said accelerating electrode having a beam-forming aperture therein disposed in substantial axial alignment with and parallel to said emissive surface, means for applying an accelerating potential to said accelerating electrode which is positive with respect to the focusing potential, electrically responsive positioning means for moving said source to an adjusted position, and means external to said tube for controlling said positioning means.

17. In an electron gun assembly, a source of electrons for producing an electron beam, means including at least one electrode having a beam-forming aperture therein for controlling said electron beam, means mounting said source of electrons for adjustment in relation to said beam-forming aperture of said one electrode, electrically-responsive positioning means for moving said source of electrons to an adjusted position, and means external to said tube for controlling said positioning means.

References Cited in the file of this patent

UNITED STATES PATENTS

1,870,975	Ulrey	Aug. 9, 1932
2,111,942	Schlesinger	Mar. 22, 1938
2,151,992	Schwartz	Mar. 28, 1939
2,194,547	Haines	Mar. 26, 1940
2,480,462	Garbe	Aug. 20, 1949
2,483,457	Feldt	Oct. 4, 1949
2,516,704	Kohl	July 25, 1950
2,565,533	Szegho	Aug. 28, 1951
2,810,091	Harsh	Oct. 15, 1957

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,937,314 May 17, 1960

Norman F. Fyler

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 5, line 30, and column 8, line 11, for "78", each occurrence, read -- 76 --; same column 8, line 41, for "98" read -- 96 --; column 9, line 31, for "benig" read -- being --; column 14, line 56, after "source" insert -- to establish a focusing field for bringing electrons emitted from said source --.

Signed and sealed this 15th day of November 1960.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

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