Nov. 24, 1942. J. D. McGEE ET AL 2,302,786

ELECTRON DISCHARGE DEVICE

Filed July 5, 1941 4 Sheets-Sheet 1

Fig. 1

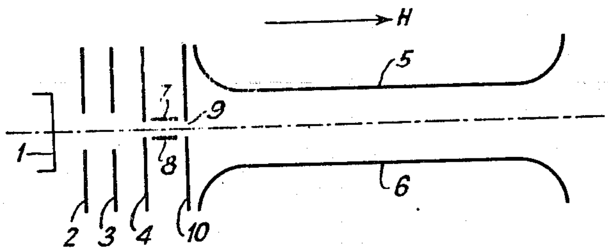

Fig. 2

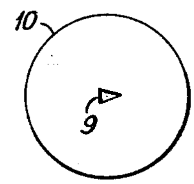

Fig. 3

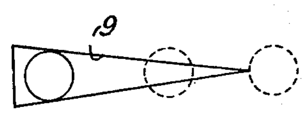

Fig. 4

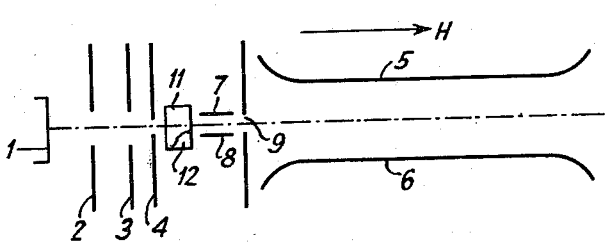

Fig. 5

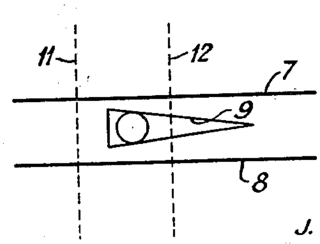

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Fig. 6

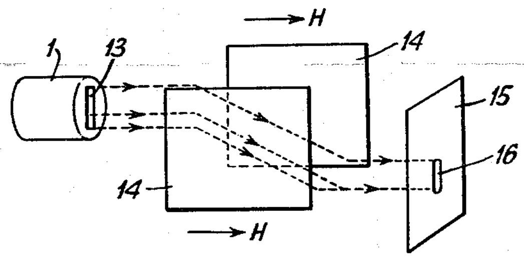


Fig. 7

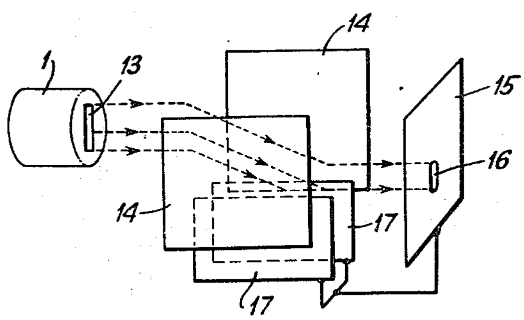


Fig. 8

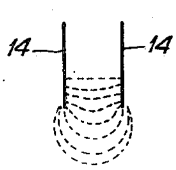
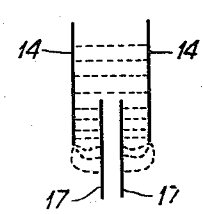


Fig. 9



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ELECTRON DISCHARGE DEVICE

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Fig. 10

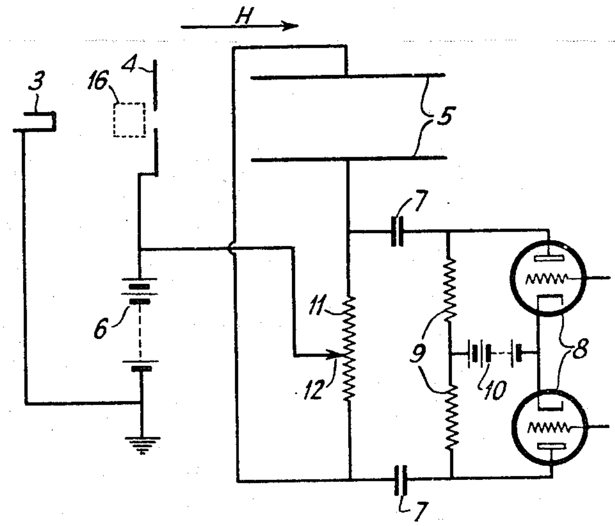
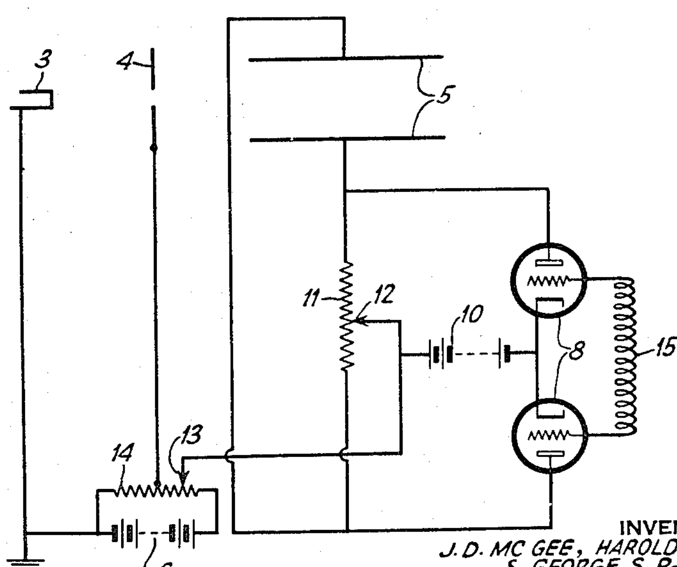


Fig. 11



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ELECTRON DISCHARGE DEVICE

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Fig. 12

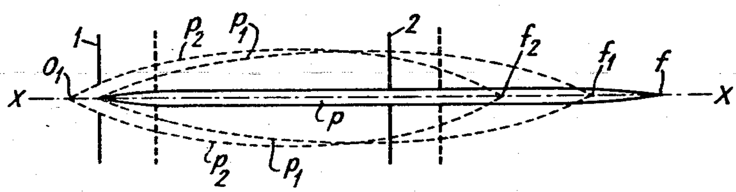


Fig. 13

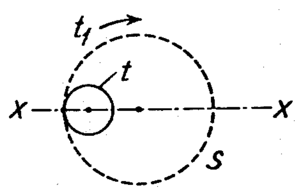
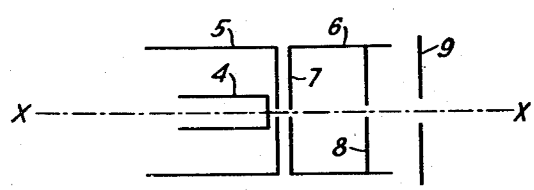


Fig. 14



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2,302,786

UNITED STATES PATENT OFFICE

2,302,786

ELECTRON DISCHARGE DEVICE

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Application July 5, 1941, Serial No. 401,132
In Great Britain May 2, 1940

10 Claims. (Cl. 250—163)

The present invention relates to electron discharge devices in which an electron beam is constrained to move in a strong and substantially uniform magnetic field, and deflection fields are applied to said electron beam while it is travelling in the magnetic fields so that after passing through a deflecting field, the beam again moves in a path which is substantially parallel to its path prior to entry into the deflecting field. The present invention relates particularly, but not exclusively, to cathode ray devices of the kind described in United States Patent specification No. 2,213,174.

In cathode ray devices of the kind generally employed, wherein the cathode ray emerges from a deflecting field at an angle to its direction upon entering the field, the ray is usually projected through a system of electrodes including an electrode termed a modulating electrode, adjacent the cathode, an and anode or anodes. The modulating potential is usually biassed to or maintained at a negative potential, and produces a cross-over in the beam near the cathode, the position of which is shown in relation to the potentials on the other electrodes in the devices so that a "spot" of the required size is produced on the screen or mosaic electrodes or other receiving element which is scanned by the cathode ray. In some cases the electron beam forming the ray may be caused to cross-over more than once.

In the case of devices of the kind to which the present invention relates, the electrons proceed through the magnetic field in spiral paths, the radii of which are dependent on the components of the electron velocities at right angles to the magnetic field. Thus, if good focussing is to be obtained in such a device, it is essential that electrons in the cathode ray projected into the deflecting field shall have as small as possible a component of velocity normal to the direction of the ray. Thus it is not feasible to use an electrode system which tends to produce a cross-over in the cathode ray.

Furthermore, in devices of the kind set forth the cathode ray is usually limited at a limiting aperture in an anode which selects from the total cathode emission some fraction, the electrons in which serve to traverse the aperture and constitute the cathode ray. However, the electrons emitted from the cathode have a random distribution of velocities, some electrons having relatively high components of velocity perpendicular to or radially of the axis of the gun and others having relatively high components of velocity axially of the gun. Unless the electrons are subject to a deflecting field the motion of the electrons transversely of the beam will be wholly oscillatory and practically all the electrons emitted from the cathode will follow spiral paths to the magnetic field, the periodic time, or time taken by the electron in traversing a turn of its spiral path, for each of the electrons, being the same, but the amplitude of the spiral in each case will be determined by the radial component of the velocity of the electron. The electrode having the limiting aperture above referred to will probably intercept a large number of the electrons emitted from the cathode having very high radial components, but some of these electrons pass through the limiting aperture and are included in the cathode ray projected from the gun, thus increasing the effective cross-section of the ray undesirably. In tubes which operate with electrostatic deflection of the cathode ray in a magnetic field as above described, it is important to ensure that the electrons in the cathode ray emerge from the deflecting field with their velocities transverse to the direction of the magnetic field unchanged or reduced, otherwise the tube may operate with poor definition particularly in parts of the scanned patch which is away from the axis of the tube. To ensure that these velocities are not increased, the strength of the deflecting field and the strength of the magnetic field must be so co-related or the deflecting electrode system must be so designed that electrons passing through the deflecting field complete a discrete number of oscillatory cycles transversely of the general direction of movement of the beam. This question is discussed more in detail, for example, in United States Patent specification No. 2,213,175.

In addition to paying careful attention to the design or arrangement of the deflecting electrodes, difficulty is also experienced if the cathode ray is not correctly centered between the deflecting electrodes. The region in which the deflected ray moves should be one in which the potentials remains substantially constant so that the electron speed likewise remains substantially constant, otherwise when the ray is deflected the electrons therein may acquire undesired velocity components which persist after the ray has emerged from the deflecting field. In the case where the deflecting potentials are applied to the deflecting electrodes in push-pull relation there is a region, herein termed the "electrically neutral region" between the electrodes wherein the potential does not vary with the deflecting potential. For example, if the deflecting potentials are balanced, the electrically neutral region will be located midway between the deflecting electrodes. Thus, it is possible to centre the cathode ray gun so that the ray is projected between the deflecting electrodes in a region of substantially invariant potential. It is however, difficult to ensure that the correct centering of the cathode ray gun shall be maintained during the life of a tube and also, in some circumstances, for example, in cases where the cathode ray is variably deflected before entering the main deflecting field.

One object of the present invention is to provide novel electron discharge devices and operating circuits therefor wherein a beam of electrons is projected in a strong substantially uniform magnetic field, and means are provided for adjustably limiting the cross-section of the beam.

A further object of the present invention is to provide an arrangement, including an electron discharge device of the kind set forth, wherein electrons having undesirably large radial components of velocity can be eliminated from the electron beam which is produced when the device is in operation.

The invention also provides novel electric circuit arrangements employing electron discharge devices of the kind referred to, wherein a beam of electrons is projected in a strong substantially uniform magnetic field and in which difficulties experienced in centering the beam are overcome.

In one form of the invention, an electron discharge device is provided including within an evacuated envelope, an electrode system including a source of electrons, a pair of deflecting electrodes and an electrode having an aperture, the arrangement being such that, in operation, if said electrode system is immersed in a uniform magnetic field having lines of force extending between said source of electrons and said electrode, electrons are projected from said source in the form of a beam which passes between said deflecting electrodes and emerges therefrom with a direction substantially parallel to its initial direction and moves towards said aperture to be limited therein in accordance with the deflection of the beam between said deflecting electrodes, whereby the beam, after passing said electrode, has its cross-section deformed in a desired manner in accordance with potentials applied between said deflecting electrodes without introducing in the motion of electrons within the beam components of velocity normal to said direction. If desired, a device in accordance with the invention may include a second pair of deflecting electrodes between which, in operation, said beam passes, said second pair of deflecting electrodes being adapted to be charged to establish a deflecting field to operate on said beam after it has passed through said aperture to produce a deflection in said beam substantially equal and opposite in sense to the deflection produced by the first-mentioned pair of deflecting electrodes.

In one form of the invention, the first mentioned deflecting electrodes may be arranged with parallel edges extending parallel to an axis through said apertures substantially perpendicular to the plane of the aperture said electrode being so disposed that, in operation, that part of said beam which emerges from between said edges of said deflecting electrodes is intercepted while the remainder of said beam passes through said aperture.

In a further form of the invention a further pair of deflecting electrodes may be provided between which, in operation, said beam passes, said further pair of deflecting electrodes being adapted to be charged to produce a deflecting field for setting the position of said beam with relation to said electrode in a desired manner.

In a still further form of the invention an electric circuit arrangement is provided including an electron discharge device in which, in operation, a beam of electrons is projected through a strong and substantially uniform magnetic field wherein for the purpose of defining the size of the spot produced by said beam on a target, screen or the like, the cross-section of said beam is stopped down and wherein some of the electrons passing the region at which said beam is stopped down may have oscillatory motion transversely of the beam of amplitude in excess of a predetermined value which would cause said spot to be larger than is desired, the arrangement being characterised by the provision of means which stop the beam down at a further region, the further stopping means being so arranged that, in operation, the size of said spot is caused to approach more closely the desired size than would otherwise be the case. Preferably said beam is stopped down by two spaced diaphragms which are so spaced and arranged to be maintained in operation at such potentials that said electrons in said beam which pass both said diaphragms undergo between said diaphragms a net oscillatory displacement from their position in the first-mentioned region which is a maximum or approximately a maximum.

In still another form of the invention, an electric circuit arrangement is provided including an electron discharge device wherein, in operation, a beam of electrons is projected between a pair of deflecting electrodes, the arrangement including means for applying deflecting potentials to said deflecting electrodes, said means being adjustable to vary the degree of unbalance in the potentials developed on said deflecting electrodes to permit of the adjustment of the position of the electrically neutral region between said deflecting electrodes.

In order that the said invention may be clearly understood and readily carried into effect, the same will now be more fully described with reference to the accompanying drawings which illustrate diagrammatically embodiments of the present invention by way of example, and in which,

Figure 1 illustrates the electrode system employed in one form of the invention,

Figure 2 is a front elevational view of the modulating electrode employed in accordance with the invention in the system of Figure 1,

Figure 3 is an explanatory diagram referred to in connection with the description of the mode of operation of the arrangement of Figure 1,

Figure 4 illustrates the electrode system in a further form of the invention,

Figure 5 is an explanatory diagram referred to in connection with the description of the mode of operation of the arrangement of Figure 4,

Figures 6 and 7 illustrate further electrode systems employed in forms of the invention,

Figures 8 and 9 are explanatory diagrams referred to in explaining the method of defining the deflecting field accurately of the arrangements of Figure 7, Figures 10 and 11 are each a circuit diagram of an arrangement wherein the electrically neutral plane between the deflecting electrodes is adjustable in accordance with the present invention,

Figures 12 and 13 are diagrams referred to in explanation of the mode of operation of a system of stops or limiting electrodes employed in accordance with a feature of the present invention, and

Figure 14 illustrates diagrammatically an electron gun operating in accordance with the teachings outlined in connection with Figures 12 and 13 above.

The device represented in Figure 1 of the drawings is of the kind described in aforesaid United States specification No. 2,213,174, and comprises an electron gun system having a cathode 1 and anodes 2, 3 and 4 from which, in operation, a fasciculated beam of electrons or cathode ray is projected into a space between a pair of deflecting electrodes 5 and 6 which are shown as being of curved form in the manner described in the specification of United States Patent No. 2,213,175. The electrodes 2, 3 and 4 are in the form of axially apertured diaphragms, the aperture in the electrode 4 being smaller than those in electrodes 2 and 3 and so small that the cross-sectional size of the ray leaving the gun is determined by the size of the aperture in electrode 4. The size of the aperture in electrode 4 thus determines the resolution which can be obtained on the mosaic electrode, or screen or other receiving element in the device when the beam is caused to scan the screen or other receiving element which is not shown in the drawing. The aperture in the electrode 4 may have, for example, a diameter of 0.01 cm. In operation, the anodes 2, 3 and 4 are maintained at suitable potentials with respect to the cathode 1 to form the beam of electrons, for example, anode 2 may be maintained at about thirty volts positive with respect to the cathode, while anode 3 may be maintained at between 100 and 200 volts positive and anode 4 at a lower potential than anode 3, for example, of the order of thirty volts. Scanning potentials are applied to the electrodes 5 and 6 in such manner that the potential in the path of the electron beam between the deflecting electrodes is positive with respect to the cathode, though possibly somewhat lower than that of the second anode 4, so that electrons move at low speed within the deflecting field. The whole device is immersed in a strong substantially uniform magnetic field in which the lines of force extend parallel to the axis of the electron gun, as indicated by the arrow H in the upper part of Figure 1.

With the above described arrangement, the scanning potentials applied between the electrodes 5 and 6 are effective to accomplish a relative rapid deflection of the cathode ray at high frequency and the ray emerges from the electrostatic field provided by the plates moving in a direction substantially parallel to the initial direction by motion prior to entering the electrostatic field.

In accordance with the present invention, in the arrangement above described, exact control of the cross section of the cathode ray is afforded by means of a further deflecting field established between additional deflecting electrodes 7 and 8 which co-operate with a further apertured electrode 10 of which a front view is shown in Figure 2. The aperture 9 in this electrode is shown clearly in the front view shown in Figure 2, from which it will be seen that the aperture is wedge shape. The aperture 9 is further shown enlarged in Figure 3 and the path of the electron beam is shown in three positions in full line and dotted circles.

In operation, modulation is effected by applying the modulating potentials between the electrodes 7 and 8, the electron beam being deflected between these electrodes in a similar manner to, but generally to a lesser extent than that in which it is deflected between the electrodes 5 and 6 to which the scanning potentials are applied. Thus, the electron beam emerging through the disc 4 enters the field between deflecting plates 7, 8 and is deflected at a rate determined by the potential between the electrodes in a direction at right angles to the electrostatic field and the magneic field between the plates. That is to say, if the deflecting electrodes are plane and parallel as represented in the drawing, the electron beam passing between them is displaced in a direction parallel to the planes of the deflecting electrodes. Moreover, the deflected beam will also emerge from the field between the deflecting electrodes 7, 8 with a direction parallel to its initial direction, and will move towards the electrode 10.

The electrode 10 is disposed with its aperture 9 positioned so that more or less of the electron beam is passed through the aperture 9 as the position of the beam is varied. For example, as illustrated in Figure 3, the aperture 9 may be tapered in a direction parallel to that in which the beam is deflected so that in one position of the beam, shown in full line in Figure 3, the beam just passes through the aperture 9, while when the beam is deflected to the right as seen in Figure 3, edge portions of the beam are intercepted, for example, as in the case when the beam is deflected in the position of the left hand dotted circle, the size of these edge portions increasing as the beam is deflected till the beam reaches the position represented by the right hand dotted circle, whereat the beam is wholly intercepted.

The aperture 9 is preferably so dimensioned that substantially the whole of the electron beam from the plate 4 can pass through it at only one position. Thus, in the case considered where the beam is limited to a diameter of 0.01 cm., the diameter of the largest circle that can be drawn inside the aperture 9 would be of the order of 0.01 cm. Conveniently, the length of the aperture would be about 2 mms. Preferably, if the electron beam is projected mid-way between the electrodes 7 and 8, the potentials of each of the deflecting electrodes is caused to vary by the same amount, the two variations being opposite in sense, so that the potential of the region through which the beam passes is substantially invariant. Thus, the speed of the electron beam will remain substantially constant as the beam passes through the deflecting field provided by electrodes 7 and 8. The width of the electrodes 7 and 8 need be only slightly larger than the maximum displacement required to be produced in the electron beam. The change in potential required between the plates 7 and 8 deflect the electron beam so that instead of substantially all of the electron beam passing through the aperture substantially none passes through, is proportioned to the length of the aperture 9, the distance part of the electrodes 7 and 8, the strength of the longitudinal magnetic field and to the speed of the beam, and is inversely proportional to the axial length of the electrodes 7 and 8. Calculation shows that with an axial length of 1 cm. for plates which are 0.2 cm. apart, a beam having a speed corresponding to a voltage of 100 volts moving in a magnetic field of 100 gauss, required a potential difference of 24 volts between the plates to deflect the beam through 2 cms.

The deflection produced by the electrodes 7 and 8 displaces the electron beam away from the axis of the gun, and, if desired, the axial displacement may be nullified after the beam has passed through electrode 10, to restore the beam to its initial direction of motion along the axis of the gun, by utilising a further pair of deflecting electrodes which have the same potentials applied to them as have the electrodes 7 and 8 and are identical with those electrodes or form a spacing between these plates in the opposite direction to that to which the deflecting potentials are applied in reversed sense so that the further electrostatic deflecting field set up is opposite to that between the electrodes 7 and 8. However, if the aperture 9 is arranged to taper in a direction parallel to the planes of the main deflection electrodes 5 and 6, as in the case considered, the displacement of the electron beam is in the direction produced by the plates 5 and 6, and since it is only of a magnitude of about 2 mms., it can be neglected in comparison with the displacement of the beam which occurs in the field between the main deflecting electrodes. Also, if the slight displacement of the beam for modulation purposes cannot be neglected, it can easily be corrected by the circuit arrangement used to apply deflecting potentials to the main deflecting electrodes 5 and 6.

Modulation or regulation of the electron beam by deflection across a wedge-shaped aperture as above described causes the electron beam to change in cross-section from a circular form to a form which is approximately that of a trapezium, the longer dimension of the trapezium being parallel to the direction in which the aperture is tapered. If it is desired that the length or dimension of the scanning beam should be parallel to the scanning line it is satisfactory to arrange the electrodes 7 and 8 so that they produce a deflection parallel to that produced between the electrodes 5 and 6 and to dispose the aperture 9 in electrode 10 with its length parallel to the planes of electrodes 7 and 8 in the manner described above. If, however, the length or dimension of the scanning rectangle is required to be perpendicular to the scanning line, electrodes 7 and 8 and the wedge-shaped aperture 9 must be disposed perpendicular to the directions represented in the drawing so that the electron beam is deflected by the modulation field in a direction perpendicular to the direction of the deflection produced between the electrodes 5 and 6. It is always desirable, however, that the electron beam shall pass between the electrodes 5 and 6 in a plane in which the potential is invariant. When the beam is modulated by displacement in a direction away from the electrical control plane, the beam should be brought back to this plane, for example, by use of a second pair of plates with a reversed electrostatic field between them, as previously mentioned. Alternatively, the position of the plane itself can be shifted by developing the scanning potentials applied to electrodes 5 and 6 with slight unbalance. Means for doing this are described with reference to Figures 13 and 14 below.

It may be found difficult to adjust the electron beam so that it is symmetrical with respect to the long axis line bisecting the angle of the wedge shaped aperture. This may be overcome, as illustrated in Figures 4 and 5 by using a further pair of deflecting electrodes 11 and 12 positioned perpendicularly with respect to the electrodes 7 and 8, the embodiment shown in Figure 4 being otherwise the same as that shown in Figure 1. By producing a potential difference between the electrodes 11 and 12 the axis of the beam may be adjusted upwards or downwards so as to coincide with the aforesaid line.

The wedge-shaped aperture 9 serves as a second aperture defining the electron beam and it is desirable that its distance from the first defining aperture in the disc 4 shall be such that the amplitude of the net oscillatory displacement of an electron transversely of the magnetic field occurring between the disc 6 and the electrode 9 is a maximum or nearly so. This is explained more fully with reference to Figures 12 and 13 below. For a beam having a speed corresponding to a voltage of 100 volts, and in a device employing a magnetic field strength of about 100 gauss, a distance of about 1 cm. or a multiple thereof between the two apertures is suitable.

In another embodiment of the invention shown in Figure 6 a source of electrons represented in this case by an electron gun 1 is caused to limit a beam of electrons through an aperture 13 in the shape of a long slot, the emitted electrons being constrained to move in paths which are substantially straight lines due to the action of a strong substantially uniform magnetic field indicated by the arrows H, H. The electrons emitted from the slot 13 are subjected to a deflection field provided by suitable potentials applied to the deflecting electrodes 14 which are shown as plane. The electron beam is consequently deflected in a direction parallel to the planes of electrodes 14, shown as downwards in Figure 6.

After emergence from the deflecting field between the electrodes 14, the electrons move in paths which are substantially parallel to their initial direction prior to their entering the deflection field and impinge on a plate-shaped electrode 15 having an aperture 16 therein. The potentials applied between electrodes 14 are arranged to be such that as the strength of the field is increased the whole electron beam will be deflected until one edge thereof passes out of the boundary of the field provided by the deflection electrodes, this edge then moving substantially parallel to its initial direction of motion. Further increase in the strength of the deflecting field will cause more of the electron beam to pass outside the boundary of the deflecting field, so that more and more of the beam is compressed to move in a line which lies just outside the boundary of the deflection field and which lies parallel with the initial direction of motion of the electron beam emitted from the electron gun. With sufficient potential difference between the electrodes 14, the whole of the electron beam may be compressed to move along this line. The aperture 16 in the plate 15 which is utilised to limit the beam subsequently employed in the electron discharge device, is positioned such that its lowermost portion corresponds with the boundary of the deflecting field, and thus the aperture 16 will not permit passage of that part of the beam which has been deflected to the edge of the deflecting field. Thus, by adjusting the potentials of the electrodes 14, the fraction of beam passing through the aperture 16 can be varied from unity to zero.

The breadth of the electron beam emanating from the electron gun should be made greater than that of the aperture 16 so that the alignment of the gun with respect to the aperture is not critical. Alternatively, the electron beam may be made of substantially the same width as the aperture 16, the alignment of the electron beam with respect to the aperture 16 being adjustable by means of another pair of deflecting electrodes providing another deflection field in a direction at right angles to that provided by the electrodes 14 and by adjusting this other deflection field to the appropriate strength the desired section of the beam may be made to pass through the aperture 16.

Further, a large source of electrons may be employed, and the electron beam may be of rectangular or circular cross-section, and this beam may be reduced in effective cross-section by deflecting electrodes having suitable potentials between them to compress the beam to render only a portion of its area effective, in the manner of the electrodes 14, and such a large source in conjunction with such plates may be employed instead of a gun with an apertured slot.

In the embodiment described in connection with Figure 6, the electron beam from the gun aperture 13 is deflected by the electrodes 14 to the boundary of the field provided by the electrodes 14. With two deflecting electrodes alone this boundary is somewhat ill-defined and in order to define this boundary more exactly further electrodes such as 17 in Figure 7 may be positioned towards the lower edge of the electrode 14, the electrodes 17 being maintained at the same potential as the electrode 15 by being connected thereto, the arrangement in Figure 7 being otherwise the same as that illustrated in Figure 6.

The effect of electrodes such as 17 is illustrated in Figures 8 and 9, the nature of the field between the plates being shown by the lines of force. The fringing effect of the field between the plates 14, and which is shown at the lowermost portion of those electrodes in Figure 8, is largely dispelled when the electrodes are used and is replaced by the more even field between the electrodes 17 shown in Figure 9.

Arrangements for adjusting the electrically neutral plane between a pair of deflecting electrodes are illustrated in Figures 10 and 11.

Referring to Figure 10 of the drawings, 3, 4 and 5 represent the cathode, final gun anode and plane plate shaped deflecting electrode respectively in a device of the kind described in aforesaid patent specification No. 2,213,174. In operation, this device is immersed in a substantially uniform magnetic field of which the direction is indicated by the arrow H in Figure 10.

In operation, the anode 4 is maintained at a positive potential with respect to the cathode 3 by means of a source of potential 6. The anode 4 may for example be maintained in operation at about 30 volts positive with respect to the cathode and an anode or anodes may be provided between the cathode 3 and anode 4 maintained at a higher potential or potentials than that of the anode 4.

The deflecting electrodes 5 are fed through blocking condensers 7 from an amplifier of which the output stage is shown as including a pair of electron discharge tubes 8 connected in push-pull relation having anode load resistances 9 and high tension supply 10.

The arrangement so far described will operate in the following way.

Electrons are accelerated from the cathode 3 through the anode 4 in the form of a beam or ray which passes between the deflecting electrodes 5 on to a mosaic electrode or other similar device from which signals coresponding to an image to be transmitted can be derived. Potentials of sawtooth waveform are applied to the plates 5 from the amplifier including tubes 8 and the effect of the crossed magnetic and electrostatic fields between the electrodes 5 is to cause the electron ray to be scanned in a plane at right angles to both fields and parallel to the planes of the deflecting electrodes. Co-ordinate scanning in two directions at right angles, termed "line" and "frame" scanning in television parlance, may be provided for by passing the cathode ray between a further pair of deflecting electrodes arranged at right angles to the plates 5 or by employing a magnetic coil for producing a further magnetic field at right angles to the field H and producing a deflection at right angles to that produced by the electrostatic deflecting field between the electrodes 5. In practice it is preferred to employ deflection electrodes such as 5 for producing the line scan, which is required to be effected at a higher frequency, while for the frame scan, electro-magnetic deflection is employed, the electro-magnetic coil being arranged to operate between the deflecting electrodes 5 and the aforesaid mosaic electrode or screen, so that the deflection of the beam in each co-ordinate direction can take place in a region of substantially uniform potential.

In order that the deflection of the ray between the electrodes 5 may take place in a region of substantially uniform potential it is necessary to project the cathode ray between these electrodes about the electrically neutral plane whereat the potential is constant as the potential of the deflecting electrodes is varied, and if the distribution of deflecting potentials between the deflecting electrodes 5 is not variable, exact alignment of the electrodes which determined the path of the ray between electrodes 5 is necessary. In the case illustrated, for example, the position of the electron gun arrangement including cathode 3 and anode 4 would have to be very carefully and critically adjusted.

However, in accordance with the present invention, the position of the aforesaid electrically neutral plane is rendered adjustable by providing means which enable the distribution of the deflecting potentials between the electrodes 5 to be varied so that a desired amount of unbalance or asymmetry can be introduced in the potentials developed on these electrodes, whereby the position of the electrical neutral plane can be adjusted to the region into which the cathode ray is projected. For this purpose, a high resistance 11 is connected across the deflecting plates 5 and an adjustable tapping 12 on this resistance is connected to the gun anode 4 or to another point of fixed potential such that the potential in the aforesaid electrically neutral plane is positive with respect to the cathode 3.

With this arrangement the deflecting potentials will be applied to electrodes 5 as variations in opposite senses, the magnitudes of which are in the ratio of the two parts of resistance 11 on either side of tapping 12. Thus, the position of the electrically neutral plane will correspond with the setting of tapping 12.

It will be seen that in the above arrangement, the deflecting electrodes 5 are both biassed to the potential of the source 6 and anode 4 and that the potential of the electrically neutral plane between this will likewise be that of the source 6 and anode 4. In some cases, however, it may be desirable to arrange for the bias of the electrodes 5 and the potential of the electrically neutral plane to differ from the potential of the anode 4 so that the arrangement can be set to operate with optimum deflection sensitivity between the electrodes 5. It is of course possible to connect the tapping 12 to a further source of potential instead of to the source 6 as shown or a further source of potential can be interposed between the tapping 12 and the source 6. Such an arrangement is, however, cumbersome and not altogether flexible. Thus, the arrangement shown in Figure 11 may be preferred.

In the arrangement shown in Figure 11, the resistance 11 is utilised to provide the anode loads for tubes 8, the tapping 12 being connected to the source 10, and connection between the tapping 12 and the source 10 and anode 4 is effected through a tapping 12 on a potentiometer 14. In this case, the stage of amplification including tubes 8 must be isolated from earth or other fixed or reference potential except through the connection through tapping 13 and potentiometer 14 so that the stage "floats" up and down in potential with reference to earth as tapping 13 is moved. Thus, the input to tubes 8 cannot be resistance coupled with the preceding stage. For example, transformer coupling may be employed as indicated at 15 in Figure 11.

With the arrangement of Figure 11, the setting of tapping 13 on potentiometer 14 determines the potential of tapping 12, while the setting of tapping 12 determines the potential to which the electrodes 5 are biassed with respect to the potential of tapping 13 and the gains of the tubes 8. It will be seen that the bias of each electrode 5 is determined by the potential of resistance 11 to which the electrode is connected in the absence of signal potentials on the grids of tubes 8. Thus, the bias potentials of the electrodes 5 will be the same or different in accordance with the setting of tapping 12. The ratio of the gains of tubes 8 will determine the degree of unbalance in the distribution of signals between the electrodes 5. Thus, both the position and potential in the electrically neutral plane between electrodes 5 will be readily controllable.

If desired, in the arrangement of Figure 11, blocking condensers can be inserted between the ends of resistance 11 and electrodes 5, and the D. C. bias on the electrodes applied by means separate from the arrangement by which the deflecting potentials are developed on the plate.

Figures 12 and 13 of the drawings illustrate the mode of operation of two spaced electrodes referred to above in connection with Figures 1 to 5 of the drawings. The two electrodes are represented in Figures 12 and 13 at 1 and 2 respectively.

Referring to Figure 12, it will be seen that the envelope of a pencil of electrons which it is desired that the electrodes 1 and 2 should pass is indicated in full lines at p and the envelope of the tracks of certain electrons which are intercepted by electrode 2 are indicated in dotted lines at p_1 and p_2. The pencil p of electrons is formed by electrons which pass through the point O which lies within the aperture in electrode 1 on the axis XX, shown chain dotted, along which the beam is projected, the electrons forming this pencil having radial components of velocity lying within a small range such that the amplitudes of their spiral paths in the magnetic field parallel to the axis XX do not exceed that of the envelope p. Electrons within this pencil will all recross the axis again approximately at the point f after each electron has executed a complete turn in its spiral path. The time taken by an electron to execute a turn in its spiral path is dependent only on the strength of the magnetic field in which it is moving, and is inversely proportional to this strength. Thus, in a uniform magnetic field, the distance between points O, and f will be proportional to the axial component of velocity of the electrons. Likewise the radius of the spiral executed by an electron will be proportional to the radial component of velocity. This will be better appreciated by reference to Figure 13 of the drawings which is a representation of the tracks t and t_1 respectively lying within the envelopes p and p_1 respectively of Figure 12 viewed from the direction of the axis XX, the track t being shown in full lines and track t_1 being shown in dotted lines. It will be seen that, viewed in the direction of the aforesaid axis, which is indicated by point X in Figure 13, each track appears as a circle, the diameter of the track t corresponding to the radius of the aperture in electrode 2. It will be further seen that as far as its movement transversely of the axis is concerned, the electron may be regarded as oscillating to and from the axis XX.

In order to ensure that good focus is obtained at any point in the beam, it is necessary to limit the above-described transverse oscillatory motion of electrons. To effect this, in accordance with the invention, the electrode 2 is employed to intercept electrons passing through the aperture 1 of which the oscillatory movement is large. In the preferred form of the invention, the limiting electrode or diaphragms 1 and 2 are spaced apart by a distance equal or approximately equal to half the distance O, f and have similar apertures which serve to stop the electron beam down to the desired diameter. That is to say, the electrodes 1 and 2 are so disposed that in the case of electrons passing through the aperture in electrode 1, the net oscillatory displacement of electrons transversely of the direction of the electron beam occurring between electrode 1 and electrode 2 is substantially a maximum.

Thus, consider electrons passing through the point O in spiral paths of which the envelope is represented by the dotted line p_1, these electrons having a larger radial component of velocity, and hence a larger radius in their spiral paths than is desired. Since all the electrons in the beam have approximately the same energy the magnitude of the velocity of all the electrons will be approximately the same, so that the longitudinal component of velocity of electrons having a large radial component will be smaller than is the case with electrons having a small radial component of velocity. Thus, electrons passing through O and following the paths having the envelope p_1, will recross the axis XX at a point f_1 nearer the point O than the point f. In a well designed field, the electrons will be mainly accelerated longitudinally and, provided that the electrons are sufficiently accelerated, even the largest radial components of velocity will be small relative to the longitudinal components. Thus the distance f_1f

will be small compared with the distance O, *f*. Thus the electrons such as those of which the envelope of their trajectories is indicated by p_1 will be at practically their greatest distance from the axis OX when they reach electrode **2** and will be intercepted at points such as S (see Figure 13). Thus it can be seen, that electrode **2** will intercept nearly all those electrons passing electrode **1** whose trajectories are spirals passing through axis XX at O but having radii greater than the radius of the aperture in electrode **2**, if this aperture is circular, the electrons remaining in the pencil after passing electrode **2** including a small number of electrons whose paths have radii greater than the radius of the aperture **2**, and the radii of this small number will only be slightly greater than the radius of the aforesaid aperture.

It will be further seen that electrons which pass through a point such as O_1 on the line XX to the left of electrode **1**, which are not intercepted by electrode **1** and have their paths included in the envelope p_2 of large maximum radius, will also be mainly intercepted by electrode **2**. Furthermore, electrons whose trajectories have large radius, but do not cross the axis close to the point O within the aperture in electrode **1** will be intercepted by electrode **1**. Thus the electrodes **1** and **2**, in combination, will operate to remove nearly all the electrons having radial components of velocity such that their paths have radii greater than the radius of the aperture in electrodes **1** and **2**. The required spacing for the electrodes **1** and **2** can be calculated readily if the strength H of the uniform magnetic field and the speed v of the electrons, is known. The time T taken by an electron to execute one complete spiral, which constitutes the periodic time of the aforesaid oscillatory motion, is given by the relation

$$T=\frac{m}{e}\cdot\frac{2\pi}{H}$$

where m/e is the ratio of the mass to the charge of an electron.

As is well known, the speed v of an electron is proportional to the square root of the potential of the field in which it is moving, being given by the relation

$$v=\frac{1}{10}\sqrt{\frac{2Ve}{3m}}$$

where V is the potential in volts.

Figure 14 of the accompanying drawings shows an electron gun including an arrangement of limiting diaphragms disposed in accordance with the invention for use in a uniform magnetic field parallel to the axis of 150 gauss.

In Figure 14, **4** is a cathode for emitting electrons; **5** is a cylindrical electrode surrounding the cathode and having an apertured diaphragm disposed in front of the cathode; **6** is a cylindrical anode closed by two apertured diaphragms **7** and and **8** which form limiting diaphragms in accordance with the invention, and **9** is a final anode or rear screen in the form of an apertured diaphragm forming the outermost electrode of the gun. In this case the separation between the diaphragms **7** and **8** is 8 mm., the anode **6** being maintained in operation at from 100–200 volts, preferably at 120 volts positive, with respect to the cathode. Anode **6** may be ten mms. long. Suitable dimensions and spacings for the remaining electrodes in the gun are as follows:

Separation between the end of cathode **4** and the diaphragm of electrode **5**, 0.1 mm., diameter of aperture in electrode **5**, 0.5 mm., separation between electrode **5** and diaphragm **7**, 0.8 mm., distance between end of anode **6** and screen **9**, 5 mm., and diameter of aperture in screen **9**, 1 mm.

When this arrangement was operated with electrode **5** maintained at from 10 to 30 volts positive with respect to the cathode, and screen **9** slightly less positive than the anode **6**, the apertures in diaphragms **7** and **8** being 0.2 mm. in diameter, it was found that in a television transmitting tube the gun described gave a limiting resolution at the centre of the scanned patch where the resolution is not interfered with by the scanning fields, greater than a thousand lines per picture, the beam current being of the order of 1 μa.

It is possible that a more compact arrangement might be obtained by decreasing the strength of the magnetic field, as the reduced field would require a smaller coil or magnet to produce it. In this case the distance between the diaphragms **7** and **8** should be increased. There is, however, a limit to the extent to which this distance can be increased, owing to the difficulty of accurately aligning the anode axis along the magnetic field.

In the case of the arrangements of Figures 1 and 4, where spacing between electrodes **4** and **9**, referred to above, is such that the oscillatory displacement transversely of the direction of the beam of electrons occurring between the two electrodes, of electrons in the beam passing through the aperture in electrode **9** is a maximum, or approximately a maximum, there is a slight difference in the mode of operation of the arrangement over the arrangements illustrated in Figure 14, in that when a deflecting field is set up between electrodes **7** and **8**, or **7** and **8** and **11** and **12**, the line of motion of the beam of electrons through the deflecting field is curvilinear instead of rectilinear and in the deflecting field or fields the electron paths become trochoidal instead of spiral. However, the aforesaid oscillatory components of motion persist, so that in arranging electrodes **15** and **17** the same considerations apply as in the case of the arrangement discussed with reference to Figure 1 where no deflecting field is present.

In some cases, the pair of spaced diaphragms **7** and **8** in Figure 14, may be eliminated by forming the anode **6** as a tube or as a block with a bore through it affording passage to the beam, but restricting the beam to the diameters of the apertures in diaphragms **7** and **8**. However, in this case difficulty may be experienced in aligning the bore and due to secondary emission of electrons, so that, in general, the use of a tube is not to be recommended.

We claim:

1. An electric discharge system comprising an evacuated cylindrical envelope, means for producing an electromagnetic field whose lines of force are parallel to the axis of said envelope, the density of said lines being substantially constant throughout a cross-section perpendicular to the axis of said envelope, an electron-emitting surface normal to the axis of said envelope, a plurality of beam-forming electrodes positioned in register with said emitting surface, a target surface normal to the axis of said tube positioned beyond said beam-forming electrodes, scanning deflection electrodes positioned between said target and said beam-forming electrodes, and auxiliary electrostatic means for controlling the cross-sectional configuration of the formed beam,

said auxiliary means being located intermediate said deflecting means and said beam-forming means.

2. The system as claimed in claim 1 wherein the auxiliary electrostatic means comprises a pair of deflecting electrodes and an apertured electrode in register with said deflecting electrodes.

3. The system as claimed in claim 1 wherein the auxiliary electrostatic means comprises a pair of parallel deflecting plates and an apertured electrode in register therewith, said electrode having a triangular aperture.

4. The system claimed in claim 1 wherein the auxiliary electrostatic means comprise a first pair of deflecting electrodes, an apertured electrode, and a second pair of deflecting electrodes, said apertured electrode being located in the electron path beyond the deflecting electrodes and the second pair of deflecting electrodes producing a deflection opposite to the deflection produced by said first pair of deflecting electrodes.

5. The system as claimed in claim 1 wherein the beam-forming electrodes include a pair of apertured diaphragms spaced from each other a distance equal to half the longitudinal distance of the spiral path executed by electrons from the emitter surface and passing through the magnetic field.

6. The system as claimed in claim 1 wherein the auxiliary electrostatic means comprise a pair of deflecting plates and an apertured electrode and auxiliary electrostatic means positioned between said deflecting plates for controlling the boundary of the formed beam.

7. An electric discharge system comprising an evacuated cylindrical envelope, means for producing an electromagnetic field whose lines of force are parallel to the axis of said envelope, the density of said lines being substantially constant throughout a cross-section perpendicular to the axis of said envelope, an electron-emitting surface normal to the axis of said envelope, a plurality of beam-forming electrodes positioned in register with said emitting surface, a target surface normal to the axis of said tube positioned beyond said beam-forming electrodes, scanning deflection electrodes positioned between said target and said beam-forming electrodes, auxiliary electrostatic means for controlling the cross-sectional configuration of the formed beam, said auxiliary means being located intermediate said deflecting means and said beam-forming means, and means for producing between said scanning deflection electrodes an equi-potential plane lying on a line passing through said auxiliary electrostatic means, said equi-potential plane being maintained in the same potential as said auxiliary electrostatic means.

8. The system as claimed in claim 7 wherein the means for producing the equi-potential plane includes means for supplying deflecting potentials to said scanning deflection electrodes and a connection between said auxiliary deflection means and said means for supplying the deflection potentials.

9. The system as claimed in claim 7 wherein the means for producing the equi-potential plane includes means for supplying deflecting potentials to said scanning deflection electrodes and a connection between said auxiliary deflection means and said means for supplying the deflection potentials, said connection including a source of biasing potential.

10. The method of operating an electron discharge device having means for forming a beam of electrons and means for deflecting the beam of electrons, which includes the steps of altering the cross-sectional area of the formed beam of electrons prior to the deflection of the beam of electrons and producing a plane of equi-potential between the deflecting electrodes along the line symmetrical with the altered cross-section of the beam.

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