Dec. 7, 1937. E. BRÜCHE ET AL 2,101,669

DEVICE FOR THE DEFLECTION OF ELECTRON BEAMS

Filed Aug. 5, 1935

Fig.1.

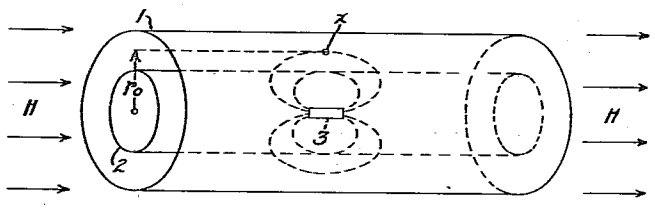


Fig.2.

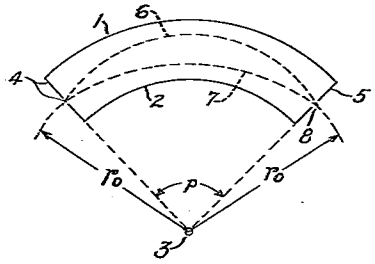


Fig.3.

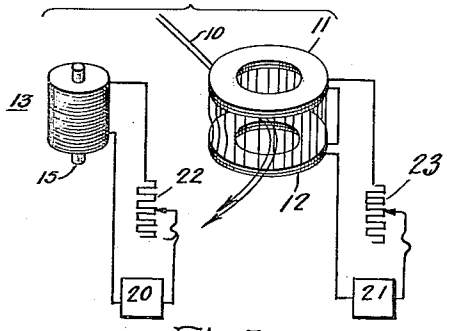


Fig.4.

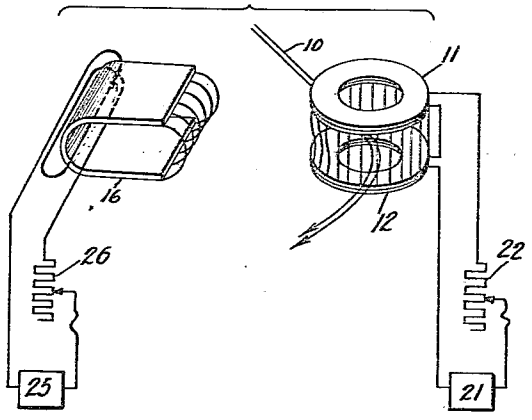
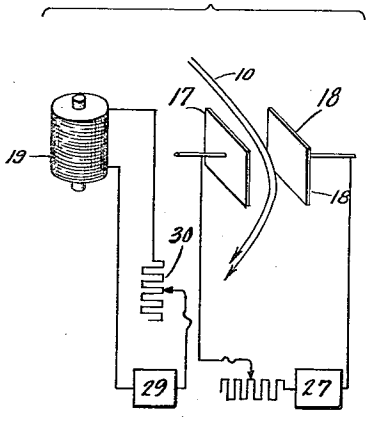


Fig.5.



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DEVICE FOR THE DEFLECTION OF ELECTRON BEAMS

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5 Claims. (Cl. 250—27)

The present invention relates to an improved electron deflecting device of the type whose operation depends on the combined action of superposed electrostatic and electromagnetic fields.

For the deflection of electron beams as, for instance, in the so-called Braun tube or cathode ray tube, or in similar electron optical systems, it has been proposed to use pairs of deflecting windings or deflecting plates. Such devices as have previously been used, however, have the serious disadvantage that they focus as well as deflect the electron beam. Since such focusing action is in some applications equivalent to a distortion effect, its occurrence may be extremely objectionable.

It is, therefore, an object of the present invention to provide an "electron prism" or deflecting system which is capable of changing the direction of an electron beam without distorting it in this way. To this end we may in the practice of our invention use superposed fields, either electrostatic or magnetic, of such nature that the diverging action of one field exactly compensates the focusing action of the other.

The novel features which we consider to be characteristic of our invention will be pointed out with particularity in the appended claims. Our invention itself will best be understood by reference to the following description taken in connection with the accompanying drawing, in which Fig. 1 represents an idealized electron deflecting system useful in the explanation of our invention, while Fig. 2 is a diagrammatic view showing another aspect of such a system. Fig. 3 is a perspective view illustrating a structure suitable for the practice of our invention, and Figs. 4 and 5 are appropriate modifications thereof.

Referring particularly to Fig. 1 we have illustrated an electrostatic condenser comprising a pair of mutually concentric cylinders 1 and 2 suitably spaced from one another. It will be readily appreciated that if potential is impressed between the two cylindrical plates thus formed, an electrostatic field will be produced in the inter-cylinder space which may be defined as having a magnitude $E=r_0E_0/r$. In this equation E_0 designates the value of the electrostatic field at a particular distance r_0 between the radii of 1 and 2. The quantity r is a variable definitive of any radial distance from the cylinder axis which it is desired to consider, while E is the electrostatic field strength at such radial distance, being positive when the inner cylinder is positive and vice versa.

We have also illustrated conventionally a uniform magnetic field H having its axis parallel to the axis of the cylinder 2 and a concentrated or dipole magnetic field source 3 axially disposed within the cylinder 2 and defined as producing at any distance r from the cylinder axis an inherently non-homogeneous field H' equal to M/r^3 where M represents the strength of the dipole 3.

Suppose the field combination just described to be acting on a particle x in the inter-cylinder space having a mass m and a charge e and at a distance r from the axis of cylinder 2 and moving in a plane perpendicular to that axis. It will then be apparent to those skilled in the art that the fundamental equations of motion of such a particle are:—

$$d^2r/dt^2=rw^2-(\mu/r^3+h)rw-f/r \quad (1)$$

$$d(r^2w)/dt-r(dr/dt)\ (h+\mu/r^3)=0 \quad (2)$$

In these equations the various quantities are defined as follows:—

$w=dp/dt$ (the angular velocity of the particle x with respect to the cylinder axis)
$h=(e/mc')H$
$f=r_0eE_0/m$
$\mu=eM/mc'$
$c'=3\times10^{10}$

E and e are given in electrostatic units, M and H in electromagnetic units.

Integration of Equation (2) gives the following:

$$r^2w+\mu/r-hr^2/2=c=\text{const.} \quad (3)$$

This equation may now be used in connection with Equation (1) to eliminate the quantity w and give the radial distance as a function of time:—

$$d^2r/dt^2=2\mu^2/r^5-3\mu c/r^4+c^2/r^3-\mu h/2r^2-f/r-h^2r/4 \quad (4)$$

As a limiting condition it is possible to state that the particle x will travel in a circle (of radius r_0) when in particular $dr/dt=0$ initially and $d^2r/dt^2=0$. Referring to Equation (1) above, this means that

$$r_0w_0^2-(\mu/r_0^3+h)r_0w_0-f/r_0=0 \quad (5)$$

w_0 being used to denote the particular value of angular velocity required for the circular trajectory. This equation can be simplified to

$$h=w_0(1-y-n) \quad (6)$$

by introducing the quantities

$$y=f/r_0^2w_0^2, n=\mu/r_0^3w_0 \quad (7)\ (8)$$

Equation (5) represents a solution of Equaton (2) for $r=r_0$, a constant. To determine the focusing action of the field combination, assume an electron particle of the same velocity as x but whose path makes a slight angle a with a tangent to the circular path described by x. It is then mathematically possible to define the varying distance of such a particle from the axis of the cylinder **2** as a function of both r and a. An appropriate expression of this relationship is

$$r=r_0+ar_1+a^2r_2+\ldots \quad (9)$$

it being understood that r_1, r_2 etc. are functions of time or of the angular displacement P of the particle. Considerable simplification and a sufficient degree of mathematical accuracy will result if all terms in a beyond those of the first power be disregarded. With this in mind substitution of the equality $r=r_0+ar_1$ in Equation (4) will be found to result in the elimination of all terms not involving a. The resulting equation, when modified by disregarding all terms containing a to a power higher than the first and using Equation (6) to eliminate h gives:

$$\ddot{r}_1=w_0^2(1+y^2-3n)r_1 \quad (10)$$

The solution obtained by integrating Equation (10) is the following:—

$$r_1=[r_0/\sqrt{1+y^2-3n}]\sin[(\sqrt{1+y^2-3n}w_0(t-t_0)] \quad (11)$$

The physical significance of this solution may be best appreciated by an inspection of Fig. 2 in which the dotted lines indicated by the numerals **6** and **7** represent two trajectories in a slightly divergent electron beam assumed to start from a slit **4** as from a point source. It is assumed that this beam is so directed as to have at its center a circular orbit between condenser plates **1** and **2** which represent sectionalized portions of corresponding cylinders **1** and **2** of Fig. 1. It is also assumed that the electron beam is subjected to an electrostatic field E, a uniform magnet field H and a non-uniform magnetic field H′ similar to those considered in connection with the foregoing discussion. It will be apparent under the conditions illustrated that when, at time t_0, any electron traverses the entrance slit **4**, it will be moving at a definite distance r_0 from the cylinder axis. At such time, therefore, r_1, which, as described above, indicates a deviation from the initial radial position r_0, should also be equal to zero. By the interpolation of the various applicable quantities in Equation (11) it will appear that this condition is in fact satisfied.

If, as has been found experimentally to be the case, a combination of electrostatic and magnetic fields such as that under consideration actually exerts a focusing action on an electron beam within its influence, it is possible to predict that at several successive times, t_1, t_2, etc. later than t_0, all particles of the beam will pass through additional focal points of radial distance r_0 from the cylinder axis. By inspection of Equation (9) it will appear that the first of these focal points, occurring at time t_1 and shown at points **8** of Fig. 2 must satisfy the equation:

$$w_0(t_1-t_0)=\pi/\sqrt{1+y^2-3n}$$

Under such circumstances r_1 will again be equal to zero which is the physical condition required to be fulfilled at a focal point. Since the quantity $w_0(t-t_0)$ is in fact a representation of the angular distance (indicated in Fig. 2 as P) through which the electron beam has moved before reaching the focal point **8**, it may be stated as a matter of definition that the focusing angle, P, is given by

$$P=\pi/\sqrt{1+y^2-3n} \quad (12)$$

To create a system in which focusing shall be entirely avoided it is now only necessary to establish conditions under which the focusing angle P shall become infinite. Stated in terms of the relationship already derived this requires that

$$\pi/\sqrt{1+y^2-3n}=\infty$$

or correlatively that

$$1+y^2-3n=0 \quad (13)$$

By a comparison of this last equation and the previously derived Equation (6) it will be obvious that we have succeeded in defining the relationship which must exist between the original angular velocity of an electron beam and the various electrostatic and magnetic forces operating upon it, in order to avoid focusing of the beam. It should be noted that all the quantities contained in Equations (6) and (13) may alternatively be expressed as functions of the factors E, H, M, e, m, r_0, w_0 and (t_1-t_0) as originally defined.

Referring now to Fig. 3 we have shown an electron-beam prism practically embodying our invention. An electron beam **10**, having a characteristic energy V, expressed in volts, which it is desired to deflect without focusing is illustrated as passing between a pair of magnetic field coils **11** and **12** so distributed as to create therebetween a substantially homogeneous field of uniform strength H. Adjacent the coils **11** and **12** and spaced from their common axis by a distance r_0, we provide a magnetic dipole **13** in the form of a spool-type coil having a concentrated iron core **15**. The coils **11** and **12** and the dipole **13** are energized by voltage sources **20** and **21** respectively. These sources are indicated schematically and may comprise either a direct current source of potential such as a battery or a voltage network depending on the use to which the device is to be put. Voltage varying means including adjustable impedances **22** and **23** may be provided for adjusting the magnitudes of the respective fields. In accordance with the conventions already established we may designate the strength of the dipole as M and the magnitude of the field created by it as M/r^3, r being the distance from the dipole axis at which such field is measured. As illustrated and as described in connection with Fig. 1, this field is parallel to the homogeneous field in the region of beam deflection.

It should be apparent in view of the foregoing discussion and may readily be verified by experiment that either of the fields H and H′ acting alone will tend to produce a definite focusing or divergence of the electron beam. In accordance with our invention, however, the two fields may be made of such nature as to cause mutual neutralization of these focusing effects. While the necessary adjustment of values may be attained by experimental means, we prefer to accomplish it by reference to the physical relationships established by Equations (6) and (13) above. In the particular case under consideration the computation is simplified by the fact that there is no electrostatic field to be considered. For this reason the term y^2 appearing in Equation 13 becomes equal to zero, and the quantity n is readily evaluated as ⅓. With this simplification it is

an easy matter to solve for H and M as functions of the original electron angular velocity w_0 and the radial distance r_0. Having due regard to the relation

$$V=300\frac{m(w_0/r_0)^2}{2e}$$

in which account is taken of the relation between electrostatic and practical units of electrical measurement and r_0 is in *cm*, the desired values of M and H are found to be:

$$M \text{ (in Oersteds}-cm^3)=1.12r_0^2\sqrt{V}$$

$$H \text{ (in Oersteds)}=2.25\sqrt{V/r_0^2}$$

Since V is also the value of the potential impressed between the cathode and anode of the electron beam source, the constants of a non-focusing beam prism are thus evaluated in terms of easily measurable quantities.

Referring to Fig. 4 we have illustrated an embodiment which differs structurally from that of Fig. 3 in utilizing a horseshoe magnet **16** (having an energizing source **25** and adjusting means **26**) in place of the ideal dipole **13** described in connection with Fig. 3. For most purposes it will be found that the operation of this modification is exactly similar to that already described, and that the same formulas may be applied for determining the proper strength of the magnet **16**.

In Fig. 5 we have shown an arrangement in which deflection of the electron beam **10** is produced by passing the same through the homogeneous electro-static field existing between a pair of condenser plates **17** and **18** which are energized from a suitable potential source **27**. A dipole **19**, energized by means of a potential source **29** and a variable impedance **30**, is arranged at a distance, say r_0, from the axis of the beam. If the field potential due to the plates **17** and **18** is assumed to be E_0 at the center or axis of the beam, then the potential E at any chosen distance r from the dipole **19** will be determined by the formula $E=r_0E_0/r$. A non-homogeneous magnetic field transverse to the electron beam and to the electrostatic field will be superimposed on the region of beam deflection by the action of the dipole **19**. The strength of this field at any point will be M/r^3 where r again represents a distance measured from the axis of the dipole. In order to determine non-focusing values of E_0 and M in terms of the characteristic energy V of the electron beam and the quantity r_0, we may once more have reference to Equations (6) and (13) as derived above. It will be observed that with the modified structure under consideration the quantity h appearing in Equation (6) is equal to zero, since it is assumed that no homogeneous magnetic field is present. Simultaneous solution of the simplified expressions resulting from this circumstance yield the two pairs of values for M and E_0 as follows:—

$$M \text{ (in Oersteds}-cm^3)=1.48\ r_0^2\sqrt{V} \text{ or } 15.4\ r_0^2\sqrt{V}$$

$$E_0 \text{ (in volts per cm.)}=1.12\ V/r_0 \text{ or} -7.12\ V/r_0$$

The meaning of the negative sign in the second pair of values is that the electrostatic field is to be reversed in a direction relative to the fields so far dealt with. In other words, the inner plate **17** will become negative with respect to the outer plate **18** so that the electric field will exert an influence opposed to that of the dipole rather than in coordination with it as was formerly assumed. Under these conditions the dipole must be of sufficient strength to offset the centrifugal action of both the electric field and the electron momentum.

It will thus be seen that by the use of the principles of our invention as outlined above an electron-beam prism may be devised utilizing either electrostatic or magnetic superposed fields of such related values that beam deflection may be obtained without attendant distortion or focusing. The importance of this possibility in connection with electron optical systems pertaining to electron microscopy, television and equivalent arts relating to the reproduction of electrical images may be fully appreciated by comparison with analogous devices as utilized in light optics. In effect, our invention provides an electron optical device of a nature substantially similar to the well-known light refracting prism.

While we have shown a particular embodiment of our invention, it will of course be understood that we do not wish to be limited thereto since many modifications in the structure may be made, and we contemplate by the appended claims to cover all such modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States, is:—

1. A device for deflecting an electron beam having a characteristic energy V comprising a concentrated magnetic field source spaced from said beam a distance r_0 and having a strength

$$M=1.12r_0^2\sqrt{V}$$

and means additionally impressing on said beam a substantially homogeneous magnetic field of strength

$$H=2.25\sqrt{V/r_0^2}$$

said field source and said means being arranged so that their fields are substantially parallel to one another and transverse to the beam in the region of beam deflection.

2. A device for deflecting an electron beam having a characteristic energy V comprising a concentrated magnetic field source spaced from said beam a distance r_0 for producing a non-homogeneous field transverse to the beam, said field source having a strength

$$M=1.48r_0^2\sqrt{V}$$

and means additionally impressing on said beam an electrostatic field transverse to the field produced by said concentrated field source and having a value variable with radial distance r from said field source according to the formula $E=1.12V/r$ for substantially avoiding focusing of said beam.

3. The method of accomplishing distortionless deflection of an electron beam which comprises producing in a region traversed by said beam a substantially homogeneous magnetic or electrostatic field adapted to deflect the beam in a desired manner and superimposing on said region a non-homogeneous magnetic field of such nature and magnitude as substantially to neutralize the focus-changing effects of said first-named field.

4. An electron beam deflecting device comprising means producing in a region traversed by an electron beam a substantially homogeneous magnetic field transverse to the beam for deflecting the same, and means including a concentrated magnetic field source displaced from the axis of the beam for producing in the region of beam deflection a non-homogeneous field substantially parallel with the homogeneous field, said non-

homogeneous field being of such magnitude as substantially to neutralize the focusing effects of the homogeneous field.

5. An electron deflecting device comprising means producing in a region traversed by an electron beam a substantially homogeneous electrostatic field transverse to the beam for deflecting the same, and means including a concentrated magnetic field source displaced from the axis of the beam for producing in the region of beam deflection a non-homogeneous magnetic field substantially transverse to the electrostatic field and to the beam, said magnetic field being of such nature and magnitude as substantially to neutralize the focusing effects of the electrostatic field.

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