Nov. 17, 1936. H. C. RESSLER ET AL 2,060,825

CONTROL OF ELECTRON STREAMS

Filed Aug. 3, 1934 2 Sheets-Sheet 1

Fig. 1.

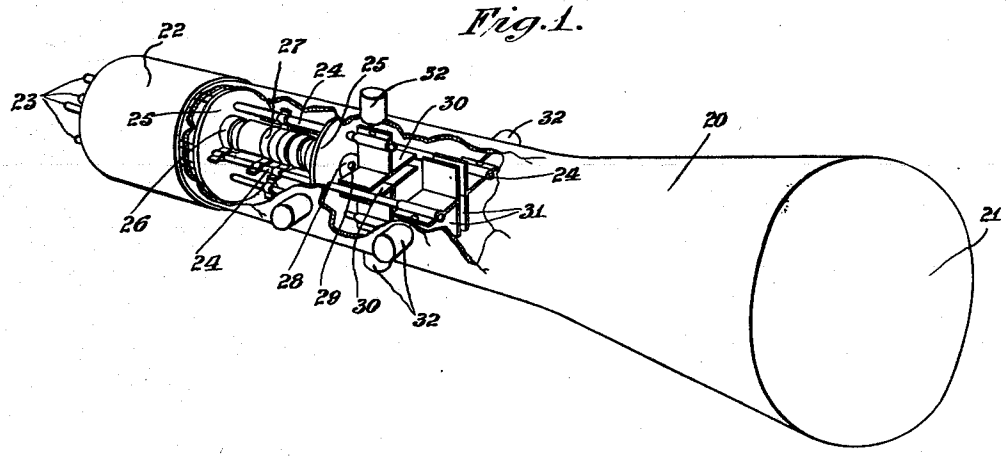


Fig. 2.

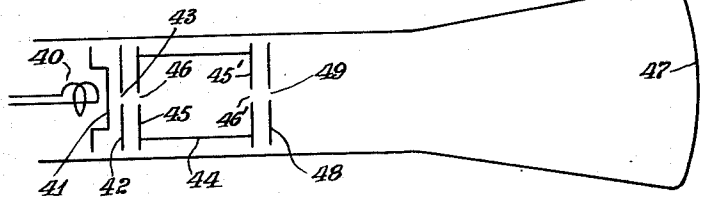


Fig. 3.

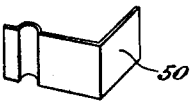


Fig. 4.

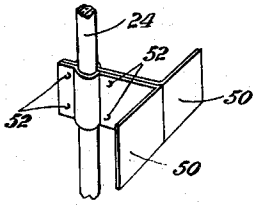


Fig. 5.

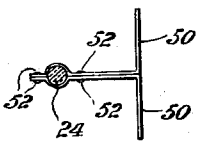


Fig. 6.

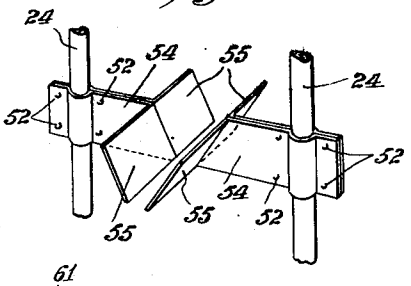


Fig. 7.

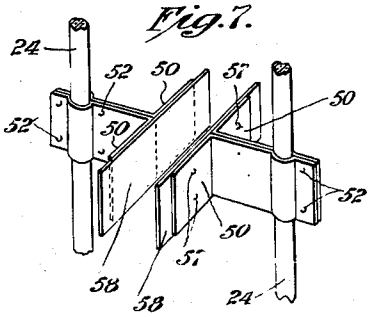
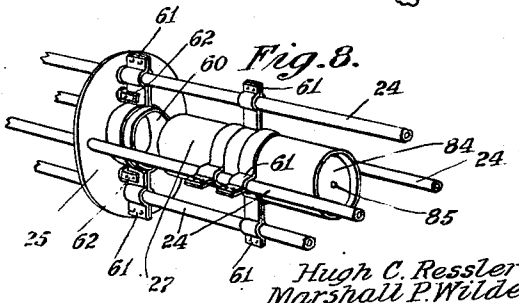


Fig. 8.



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Fig. 9.

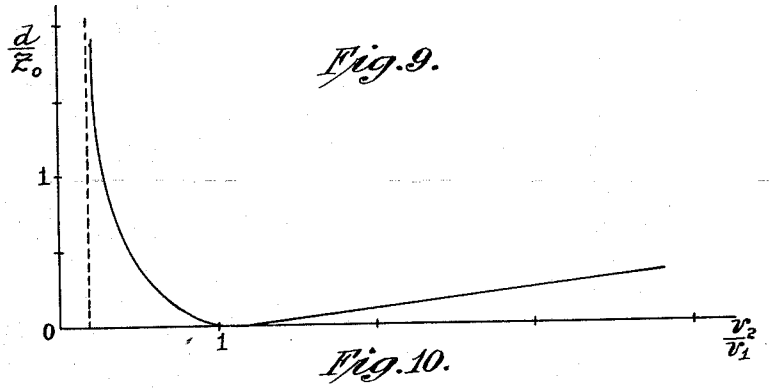


Fig. 10.

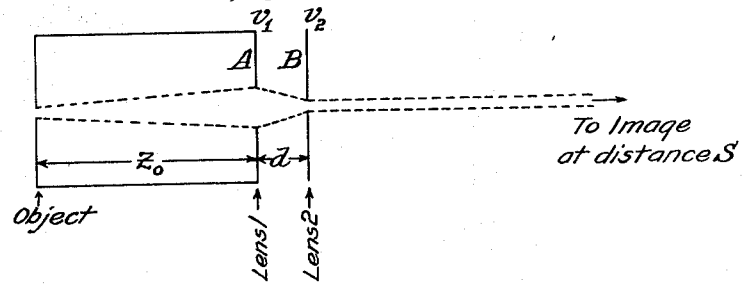


Fig. 11.

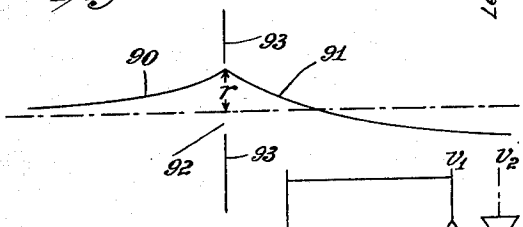


Fig. 12.

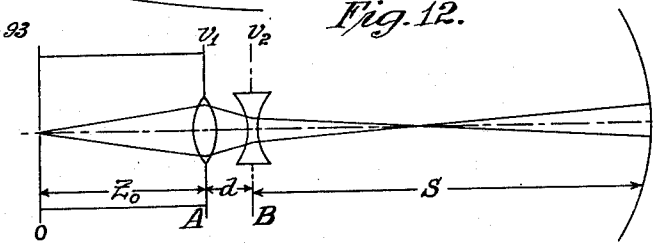
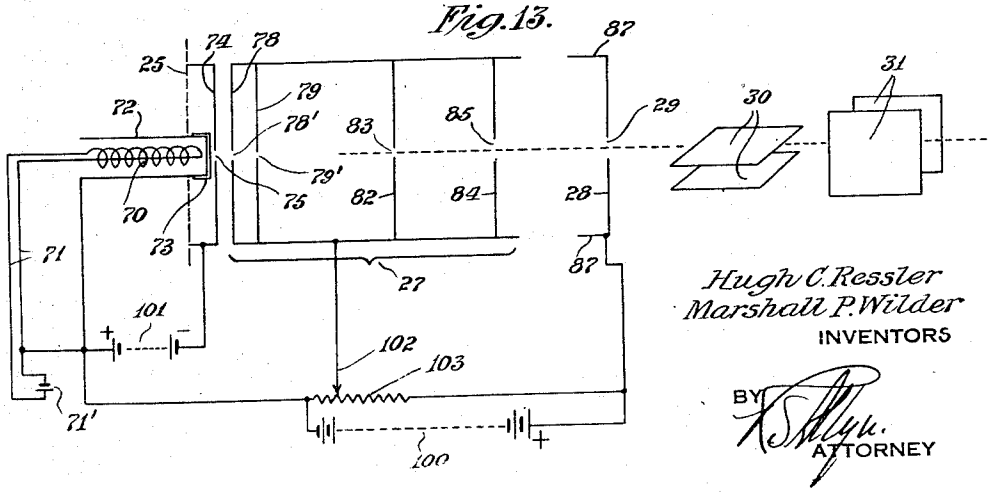


Fig. 13.



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UNITED STATES PATENT OFFICE

2,060,825

CONTROL OF ELECTRON STREAMS

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Application August 3, 1934, Serial No. 738,220

11 Claims. (Cl. 250—27)

This invention relates to cathode ray tubes in general. Certain advantages secured by this invention are especially valuable when such tubes are employed for television scanning purposes.

Cathode ray tubes employ a stream of electrons impinging upon a screen of fluorescent material so as to produce thereupon a luminous spot, whose size, shape, intensity and position may be altered by subjecting the electron stream to the influence of various controlling members before the stream reaches the fluorescent screen. These controlling members usually act upon the stream by virtue of the electrostatic or electromagnetic fields which are associated with or developed by such controlling members. These fields may alter the electron stream passing therethrough, with respect to its velocity, intensity, cross-sectional size and shape, and direction.

The use of cathode ray tubes as hitherto known has been subject to certain difficulties. One important difficulty encountered in tubes of the prior art has been that of definitely determining and maintaining the various qualities or parameters of the electron stream, as above described, independently with respect to one another. For example, when the electron stream was altered with respect to its intensity, in many cases its cross-sectional area or its direction would simultaneously be altered.

Such difficulty in maintaining independent control of the various parameters of the electron stream and consequently of the luminous spot produced thereby, has given rise to certain disadvantageous limitations and introduced undesirable errors in the general employment of cathode ray tubes, and especially when such tubes were employed for television scanning purposes.

One object of the present invention is to produce a cathode ray tube in which the luminous spot is clearly defined both as to shape and size, and maintains such desired shape and size substantially independently of any alteration in its intensity or position.

Another object of this invention is to produce in a cathode ray tube, an electron stream of a definite and controllable cross-sectional shape and size, giving rise to a clearly defined luminous spot of a definite and controllable shape.

A further object of this invention is to employ electrostatic fields and the elements governing the production of such fields so as to act, in controlling and influencing the electron stream of a cathode ray tube, in a manner generally analogous to the action of optical lenses upon "rays" of light (or streams of light quanta). Such action will hereinafter be referred to as "electro-optical".

Yet another object of this invention is to employ a conducting body provided with an aperture therein, as the virtual source of an electron stream in a cathode ray tube.

Another object of this invention is to provide a novel method of mounting the electrodes in such a cathode ray tube, in order that a great degree of stability and proper alignment of such plates with the other elements of the tube may readily be secured.

A further object of this invention is to provide an "electron lens" generally equivalent in action to a compound lens in optics, by combining and arranging in suitable relationship to one another and to an electron stream passing therethrough, a series of apertured conductors located in suitable electrostatic fields.

Another object of this invention is to provide an electron lens which may be termed a "thin" lens, in distinction from the "thick" lenses of the prior art.

Yet another object of this invention is to improve the analysis of an electron stream comprising electrons moving at different velocities, in such a cathode ray tube, so that there may be secured therefrom an electron stream substantially homogeneous with respect to the velocities of the electrons composing the same.

Another object is to produce a device of the character described whose action can in large measure be quantitatively predetermined.

Other objects of this invention will be apparent from the following description and from the drawings where

Fig. 1 is a perspective view of one form of cathode ray tube embodying this invention.

Fig. 2 illustrates diagrammatically in part a simplified cathode ray tube illustrating certain principles of this invention.

Figs. 3, 4 and 5 show details of an improved method of mechanically supporting and mounting deflecting plates in cathode ray tubes.

Fig. 6 shows an alternative method of constructing and mounting such deflecting plates.

Fig. 7 shows still another method of constructing and mounting such deflecting plates.

Fig. 8 shows one method of mounting electron lens elements in a cathode ray tube constructed according to this invention.

Figs. 9, 10, 11 and 12 diagrammatically illustrate certain electro-optical principles of this invention.

Fig. 13 shows in diagrammatic form certain portions of the electrical system and connections of the tube illustrated in Fig. 1.

Referring now to Fig. 1, there is indicated at 20 an enclosing vessel or tube of the conventional cathode ray form. This tube may be of any suitable material such as glass and is provided at one extremity with a screen of fluorescent material 21 and at the other end with a base 22 provided with prongs 23 suitable for insertion in a socket to afford mechanical support and electrical connection thereto. The smaller portion of tube 20 is indicated as broken away in order to disclose the assembly of electrical elements contained therein.

These electrical elements obtain their support partly from longitudinal rods 24 which terminate in the usual press, here concealed within base 22, and partly from mica washers 25 which fit snugly the interior wall of tube 20. There is indicated at 26 an electron emitting assembly hereinafter described in detail and at 27 and 28 a compound electron lens assembly operating upon the electrons proceeding from element 26. Element 28 also acts as an accelerating anode, being provided with an aperture 29 through which the electron stream passes after being acted upon by the elements of structure 27 and which anode further affects the electron stream with regard to focusing the same.

Reference numeral 30 indicates a pair of horizontal deflecting plates, and numeral 31 a pair of vertical deflecting plates arranged so that the electron stream will pass therebetween on its way toward screen 21. The action of these deflecting plates is well known in the art and a detailed description thereof is not considered necessary. The deflecting plates and the anode may secure their external connections through connecting caps 32 which appear on the exterior wall of tube 20 as in the form here shown or may be connected through suitable conductors to pins such as 23 on base 22 in other forms of tubes according to this invention.

Referring now to Fig. 2, a diagrammatic representation of one form of tube, reference numeral 40 indicates a heater which is placed in proximity to a cathode 41. Cathode 41 is coated in part with an electron emitting material and is maintained at a sufficiently high temperature to cause this material to become emissive of free electrons by being placed in close proximity to heater 40. At 42 there is indicated a plate or disc of conducting material provided with a central aperture 43. We term this element 42 a "virtual emitter" since, as hereinafter explained it may act, rather than cathode 41, per se, as the effective source of the electron stream.

This virtual emitter has applied to it such a potential relative to the other elements of the tube that the potential gradient on both sides of the former will be substantially identical, and therefore its interposition will not disturb the potential distribution between the cathode and the element 44 lying on the other side of the virtual emitter.

This result is attained in the structure of Fig. 2, where the virtual emitter 42 lies midway between the cathode 41 and the first accelerating electrode 45, if elements 42 and 45 are at successively and equally increased potentials with respect to 41. For example, if 41 is at zero potential, 42 may be fixed at +200 volts and 45 at +400 volts. Similarly, if 42 is not midway between 41 and 45, the desired identical potential gradients may be had by suitably choosing the relative voltages.

Thus, this element 42 so limits the flow of electrons that they appear to come from the aperture 43 in the same manner as though they were derived from an emissive cathode of the same area, except that their velocity is increased. The aperture 43 thus serves as an electro-optical "object", as hereinafter described.

It is to be understood that other sources of electrons, such as photo-emissive surfaces, may be employed. Likewise this invention is not limited to electron streams, but streams composed of any particles which have a substantially constant ratio of charge to mass may be employed therewith.

Next in order along the path of the electron stream is anode 44 which may consist of a metallic cylinder closed near its ends by metal discs 45 and 45' provided with central apertures 46 and 46' therein. The action of disc 45 is to accelerate desired electrons and to suppress any undesired electrons coming from aperture 43 as hereinafter described. Due to the action of the electrostatic fields about aperture 46', this element 44 functions together with the second anode later described, somewhat as the equivalent of a compound lens in an optical system as hereinafter explained, and brings about the focusing of an image of aperture 43 in element 42, so that such electronic image eventually will be thrown upon screen 47, which latter may be of the usual fluorescent type. Between the focusing disc 45' of anode 44 and screen 47 is interposed another or second anode 48 provided with a central aperture 49.

This second anode cooperates with element 45' as above mentioned, to secure a focusing action and has applied thereto a voltage sufficiently great to accelerate the electron stream passing through its aperture to a velocity sufficiently high for producing a satisfactory luminous spot upon screen 47. While the exact potentials employed upon the various elements in this structure are not confined within narrow limits, yet in tubes of a usual size, it has been found that the voltage applied to element 48 may be of the order of a few thousand volts positive with respect to cathode 41.

Element 44 may have applied thereto a potential materially less than that applied to anode 48, and such potential should be adjusted in order to secure the best focusing action of element 45 in accordance with principles hereinafter to be described. In Figure 2 no electrostatic deflecting plates have been indicated, since their general position and electrical function is entirely conventional with respect to the other elements therein shown, or external magnetic deflection coils may be used, as known in the art.

Referring now to Figs. 3, 4 and 5, there are illustrated in these figures various mechanical details of constructing and mounting deflecting plates in cathode ray tubes. Two plates 50 of a shape substantially as shown in Fig. 3 are assem-

bled around a supporting rod 24 indicated in Fig. 4 and may be conveniently fastened to one another, and to the supporting rod if the latter be metal, by means of spot welds 52.

As is evident from the plan view of Fig. 5, one wing of each plate coacts with the corresponding wing of the opposite plate to afford a surface which is substantially a plane. The supporting rods may be of glass or other like material instead of metal, in which case the welds to the rods themselves may be omitted and the adequate friction or pressure provided by this mode of mounting may be depended upon to hold the plate assembly in position.

In Fig. 6 there are indicated plates 54 whose wings 55 are bent at an angle so that when two plate assemblies are mounted upon supporting rods 24, 24 opposite one another, the wings 55 will coact to form two virtually plane surfaces which will not be parallel to one another but rather will form angles with a central axis of the two if such planes are prolonged until they meet that axis. This alternative form of construction may be secured by bending the individual plates in any suitable manner before assembly and such a construction if properly designed and applied will increase the deflection sensitivity of the cathode ray tube, as well known in the art.

Fig. 7 illustrates a variation of the construction of Fig. 4, where the wings 50 have fastened to their outer surfaces by any suitable means, such as the spot welds indicated at 57, metal plates 58.

Plates 58 thus afford truly plane surfaces for the deflecting plate assemblies and overcome even the usually negligible distortion of the electrostatic field between the plates due to irregularity in the plane surface presented by the coupling together of two adjacent wings 50. A similar mode of construction may be applied to the oblique form of deflecting plates indicated in Fig. 6.

The deflecting plate assemblies described above may employ the mounting rods as conductors, provided that such rods are of a suitable conducting material, and such rods may have external connections through the tube base. In case that the assemblies are made upon glass rods, connection to the plates may conveniently be obtained by connecting wires which may pass through the side walls of the glass envelope of the tube. In this last case, such wires will not have to contribute to the rigidity of the assembly, but merely need afford connection to the plates.

In the two-piece or three-piece deflection plate structures of this type, the assembly is unusually rigid. The spacing between the plates of each pair is precisely determined by the dimension of the metal pieces and the locations of the supporting rods. The plates are made parallel to each other by means of a tool for this purpose. When welded in position there is much resistance to movement out of the parallel position. The axis of deflection is automatically made precisely along a line between the supporting rods. This general rigidity and precision of assembly assures uniformity in production.

Fig. 8 shows in detail one method of mounting elements 26, 27 or 28 of Fig. 1. Supporting rods 24 are passed through a mica washer 25, and the metal cylinders 60 and 27 (or part or all of any of the elements above referred to) are encircled by formed metal straps 61 which in turn may be welded around supporting rods 24. Metal strips 62 may also be welded to straps 61 and fastened through holes in the mica washer 25, when such washers lie adjacent the straps. Supporting rods 24 may be either glass or metal or in certain cases they conveniently consist of metal rods covered on their outside with glass tubing, which affords insulation for such rods where they pass through the metal straps used to support members from which it is desired that such metal rods be insulated. A single pair of straps 61 is adequate for a short assembly such as 26 or 28; for supporting a longer assembly such as 27 it is preferred to use several pairs of straps, successively rotated to grasp different opposite pairs of support rods 24, as indicated in the figure.

It will be noted that the straps supporting cylinder 27 are all located upon rods 24 at a considerable distance from the straps supporting cylinder 60. This allows the leakage along rods 24 to be greatly reduced, in comparison with constructions where parts of relatively high potential difference lie close to one another. Such leakage reduction may be very important, due to the comparatively high voltages used in these tubes.

Another substantial advantage of this construction is that the unsymmetrical field set up by the straps does not substantially penetrate the free space adjacent the ends of assembly 27 as shown in this figure and thus distortion of the luminous spot is minimized or eliminated.

Referring now to Fig. 9, this graph illustrates the focusing action, on an electron beam, of apertures in thin metal plates and shows the ratio of the separation between two such lenses to the distance between the "object" and the first lens, plotted against the ratio of the voltages applied to the two lenses, when this voltage ratio is such that an image of the object is focused at an infinite distance from the lens system. The two voltages V_1 and V_2 are to be measured with respect to the cathode.

It is to be noted that a given focusing action may be obtained at two values of

$$\frac{d}{Z_0}$$

which will give ratios of

$$\frac{V_2}{V_1}$$

greater or less than unity, respectively. This allows the choice of two differing values of the potential ratio in a given lens system, both of which will cause the same focusing action for the same spacing ratio.

Fig. 10 shows an electron system to which the graph of Fig. 9 may be applied.

The electrostatic field or the potential gradient between plane parallel electrodes having co-axial apertures is practically homogeneous, i. e. its equipotential surfaces are planes parallel to the electrode faces, at substantially all points in the region between the electrodes except near the apertures.

It has been ascertained by plotting the equipotential lines of such a field, as computed from the exact expression for the electrostatic potential, that the region of heterogeneity is of a magnitude comparable with the linear extensions of the openings, and that except in these limited regions the field acts upon any charged particle therein with a force that is substantially constant in magnitude and direction.

Although for purposes of illustration we herein discuss certain aspects of our invention in

terms of optical analogues, it should be borne in mind that these analogues are general and therefore not necessarily strict in all cases. For example, the velocity of light quanta is generally taken as constant, and the motion of such quanta in a homogeneous transparent medium is, within practical limits, defined by a series of geometric straight lines. On the other hand, the velocity of an electron in a homogeneous electrostatic field is not constant, but is continuously determined by a positive or negative acceleration except in the special case of a zero field (as occurs within cylinders 27 and 44, or in the region between the final anode and the screen). Further, the orbit of such a charged particle moving in a homogeneous electric field is a parabola. The orbits of electrons moving in the type of field under discussion are likewise substantially parabolas except throughout the regions of heterogeneity, but as in our novel construction these regions are quite small compared with the total distance of motion of the particles, a negligible error is made in assuming that the orbits are continued parabolas throughout these small regions, except for a sudden change of slope at the plane of the aperture.

The dynamic or mechanical action of the heterogeneous field upon a particle is to exert a sudden or impulsive radial force as it moves through the opening, thereby suddenly changing the radial component of its momentum. It is this impulsive radial force which causes the particle to move inward or outward from the axis as it leaves the aperture. The simplified orbit of a particle moving through an electrically charged aperture in a homogeneous field can thus be regarded as two parabolas, the incident and exit parabolas, corresponding to the potential gradients (either finite or zero) established at the faces of the plane electrode. The parabolas are connected together at the aperture in such a way that the sudden change of slope of the orbit where the parabolas join corresponds to the sudden change of radial momentum of the moving particle brought about by the electric forces acting in the neighborhood of the aperture. A sketch of a simplified orbit is shown in Fig. 11 where 90 is an incident orbit, 91 the exit orbit of the particle and 92 an aperture in a conductor 93.

It is to be understood that the focusing power of the lens in this case will determine whether orbit 91 will remain above the axis or go below, as shown. The orbit shown will give an inverted electron image. Thus the thin lenses of this invention can operate analogously to any system of positive or negative lenses or reflectors in optics.

The change of slope of the orbit at the aperture can be determined from the expression for the electrostatic potential and depends, from a practical viewpoint, only on the difference of the potential gradients at the faces of the plane, the equivalent volt energy of the charge particles at the instant they enter the aperture, and the distance from the center of the aperture to the point of incidence of the orbit (indicated by r in Fig. 11). The equivalent volt energy of an electron is its kinetic energy expressed in volts, i. e., $\frac{1}{2}$ MV^2 where M is the mass of the electron and V its velocity.

The electric field about the aperture causes it to act as an electric lens capable of forming real or virtual images of any object emitting or illuminated by charged particles. If the initial conditions of motion of any particles are known as they leave a given object, the orbits or rays can be traced through any given arrangement of apertures and the resultant magnification and position of the image of the object can be found.

One electro-optical system employed in this novel cathode ray tube is shown in Fig. 10, and its optical analogue is indicated in Fig. 12. The two apertured electrodes A and B, nearest the fluorescent screen, focus on the screen the image of a small illuminated aperture placed at a distance Z_0 from the first lens A. In the manner sketched out in Fig. 12, two convenient rays from the subject can be traced through this analogous optical system.

The behavior of the entire system may be determined from the following equations:

$$(1) \qquad -m\frac{d^2r}{dt^2}=eG$$

$$(2) \qquad \Delta_s=\frac{-r_0}{f}=-r_0\frac{G_2-G_1}{4v}$$

$$\therefore f=\frac{4v}{G_2-G_1}$$

The equation above given identified as (1) is the Newtonian equation of motion and the Equation (2) is the law of deflection at the aperture. In these equations m and e are the mass and charge of the particle, G the potential gradient, v the potential of the lens relative to the cathode, Δ_s the change of slope of an orbit at at lens, G_1 and G_2 the potential gradients on the incident and exit sides of the lens, f the focal length of the lens, r the perpendicular distance of the charged particle from the axis of the lens, and r_0 the intercept of the orbit at the lens. The final equation gives the focal length of any electric lens in terms of the potential gradients and equivalent volt energy.

If the two rays of Fig. 12 are traced through the lens system, it is possible to express the result by the following equations:

$$(3) \qquad \frac{Z_0}{f_A}=\frac{(\sqrt{K}-1)\frac{f_B}{S}-(3\sqrt{K}-1)}{(\sqrt{K}-3)\frac{f_B}{S}-3(\sqrt{K}-1)}$$

$$(4) \qquad M=\frac{S}{\sqrt{K}Z_0\left[1-\frac{\sqrt{K}-1}{2}\left(1-\frac{f_A}{S}\right)\right]}$$

Where f_A and f_B are respectively the focal length of the electron lenses A and B, k is the voltage ratio V_2/V_1 as referred to above, Z_0 is the distance from lens A to the object, S is the distance from lens B to the image and M is the magnification of the electro-optical system.

In this lens system, the quantity f_A (the focal length of the first lens) is equivalent to

$$\frac{4d}{K-1}$$

The quantity f_B, i. e. the focal length of the second lens is equivalent to

$$-\frac{4Kd}{K-1}$$

The first lens is thus a positive or "convex" lens and the second a negative or "concave" lens.

Equation (3) is used to locate the position of the image or the object and Equation (4) is used to determine the ratio of the size of the image and object.

In this lens system as used in the tubes of this invention, focus may conveniently be obtained for a voltage ratio of 5:1. This particular ratio also allows the electrode structure to be fairly

short and yet keeps the magnification small, but other practical ratios extend at least from 2:1 to 10:1.

According to the simplified theory above given, perfect images are formed by the electric lens. A more exact determination of the orbits or rays shows that this is not strictly the case, the analogues of both spherical and chromatic aberration being present. The analogue of the former, i. e., spherical aberration, is in extent inversely proportional to the square of the F-number of the lens, and by making the ratio of focal length f to diameter of the lens aperture not less than 7 or thereabouts, it may be so far reduced that a high degree of fidelity can be obtained. The latter is due to the presence of secondary particles and can be reduced or practically eliminated by a suitable system of stops in the optical system or by an inverse voltage ratio between lenses.

When the electron beam strikes the object aperture, it is of fairly high velocity and considerable current density. Consequently it may liberate many secondary electrons where it strikes the edge of the aperture. These secondary electrons will ordinarily be mostly of low energy, of the order of a few volts. Likewise, the edge of the aperture may become hot enough so that low energy electrons may be liberated by thermionic emission. All these low energy electrons are moving at much lower velocities than the primary electron beam, and in random directions and when the primary beam is focused to a spot on the screen, the slower electrons are bent more violently and often will be spread out when they reach the screen and thus produce a general illumination or "background".

Many secondary electrons far from the central axis may reach the lens aperture either by a sort of reflection process from the walls of the cylinder, or by attractive forces due to the electrostatic field from the second lens penetrating into the space between the first lens and the object aperture. This field will ordinarily be too small to affect the primary high velocity beam, but may have considerable effect on the slowly moving electrons liberated from the edge of the object aperture, thus adding to the "background".

These effects may be reduced to negligible proportions, according to the present invention, by inserting an aperture such as 83 in Fig. 13, between the object aperture and the first lens aperture. This intercepts most of the diffuse secondary electrons that would otherwise reach the lens system. Any electrons at a distance from the central axis are intercepted by the new apertured plate, which therefore eliminates most of the undesired electrons but does not affect the main electron beam because it has no effect on the potential distribution inside the cylinder other than to improve the shielding of the object end of the cylinder.

Other methods of suppressing secondary electrons may be used, such as additional shielding of the cylinder interior, or insulating an added aperture and applying a small negative potential to it with respect to the cylinder.

A further method of overcoming chromatic aberration is by the use of an inverse voltage ratio, as stated above. By this we mean that, instead of fixing the voltage ratio of successive lenses according to the right-hand or rising branch of Fig. 9, in which case the potential of B is higher than that of A, we may choose the inverse value determined by the left-hand or falling branch of the curve. Thus the potential of the lens nearer the source of primary electrons is more positive (with respect to the cathode) than that of the second anode. This results in a strong acceleration of the desired primary electrons, sufficient to carry them against the field of the second lens and to the screen. On the other hand, the feebly accelerated secondary electrons liberated at the lens A are unable to reach the screen.

Small apertures in plane surfaces are not the only forms of electrodes that will focus electron beams in a manner generally analogous to the focusing of light beams in optics. Many other forms of electrodes, such as cylinders and cones, have a focusing action more or less similar to that of a thick electro-optical lens in which the electron speed, direction and acceleration are constantly varying along the axis in a manner which, in the present state of the art, cannot be predicted mathematically.

It will be understood that the thin electron lenses of this invention are sharply differentiated from the thick electron lenses of the prior art. For example, in thin lens systems an incident electron travels substantially with a normal parabolic orbit, which orbit is abruptly changed to a second and usually different normal parabolic orbit as the electron passes through the lens. In a thick lens system there is no abrupt change from one normal orbit to another, for the extended field of the lens causes a complex force to act upon electrons approaching and leaving the optical center of the lens so as to cause them to follow a path which is not susceptible of predetermination.

Thus, in a thin lens system the desired change in direction of the electrons takes place substantially entirely at a sharply defined plane, where, without practical error, the incident and exit parabolic orbits may be assumed to meet.

It is of importance to note that the thin lenses of this invention have many advantages over the thick lenses employed in the prior art, for instance when used as a final anode.

Ordinarily the deflecting plate system of a cathode ray tube is placed as far from the screen as possible in order to obtain maximum sensitivity, and therefore close to the final anode.

When a voltage is applied across the deflecting plates, an electro-static field is produced that may penetrate into the final anode space and distort the focusing field; so that if the focusing is adjusted with zero deflection, i. e., with the spot centered on the screen, when a deflecting voltage is then applied and the spot moved to one side the focusing will be disturbed and the spot will become unduly large.

If the final anode is a thick lens, the opening in the lens is usually comparatively large and this deflecting plate field penetrates into the lens field so as to cause a change in spot size as the spot position changes.

If the final anode is a thin lens using a small aperture, the space inside the aperture is well shielded by the sides of the aperture; the deflecting plate field does not penetrate into it to any practical extent, and this form of distortion is entirely negligible.

It should also be noted that in general the thin lenses of this invention may be employed more advantageously than may the thick lenses of the prior art, in any position of the electro-optical system of a cathode ray tube.

Another disadvantage of such a thick lens system is that it is extremely difficult to obtain mathematically the design of a lens system that will give an image of an object at a specified distance with a specified magnification and a specified ratio of the voltages applied to the electrodes. This type of calculation is not difficult for various arrangements of thin lenses, because as is not the case in thick lens systems, the equations of motions defining the orbits of the electrons are capable of integration. In thick lens systems the method of design must, in the present state of the art, be a cut-and-try experimental process which is difficult and costly.

Still another disadvantage of thick lenses is that they cannot be applied for special purposes as easily as can thin lens systems.

In order to obtain the proper spacing between the object (i. e. the aperture of the virtual emitter previously described) and the first lens of a two lens system, and have the space between them free from distorting fields, both the lens and the object aperture are preferably enclosed in a long metal cylinder as shown in Fig. 1 and Fig. 13. The cylinder may be capped at each end by means of punched cups which serve as the accelerating aperture and the first lens. Other apertures may also be inserted in the same cylinder, as above explained.

Referring now to Fig. 13, which is not to scale, but merely illustrative, there is indicated a heating coil **70** having suitable leads **71** to supply electrical energy thereto from any suitable source such as battery **71'**. This heating coil is enclosed in a metallic sleeve **72** having snugly fitting upon its farther end a metallic cap **73** coated with electron emitting material. A metal box **74** of cylindrical shape is provided with an aperture **75** and sleeve **72** enters this box and is so positioned that cap **73** is located a short distance behind aperture **75**.

As previously explained in connection with Figs. 1 and 8, mica washers, supporting rods, metallic straps may be employed to support the elements of the assembly in their proper locations relative to one another and to the other elements of the tube.

The aperture **75** in box **74** serves to govern the useful electron emission from cap **73**, acting as a control grid. It ordinarily will have a negative potential with respect to the cathode and therefore will tend to concentrate the electron stream.

The next element in sequence in the electro-optical system is the first focusing assembly, designated as a whole, as in Fig. 1, by the reference numeral **27**. This may consist of a metallic cylinder, provided with various apertures as described. The first anode **78**, having aperture **78'**, has inter alia, the function of giving a voltage gradient in the space between cathode and cylinder to draw a sufficient number of electrons from the cathode into the next aperture of the lens system. At **79'** is a small aperture which serves as the object aperture or virtual emitter previously described. Next in order is the shield **82** with larger aperture **83**, and finally, at **84** is the first lens of the double lens system. Each aperture may be in a punched cap mounted in the cylinder, thus affording a convenient and accurate means of assembling the electro-optical system of this invention.

The second lens of the compound system is indicated at **28** as an electrode provided with an aperture **29**, this lens also functioning as the final anode of the electrical system.

Longitudinal metal shields **87** may also be provided in connection with **28** and have the useful effect of supporting **28** and affording adequate electrostatic shielding thereof from stray electric fields which may exist due to proximity thereto of other active conductors. The next elements in the electro-optical system may be the horizontal deflecting plates **30** and vertical deflecting plates **31**, whose mounting and action has previously been described, or, alternatively, magnetic deflection may be used.

Since the electrode **79, 79'** is m unted within a substantially closed conducting cylinder and therefore in a homogeneous field of substantially zero magnitude, i. e., a field-free space, the potential gradients on either side are zero and the electrode thus operates as a virtual emitter without any disturbing lens action.

The methods employed in the prior art, of using as an "object" either the cathode itself or the smaller cross-section of the path of the electron beam that occurs in the space between the cathode and grid, are open to several disadvantages as compared to focusing upon an actual aperture, as is done with the virtual emitter of this invention.

First, the control grid has a lens action which in such cases disturbs the focus when the grid voltage changes. This effect is especially disturbing when the grid has a continually varying voltage applied to it, as in television. Second, the area of the cathode which emits electrons, or the area of the smallest cross-section of the electron beam between cathode and grid, depends upon the grid voltage. This causes the "object" and its image, the spot of light, to vary in size as the grid voltage changes. This effect also is most disturbing when the grid voltage is continually changing. Third, for large values of electron beam current (grid least negative or most positive) the emitting area of the cathode and the smallest cross-section of the beam between grid and cathode are usually very large, and an excessively large spot on the screen is obtained. Fourth, the size of the spot of light on the screen is indefinite and it cannot be made of special shapes for special purposes. Fifth, the edge of the spot is not clearly defined because the edge of the object is not sharp. Sixth, the axial position of the object is not sharply defined, and poor focusing results.

All these disadvantages are substantially eliminated by the use of an aperture or virtual emitter as the object of which the image is focused upon the screen. The lens action and control action of the grid has no effect upon the focusing of the image or upon its size, because such actions occur before the electrons reach the virtual emitter or object, and after they leave the virtual emitter the grid has no influence on them.

The size or shape of the object is necessarily determined by the size or shape of the aperture, and is therefore very definite and controllable in design and manufacture; and the edge of the object and its image on the screen is clearly defined.

While the various elements of a tube built according to Fig. 13 may be connected in different fashions according to the results required, the circuit shown has been found satisfactory for such tubes as constructed.

Connection lead **71** may have supplied thereto from battery **71'** an electrical current of 1 ampere at 2½ volts. The second lens or final anode may have supplied thereto from battery **100** a potential ranging from 1000 to 2000 volts positive with respect to the cathode voltage, which may be

taken as zero. Control grid 74 may have applied thereto from battery 101 a negative bias between zero and 100 volts, while electron lens assembly 27 may have applied thereto a positive voltage of the order of ⅕ of that applied to lens 28, this being conveniently adjustable by moving contact 102 along potentiometer 103. The grid and the deflecting plates may be connected to any suitable potentials in accordance with the use to which the tube is to be put. Since the external circuits for supplying the various potentials and currents to a cathode ray tube are well known in the art, it has been thought unnecessary to include herein any detailed description thereof.

While the invention disclosed herein is not limited to cathode ray tubes of any specific design or dimensions, the following data apply to a satisfactory construction having the general arrangement of Fig. 13:

Cathode sleeve: 0.08" diameter, 16 mm. long
Cylindrical electrodes and caps: ½" diameter
Space between 73 and 74: 0.015"
Aperture in 74: 1 mm. diameter
Length of shielding rim of 74: 5 mm.
Space between 74 and 78: 2.5 mm.
Aperture in 78: 1 mm. diameter
Aperture in 79: 0.25 mm.
Separation between 78 and 79: 2 mm.
Aperture in 82: 1 mm. diameter
Separation between 79 and 82: 10 mm.
Aperture in 84: 2 mm. diameter
Separation between 82 and 84: 10 mm.
Space between 84 and 28: 10 mm.
Aperture in 28: 2 mm. diameter
Distance from 28 to screen: 180 mm.

The other dimensions may be selected in accordance with the principles used in designing cathode ray tubes of the prior art.

Certain features herein disclosed but not specifically claimed, are the inventions of the individual applicants, and the right to claim such features in other applications is hereby reserved.

We claim:

1. A cathode ray tube system including a cathode emitting an electron stream, a control element immediately adjacent said cathode and controlling said stream, a conducting cylinder receiving said stream and enclosing a substantially uniform electrical field and having an apertured screen element admitting said stream, a second apertured screen within said cylinder and said uniform field whose aperture functions as an object aperture, a third apertured screen within said cylinder, functioning to prevent the passage of undesired portions of said electron stream, and a fourth apertured plate near the end of said cylinder functioning as an electron lens, said cathode ray tube structure also including a fifth apertured plate located beyond said cylinder and functioning as an electron lens, all of said elements being arranged in the order named with respect to the passage therethrough of said electron stream and including means for energizing said cathode and for applying to said elements suitable operating potentials.

2. In a cathode ray tube system a virtual electron emitter assembly including a source of electrons, a conducting apertured plate, separated from said source by a predetermined distance, means for establishing between said source and said plate a predetermined potential difference, a second apertured plate located at a predetermined distance from said source, greater than the distance between said source and said first plate, but also located upon the same side thereof, and means for establishing between said second plate and said source a potential difference having to said first mentioned potential difference the same ratio that the distances of the respective plates from said source bear to one another, said source and both said apertured plates being substantially planar in form and substantially parallel to one another.

3. In a cathode ray tube system the combination including means for producing in the tube an electrical field of substantially constant magnitude and homogeneity, means for emitting electrons, an apertured plate located in said field and receiving electrons from said emitting means, means for supplying a potential to said plate, means for controlling the electrostatic field on one side of said plate, means for controlling the field on the opposite side of said plate, substantially identical potential gradients of said fields existing upon both sides of said plate, a second plate receiving electrons from said first plate and means for providing substantially homogeneous fields of differing magnitude upon the respective sides of said second plate, whereby the direction of motion of electrons passing therethrough is altered.

4. A system according to claim 3 and also including in the tube a third apertured plate receiving electrons from said second plate and means for providing substantially homogeneous fields of differing magnitude upon the respective sides of said third plate, whereby the direction of motion of electrons passing therethrough will be altered.

5. A cathode ray tube according to claim 3, in which the first named apertured plate has an orifice of differing transverse dimensions in at least two transverse directions.

6. In a cathode ray tube system the combination including means for producing in the tube an electrical field of substantially constant magnitude and homogeneity, means for emitting electrons, an apertured electrode located in said field and receiving electrons from said emitting means, means for supplying a potential to said electrode, means for controlling the electrostatic field on one side of said electrode, means for controlling the field on the opposite side of said electrode, substantially identical potential gradients of said fields existing upon both sides of said electrode, a second electrode receiving electrons from said first electrode and means for providing substantially homogeneous fields of differing magnitude upon the respective sides of said second electrode, whereby the direction of motion of electrons passing therethrough is altered.

7. In a cathode ray tube system, the combination including means for producing in said tube an electrical field of substantially constant magnitude and homogeneity, means for emitting electrons, an apertured plate located in said field and receiving electrons from said emitting means, means for supplying a potential to said plate, shielding means preventing the development of a finite potential gradient on either side of said plate, a second plate receiving electrons from said first plate and means for providing substantially homogeneous fields of differing magnitude upon the respective sides of said second plate, whereby the direction of motion of electrons passing therethrough is altered.

8. A cathode ray tube system including a cathode emitting an electron stream, a control element immediately adjacent said cathode and controlling said stream, a conducting cylinder receiving said stream and enclosing a substantially uniform electrical field and having an apertured screen element admitting said stream, a second apertured screen within said cylinder and said uniform field whose aperture functions as an object aperture, a third apertured plate near the end of said cylinder functioning as an electron lens, said cathode ray tube structure also including a fourth apertured plate located beyond said cylinder and functioning as an electron lens, all of said elements being arranged in the order named with respect to the passage therethrough of said electron stream and including means for energizing said cathode and for applying to said elements suitable operating potentials.

9. In a cathode ray tube system, a virtual electron emitter comprising a source of electrons, an apertured electrode adjacent thereto, the area of said aperture being substantially smaller than the effective emissive area of said source, a second apertured electrode located adjacent to said first electrode and more distant from said source, means for applying different potentials to each of said electrodes, and for maintaining the ratio of the potential of said second electrode to that of said first electrode at substantially the same value as the ratio of the respective separating distances between said electrodes and said source.

10. In a cathode ray system comprising two electron lenses, the combination of a source of electrons, an object electrode, a first anode, a second anode and a target, and means for maintaining said anodes at substantially constant potentials with respect to said cathode, said system and potentials being arranged substantially according to the equation:—

$$\frac{Z_0}{f_A}=\frac{(\sqrt{K}-1)\frac{f_B}{S}-(3\sqrt{K}-1)}{(\sqrt{K}-3)\frac{f_B}{S}-3(\sqrt{K}-1)}$$

Where f_A and f_B are the focal lengths of the respective lenses, k is the reciprocal of the ratio of potentials of the respective anodes, each potential being measured with respect to the cathode. Z_0 is the distance from the first anode to the object electrode, and S is the distance from the second anode to the target.

11. In a cathode ray system comprising two electron lenses, the combination of a source of electrons, means for producing a stream of electrons therefrom, a reference plane through which said electron stream passes, means for determining the cross sectional area of said stream at said reference plane, a first anode, a second anode, and a target, and means for maintaining said anodes at substantially constant potentials with respect to said cathode, said system and potentials being arranged substantially according to the equation:—

$$\frac{Z_0}{f_A}=\frac{(\sqrt{K}-1)\frac{f_B}{S}-3(\sqrt{K}-1)}{(\sqrt{K}-3)\frac{f_B}{S}-3(\sqrt{K}-1)}$$

Where f_A and f_B are the focal lengths of the respective lenses, k is the reciprocal of the ratio of potentials of the respective anodes, each potential being measured with respect to the cathode, Z_0 is the distance from the first anode to the reference plane, and S is the distance from the second anode to the target.

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Certificate of Correction

Patent No. 2,060,825. November 17, 1936.

HUGH C. RESSLER ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 8, second column, line 28, claim 11, the last part of the numerator in the equation should read —$(3\sqrt{K}-1)$ instead of "—$3(\sqrt{K}-1)$"; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 9th day of February, A. D. 1937.

[SEAL]

HENRY VAN ARSDALE,
Acting Commissioner of Patents.