Jan. 9, 1945. O. KLEMPERER 2,367,130

ELECTRON DISCHARGE DEVICE

Filed July 25, 1940

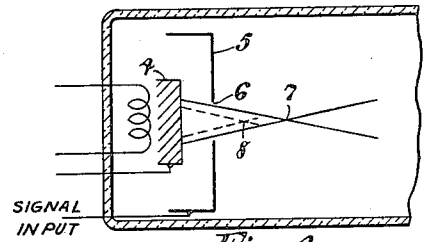


Fig. 1.

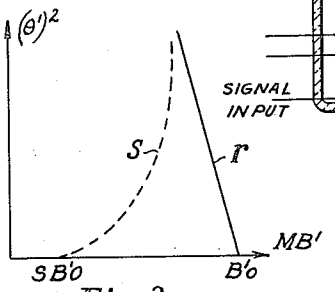


Fig. 3.

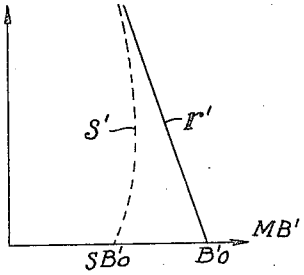


Fig. 4.

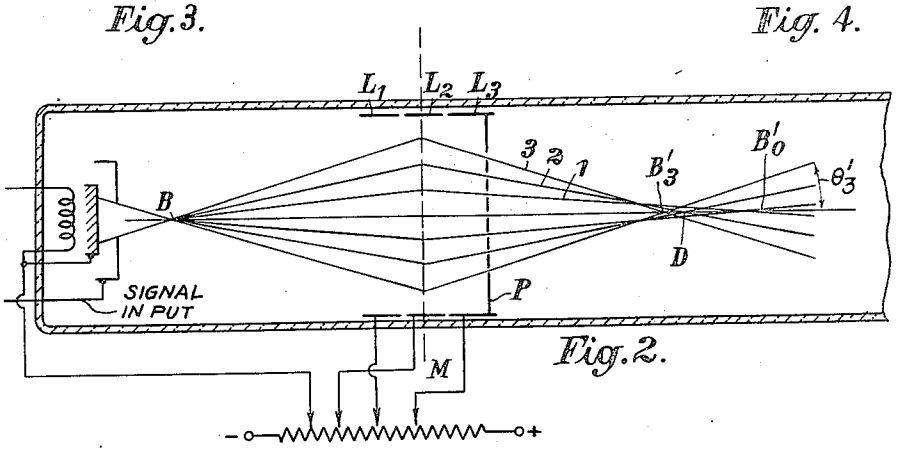


Fig. 2.

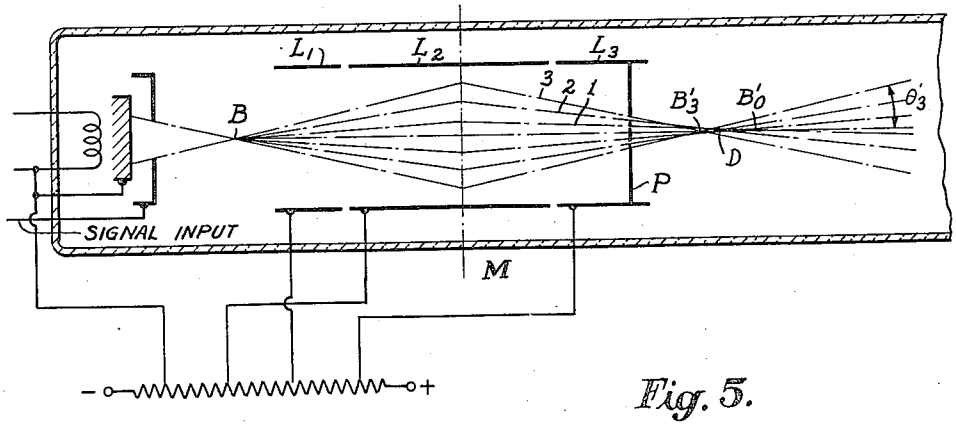


Fig. 5.

INVENTOR.
Otto Klemperer
BY H. S. Snover
ATTORNEY

Patented Jan. 9, 1945 2,367,130

UNITED STATES PATENT OFFICE

2,367,130

ELECTRON DISCHARGE DEVICE

Otto Klemperer, Iver, England, assignor to Electric & Musical Industries Limited, Hayes, Middlesex, England, a company of Great Britain

Application July 25, 1940, Serial No. 347,460
In Great Britain July 28, 1939

2 Claims. (Cl. 315—16)

The present invention relates to electron discharge devices such as cathode ray tubes of the kind wherein a beam of electrons in the form of a relatively narrow pencil is projected from a cathode through an aperture or gap in a modulating electrode which is biased to zero or a negative potential with respect to the cathode so that a cross-over is formed in the beam near the modulating electrode, the beam being projected through a further electrode system forming an electron lens system which focuses the beam so as to form at a given surface, for example, on a fluorescent screen, an image of the beam cross-over.

The nature of the present invention and the method of carrying the invention into effect will be fully understood from the following description in which reference to the drawing will be made:

In the drawing,

Fig. 1 shows schematically an electron emitter and a modulating electrode for purposes of explaining the cross-over effect;

Fig. 2 shows an electrode system embodying my invention;

Figs. 3 and 4 are graphical representations of focusing effect for purposes of explaining the invention; and

Fig. 5 shows a modification of Fig. 2.

In such devices, difficulty is experienced in that as the potential of the modulating electrode varies, the position of the cross-over in the beam varies. Thus in Figure 1 of the accompanying drawing there is shown a cathode 4 with a modulating electrode 5 surrounding the cathode and having an aperture 6 through which the cathode ray beam passes. If the electrode 5 is at cathode potential a cross-over may be formed in the beam at 7, while if the electrode 5 becomes negative the cross-over will move towards the cathode, for example, to the position shown at 8. Now, in the electron gun of a cathode ray tube, it is usual to provide an electron lens arranged to project an image of the cross-over on the tube screen. Thus, if the cross-over moves towards the cathode as the potential of the modulating electrode 5 becomes more negative, the power of the electron lens will have to be lowered if the spot is to be kept accurately in focus on the screen. The power of the lens could be altered by changing the potentials of the constituent electrodes in the lens arrangement, but the application of such a principle to obtain automatic compensation for cross-over shift would lead to circuit complications. However, I have found that as the current in an electron beam varies upon variation of the potential of the modulating electrode such as 5 the variation in the space charge within an electron lens operating on the beam, causes the power of the lens to become modified in such sense as to tend to compensate or even over-compensate for the cross-over shift.

Thus it is possible in an electron device of the kind set forth, if the electrodes constituting the electron optical system are suitably arranged and operated at suitable potentials with relation to the range of variation of the current in the electron beam, to arrange that the variation in the shift of the cross-over point in the beam and variation in the focal length of the electron optical system with the potential applied to the modulating electrode can be made to compensate each other in such manner that the beam remains in focus on the aforesaid given surface notwithstanding variation in the applied modulating potential.

This result is a very desirable one, for example, in cathode ray tubes for television reception.

Thus, in its main aspect, the present invention provides a method of operating an electron discharge device of the kind set forth such that when the potential of the modulating electrode is varied, the change in position of the cross-over in the electron beam and the change in focal length with beam current in the electron lens system are such that at least for beams of small aperture the electron beam remains in focus substantially at the given surface.

In carrying the invention into practice it is preferred to employ an arrangement wherein the electron beam is focused by means of an electron lens of the saddle field type with a decelerating voltage at the field saddle. Thus, as shown in Figure 2 of the drawing, the lens may be constituted by three aligned tubular electrodes L_1, L_2 and L_3 of which the outer or end electrodes L_1 and L_3 are maintained at a high positive potential or potentials and the intermediate electrode L_2 is maintained at a lower positive potential. The focal length of a lens of this kind is found to vary to a marked degree with the space charge set up by electrons passing through the intermediate electrode. In the case shown all the electrodes are of the same diameter and length, the length and the diameter of each lens being approximately equal, but the horizontal and vertical scale of the drawing is made different so that the electron beam can be adequately shown in the drawing.

In the case where the end electrodes L_1 and L_3 of Figure 2 were maintained at a common potential of three kilovolts and the intermediate electrode L_2 at a potential of one kilovolt, it was found that the passage through the electrodes of an electron discharge carrying a current of a few hundred microamps was sufficient to produce a change in the focal length of the system comparable with that produced by reducing the potential of the intermediate electrode by ten volts. Apparently the effect of the space charge set up by the electron discharge is to raise the potential "saddle" in the lens. Thus the greater the electron current in the beam passing through the electron lens the shorter the focal length of the lens becomes. That is to say, in a device of the kind above referred to, when the potential of the modulating electrode becomes less negative, thereby allowing more electrons to be projected through the electron lens, the focal length of the lens itself becomes shorter so that the lens tends to focus the cross-over at a point in front of the given surface. However, due to the change in the modulating potential, the cross-over point moves towards the lens so that the lens is caused to focus the beam to form an image of the cross-over at a point further away from the lens than would be the case if the cross-over remains fixed.

It was found that when a lens arrangement was used in which the two end electrodes were maintained at a common positive potential and the intermediate electrode at a lower potential as above described, the reduction of the focal length of the lens with increasing space charge was in general greater than that needed to compensate for the shift of the cross-over point. Moreover, it was not possible to raise the potential of the intermediate electrode alone sufficiently to cause the two effects to compensate each other as in this case the focal length of the lens became too long. However, by increasing the potential of the electrode most remote from the cathode as well as the intermediate electrode it was found possible to provide an arrangement which would operate satisfactorily. Thus, for example, in one case the first electrode L_1 of the system of Figure 2 was maintained at a potential of three kilovolts, the second or intermediate electrode L_2 was maintained at a potential of two kilovolts, and the electrode L_3 most remote from the cathode was maintained at a potential of five kilovolts.

To determine the particular potentials required for a given arrangement the investigation may be conducted in any known manner. Thus, in the case of the arrangement shown in Figure 2 of the drawing the investigation was carried out in the manner described below.

In the cross-sectional diagram of Figure 2 there is shown an electron source B, which is constituted by the cross-over to be imaged, arranged on the axis of the lens and from which hollow cones or pencils of rays 1, 2 and 3 symmetrically disposed about the axis are traced, the tracing being effected in well known manner using a so-called "pepper-pot" diaphragm shown at P in Figure 2. Paraxial rays may be focused by the lens to form an image of the source B at B_0' whilst marginal rays such as the rays 3 may be caused to form an image at B_3'. The "spot," or cross-sectional of a cathode ray, used for scanning purposes is that formed at D which is the circle of least confusion. If the rays 1, 2 and 3 with the semi-apertures Y_1, Y_2, Y_3 cross the axis at angles θ_1', θ_2' and θ_3' respectively, the aberration of the lens is termed positive if, for $Y_1<Y_2<Y_3'$, then $MB_1'>MB_2'>MB_3'$, where M is the point of intersection of the mid plane of the lens and the axis, and B_1', B_2' and B_3' represent the points at which the appropriate rays are focused.

In Figure 3 are plotted the squares of the angles of divergence $(\theta')^2$ against the corresponding distances MB', for the case of a lens in which end electrodes L_1 and L_3 are maintained at a common potential of three kilovolts as above described and the intermediate electrode L_2 is maintained at a potential of one kilovolt. The continuous line *r* refers to the case in which the beam only carries very small currents of the order of a microamp. This line is approximately straight and its slope indicates positive aberration throughout as in the case of ordinary optical lenses. If, however, the beam current is gradually increased the aberration curve gradually changes its shape and position so that when the current is of the order of a milliamp, the aberration curve is given by the broken line S of Figure 3. In this case it will be seen that the aberration is highly negative for rays near the axis and it varies less and less rapidly with increasing angle θ'. The paraxial image, which, with small currents, and hence negligible space charge, is at B_0' is shifted, due to the higher current in the beam and the space charge arising therefrom, to the point SB'.

In the case of cathode ray guns with saddle field lenses in which usual operating potentials are applied, and in which a cross-over point in the beam forms the object which is imaged by the lens of the screen of the tube, the effect of the space charge variation to the saddle field in the lens as the beam current is varied is usually greater than and opposed to the effect of the change in potential of the modulation electrode. Thus it is generally necessary to decrease the aberration produced by the saddle field lens to effect the desired compensation.

This decrease in the effect can be produced in two ways. In accordance with the first method the geometry of the intermediate electrode is changed. Thus in the case of the arrangement of Figure 5 where all the electrodes are tubes of the same radius, if the length of the intermediate electrode L_2 can be increased to a value three times that of the radius, instead of the curves *r* and *s* of Figure 2, the curves *r'* and *s'* of Figure 4 are obtained, which, it will be seen, are much less widely separated than the corresponding curves of Figure 3. However, if the geometry of the intermediate electrode is altered in the manner suggested, many other properties of the lens as, for example, the focal length or the state of correction or the geometric extension of the lens defining the smallest possible object distance are often altered in an undesirable manner.

The arrangement of Fig. 5, like that of Fig. 2, shows the centermost electrode L_2 as being maintained at a lower positive potential relative to the tube cathode than either of the electrodes L_1 or L_3. The preferred arrangement provides the electrode L_3 at the greatest positive voltage relative to the cathode of the tube and the electrode L_1 was maintained at an intermediate value relative to electrodes L_1 and L_3.

The second method of effecting the desired adjustment of the effect of space charge consists in raising the operating potential of the middle electrode L_2 to the value required for the

cross-over shift compensation and raising the potential of the third electrode L_3 correspondingly to keep the spot in focus at a given image distance. A practical example of the use of the method has been given above.

However, if the saddle field lens is used to focus beams of relatively large aperture, the circle of least confusion shown at D in Figure 2 would no longer be near the paraxial image. As a result the image shift produced by space charge effects appears to be the smaller, the larger the aperture stops which are used in the gun. Thus it has been found that in cases where the beam is such as to fill more than about a fifth of the aperture of a lens it is not possible to match cross-over shift and space charge shift, the latter always being too small in these circumstances. This, however, is by no means a general limitation in the application of the invention, as it refers to special types of lenses only. Moreover, beams occupying a large aperture are subject to the drawback that, due to the relatively large aberration produced by the lens, the circle of least confusion or spot, cannot be made small enough, so that the use of large beams is precluded in any case.

In order to make use of saddle field lenses in cathode ray tubes, the lenses must be of sufficiently short focal length to allow the cross-over to be brought near enough to allow the lens to collect enough beam current without introducing too much aberration.

Thus in some cases, instead of using tubular electrodes as shown in Figure 2, it may be preferred to use electrodes of diaphragm form with large spacing between them, such electrodes being capable of being used to provide lenses capable of handling beams of larger apertures than can be handled by lenses in which the electrodes are tubular.

The particular voltages used for the electrodes in the electron lens or lens system depend on the size and shape of the electrodes, as well as on the amount of cross-over shift in the particular arrangement to be compensated. Experiments indicate that it is quite a simple matter to ascertain the required potentials empirically.

I claim:

1. A cathode ray tube comprising means including a cathode for producing a focused beam of electrons with a cross-over point intermediate the cathode and a predetermined plane upon which the beam is focused, electrode means to modulate said beam, and a correcting electron lens including three tubular electrodes of substantially the same diameter interposed between said cross-over point and said predetermined plane, said tubular electrodes being in register with each other and said electrode intermediate the first and third electrode being adapted to be maintained at a lower positive potential than said first and third electrodes, said intermediate electrode having a length on the order of three times its radius, said first and said second electrodes having substantially constant inside diameter throughout their entire length.

2. A cathode ray tube comprising means including a cathode for producing a focused beam of electrons with a cross-over point intermediate the cathode and a predetermined plane upon which the beam is focused, a modulating electrode, means to modulate the developed beam of electrons, and a correcting electron lens including three tubular electrodes of substantially the same diameter interposed between said cross-over point and the said predetermined plane, said tubular electrodes being in register with each other and the intermediate electrode having a length of the order of three times its radius, and means to apply positive voltages to the said electrodes relative to the cathode of the tube with said first and third electrodes being maintained at a higher positive potential than the said intermediate electrode.

OTTO KLEMPERER.