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Ritz, Jr. [45] Mar. 12, 1974

[54] ELECTRON BEAM DEFLECTION SYSTEM

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[52] U.S. Cl. .... 315/17, 313/17 SP
[51] Int. Cl. H01j 29/70
[58] Field of Search .... 315/14–18; 313/83 SP, 79, 80

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3,319,110 5/1967 Schlesinger 315/17
3,524,095 8/1970 Himmelbauer et al. .... 313/89 SP

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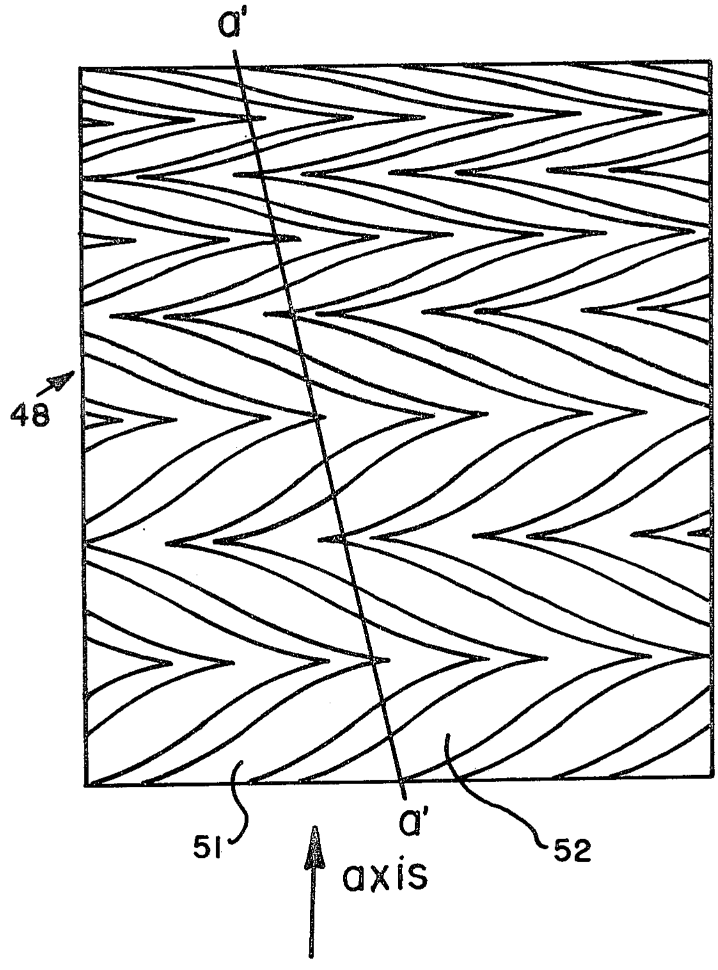
[57] ABSTRACT

A focus projection and scanning electron beam deflection system that eliminates shading error while maintaining high resolution, good deflection sensitivity and low solenoid power consumption.

19 Claims, 17 Drawing Figures



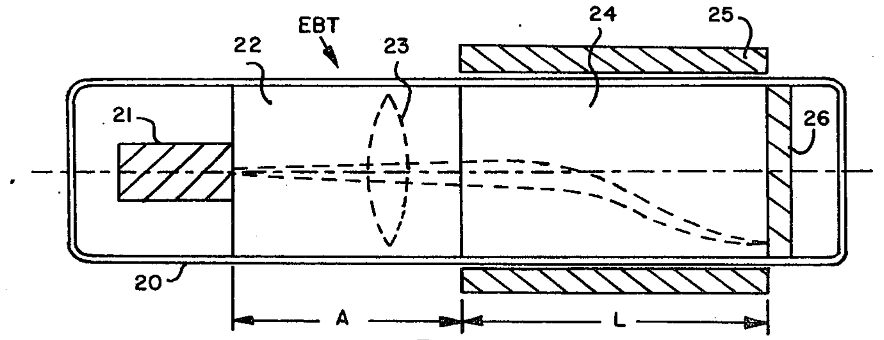


Fig-1

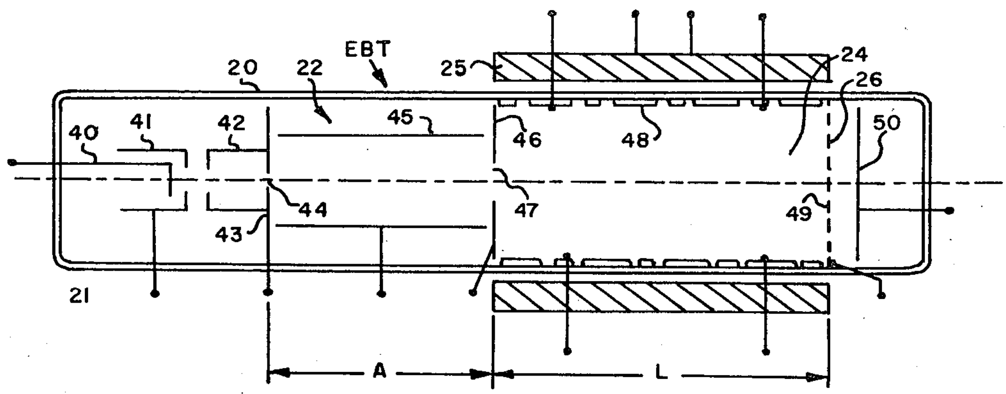


Fig-2

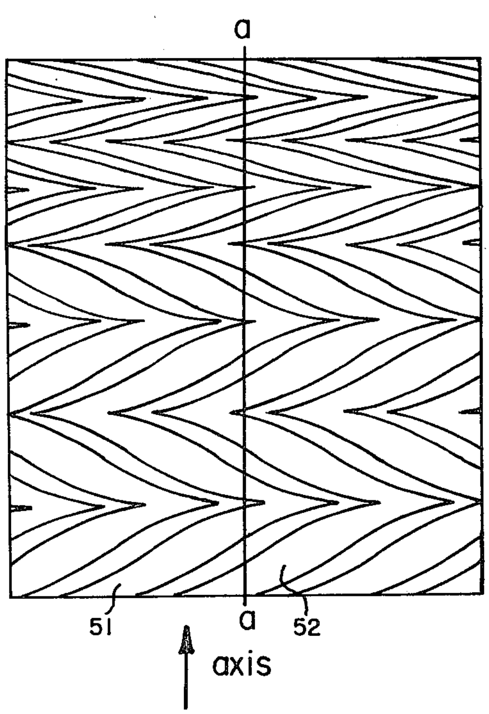


Fig-3

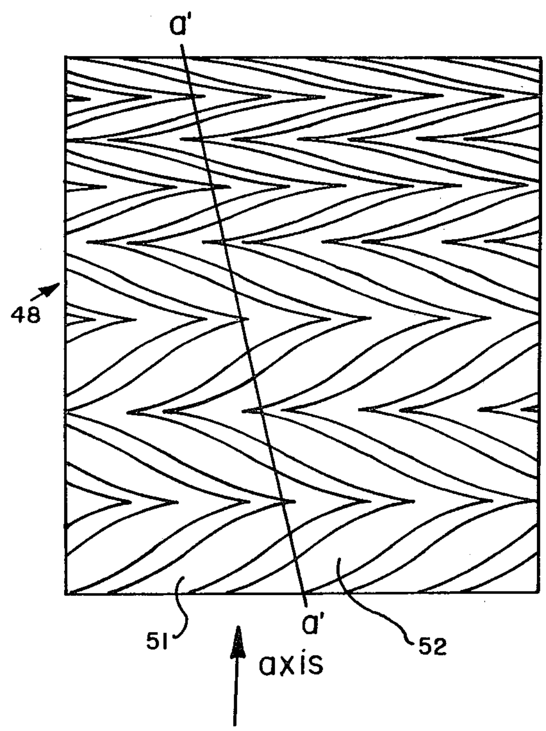
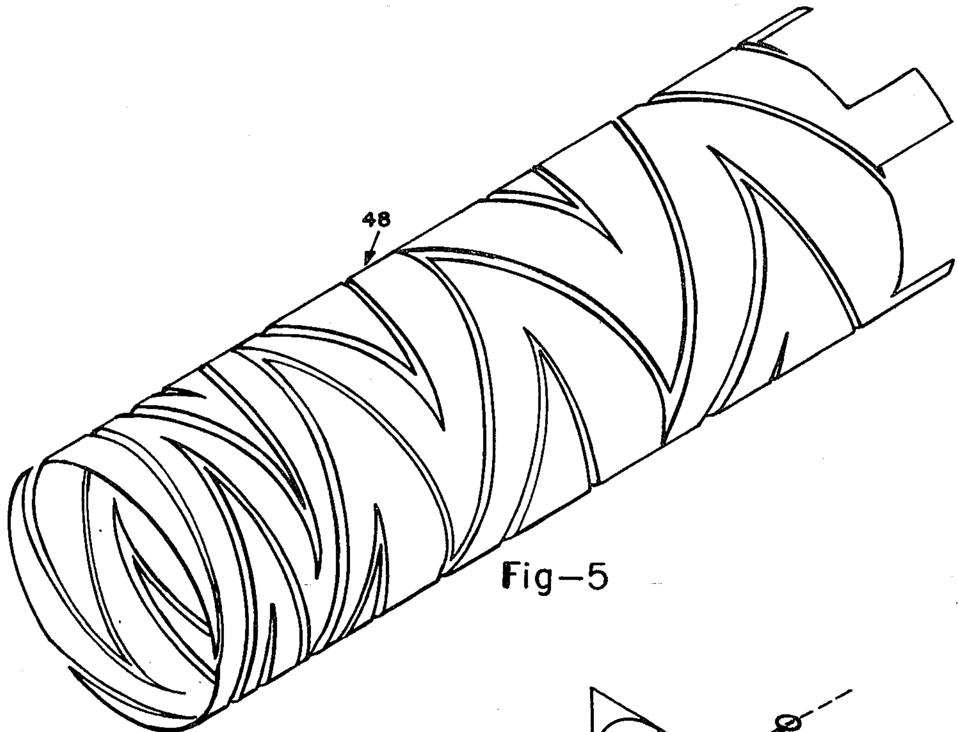


Fig-4



Fig—5

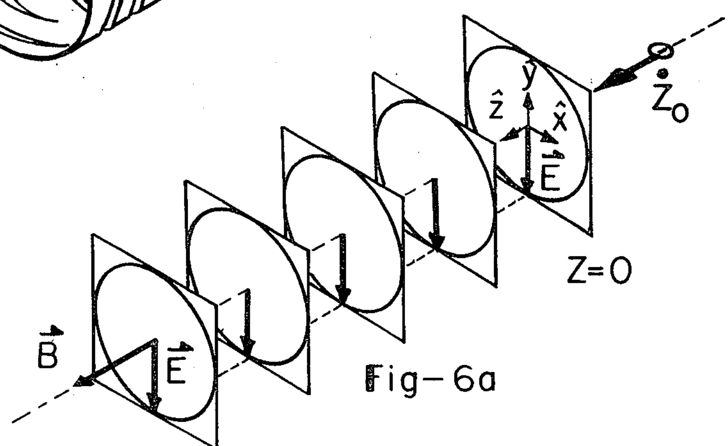


Fig-6a

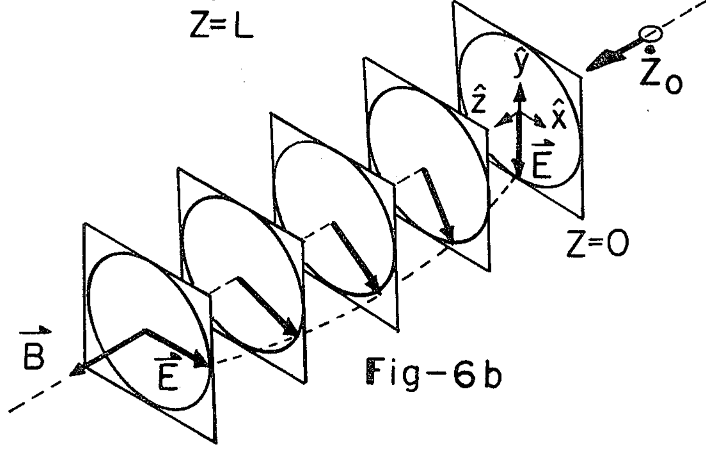


Fig-6b

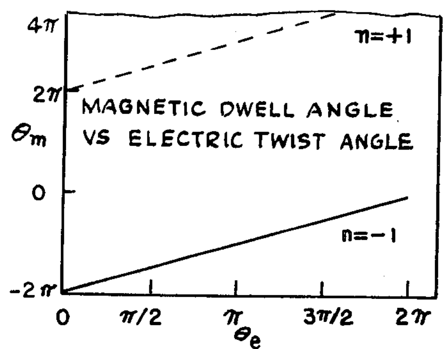


Fig-7

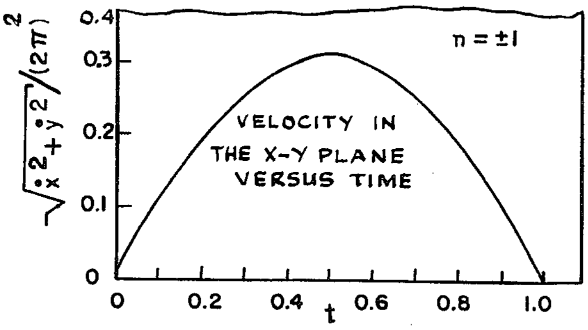


Fig-8

ELECTRON TRAJECTORIES IN THE X-Y PLANE FOR n = -1

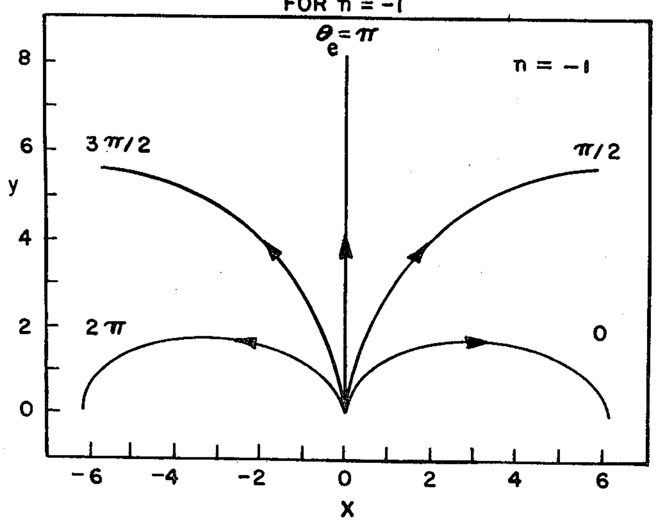


Fig-9

SHADING FACTOR VERSUS MAGNETIC DWELL ANGLE

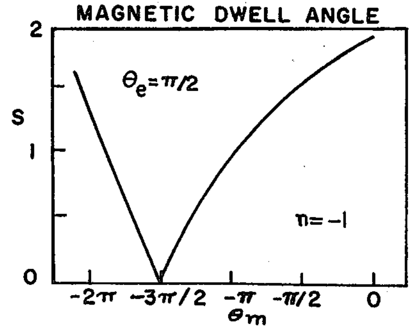


Fig-15

ELECTRON TRAJECTORIES IN THE X-Y PLANE FOR n=+1

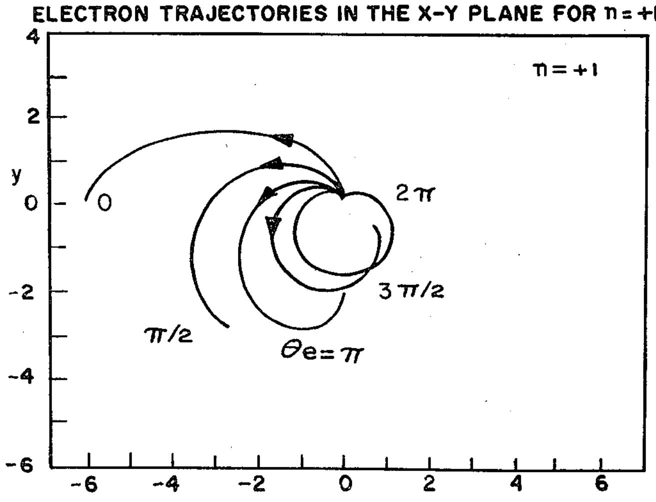


Fig-10

SHADING FACTOR VERSUS DEFLECTION TAPER RATIO

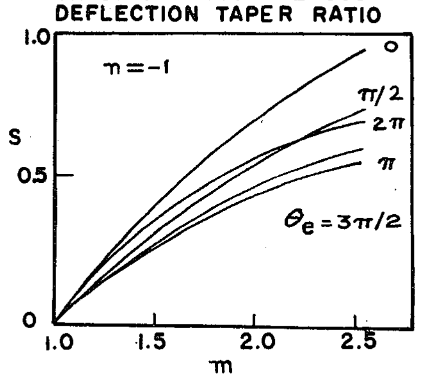


Fig-16

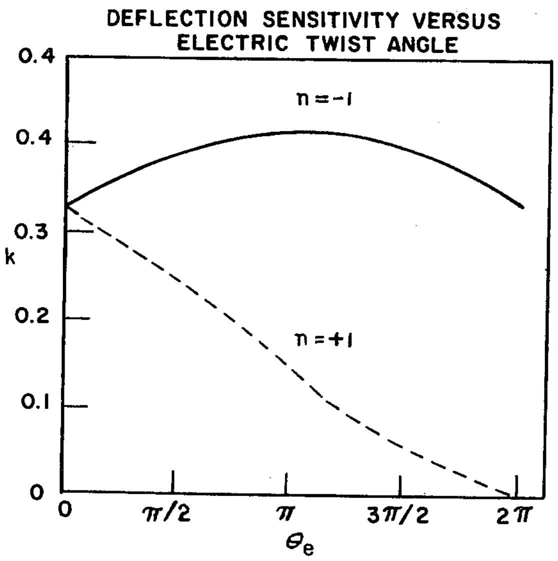


Fig-11

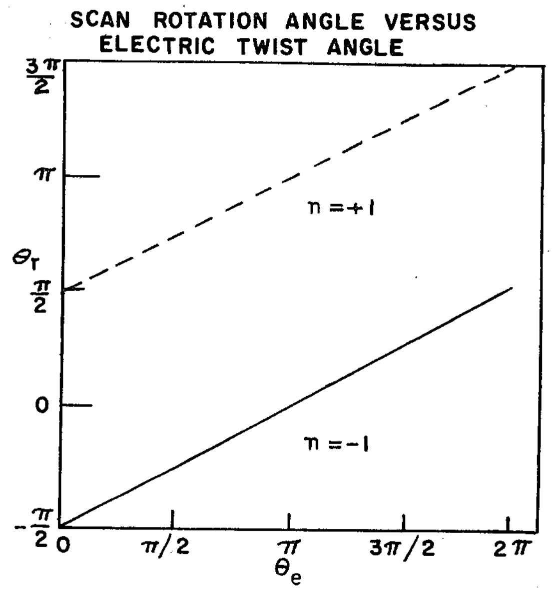


Fig-12

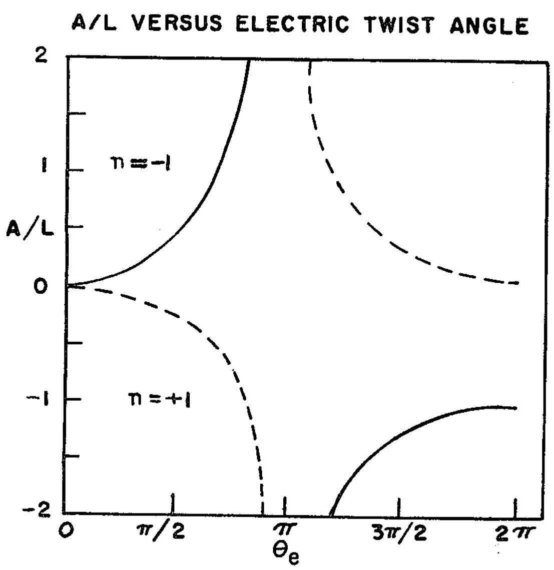


Fig-13

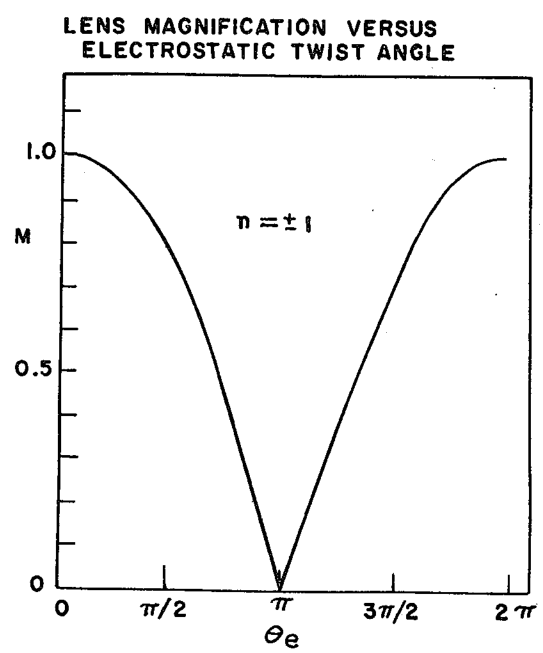


Fig-14

ELECTRON BEAM DEFLECTION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to systems for deflection and focusing of electron beams, and more specifically to improvements of the focus projection and scanning system, referred to herein as the FPS system.

Electron beam deflection systems for applications such as, for example, vidicons and scan converters, require small shading error, high resolution, low power consumption and samll size. One such system is the FPS system as disclosed in U. S. Pat. No. 3,319,110 to Schlesinger. A typical FPS system comprises an electron beam source, an electrostatic yoke, hereafter referred to as a deflectron, a solenoid coaxial and coextensive with the deflectron, a target and, for some applications, an auxiliary prefocus lens.

The FPS system, as now practiced, can provide good resolution, acceptable deflection sensitivity, low solenoid power and small shading error. Shading error is the result of non-normal beam incidence at the target and causes undesirable variations from center to edge in the signal output from the target.

However, all of these desirable features cannot be obtained simultaneously in a single embodiment of the FPS system. For example, if shading error must be substantially eliminated, and it is not desirable to use additional collimating lenses between the deflectron and the target, then the FPS system is best operated in the shading-free mode of Schlesinger, in which case the magnetic dwell angle defined by him is 2π radians or 360°. In this mode, theory predicts that shading error vanishes. On the other hand, deflection sensitivity is poor, solenoid power is relatively large, and a strong electrostatic prefocus lens is required if spot demagnification is necessary to obtain adequate resolution. This prefocus lens may increase spot aberrations and will certainly put severe requirements on the electron source.

It is possible to reduce the magnetic field, thereby increasing deflection sensitivity and reducing solenoid power. The strong prefocus lens can be omitted because of the resulting automatic spot demagnification. However, shading error also increases.

The cylindrical deflectron required for the Schlesinger shading-free mode can be replaced with a conical deflectron. Deflection sensitivity is then increased at the cost of increased shading error.

The deflectron may also be altered in a manner referred to herein as twisting. In commercially available devices, the deflectron electrode pattern is twisted through an angle of 90° in a fashion described more fully below. As presently practiced, this modification increases deflection sensitivity but worsens shading error.

For some applications of the FPS system, it is essential to eliminate shading error as nearly as possible without sacrificing other performance features. Consequently, it is an object of the present invention to provide an improvement of the FPS system of electron beam deflection and focusing.

It is another object of the present invention to provide an improved FPS system of electron beam deflection and focusing having substantially zero shading error, good deflection sensitivity, high resolution and reduced solenoid power. All of these features are obtained in a single embodiment of the invention.

It is a further object of the present invention to provide an improved FPS electron beam deflection system in which the plane of deflection of the electron beam is automatically prevented from rotating away from the initial direction of the electric field without using a multiple-section solenoid.

It is still another object of the present invention to provide an improved electron beam deflection system having substantially zero shading error without the use of a magnetic field and having deflection sensitivity which is equal to that of existing tubes provided with a shading-free mode of operation.

Further objects, features and advantages will be apparent from consideration of the following description, taken in conjunction with the accompanying drawings.

DRAWINGS

FIG. 1 is a simplified schematic view of an electron beam tube illustrating a preferred embodiment of the invention in longitudinal section,

FIG. 2 is a longitudinal cross-sectional view of FIG. 1 illustrating the essential parts in greater detail,

FIG. 3 illustrates a conventional deflectron pattern developed onto a plane,

FIG. 4 illustrates the deflectron pattern of FIG. 3 modified and developed onto a plane,

FIG. 5 is a perspective view of the modified pattern of FIG. 4 disposed on an inner surface of a cylindrical member,

FIG. 6*a* shows the coordinate system used to analyze the operation of the invention and the spatial relationships of the electric and magnetic fields in a conventional deflectron,

FIG. 6*b* shows the spatial relationships of the electric and magnetic fields in a modified deflectron, and

FIGS. 7 – 16 are graphs illustrating the characteristics of the invention.

DETAILED DESCRIPTION

The theory of operation of the invention will be discussed with reference to the schematic longitudinal section of electron beam tube EBT shown in FIG. 1, which comprises a cylindrical envelope **20** within which a vacuum is maintained; an electron source **21** which generates a longitudinally directed electron beam of narrow divergence angle; a drift space **22** next to electron source **21** of length A which may be substantially free of electric and magnetic fields, or which alternatively may contain an electrostatic prefocus lens **23**; an FPS cavity **24** of length L separated from electron source **21** by the distance A which contains electric field means for generating an electric field within the FPS cavity **24** of substantially constant magnitude but of a spatially variable orientation to be more fully discussed below; a solenoid **25** coaxial and substantially coextensive longitudinally with FPS cavity **24** and generating a substantially uniform magnetic field oriented along the longitudinal axis of the envelope **20** within the FPS cavity **24**; and target means **26**, the nature of which will vary according to the desired application and which may be placed either as close as practical to the end of the FPS cavity **24** remote from electron source **21**, or spaced from this end by some optimal distance.

FIG. 2 is a longitudinal sectional view of electron beam tube EBT of FIG. 1 illustrating the essential components thereof. In FIG. 2, the electron source 21 comprises a thermionic cathode 40, a grid 41 for controlling electron flow, an anode cup 42 for accelerating electrons, and a beam-limiting electrode 43 having a small beam-limiting aperture 44 substantially centered on the longitudinal axis of the electron beam tube for limiting the radial extent of the electron beam. The drift space 22 comprises a cylindrical barrel 45, which is bounded by beam-limiting electrode 43 and by deflection shield 46 comprising a plate held perpendicular to the longitudinal axis and having a circular aperture 47 centered on the longitudinal axis. The FPS cavity 24 comprises a cylindrical electrostatic deflection yoke or deflectron 48 for generating an electric field with properties to be more clearly specified below; deflectron 48 is to be of the type referred to herein as twisted and includes interleaved horizontal and vertical deflection electrodes. Deflectron 48 may conveniently be deposited on the inside surface of the envelope 20 in accordance with conventional photographic techniques. However, it can be formulated in any suitable manner. Solenoid 25 is positioned with the end of solenoid 25 nearest to electron source 21 and the end of deflectron 48 nearest to electron source 21 being substantially at the same location longitudinally. Target means 26 comprises a fine mesh electrode 49 spaced by a small distance from the target 50 which may be a light sensitive target, silicon oxide storage target or other suitable target structure to provide the intended operation. Mesh electrode 49 is preferably placed as close to deflectron 48 as possible.

In operation, electrons emitted by cathode 40 are accelerated and formed into a narrow, longitudinally directed beam by the action of grid 41, anode cup 42 and beam-limiting aperture 44, pass through barrel 45 and deflection shield 46 into FPS cavity 24, wherein the electron beam is deflected and focused by the action of the solenoid 25 and deflectron 48 through mesh 49 onto target 50, whereat a signal may be read out electrically in accordance with conventional readout techniques. The anode cup 42, beam-limiting aperture plate 43, deflection shield 46 and mesh 49 are operated at substantially the same voltage V_a. Scanning voltage waveforms are applied to the x and y electrodes of the deflectron 48 in accordance with conventional practice. The average voltage of the scanning waveforms should be substantially the same as V_a. If the voltage applied to the barrel 45 is V_a, then barrel 45 will act as a field-free drift space; otherwise, barrel 45 will act as a prefocus lens. A suitable current is passed through solenoid 25. The potential applied to the target 50 depends on the nature of the target, but it will typically be about 10 volts. V_1 may likewise vary, but typically it will be about 300 volts.

The twisted deflectron 48 is produced by altering the electrode pattern of a conventional deflectron in the following way. FIG. 3 illustrates a conventional deflectron pattern developed onto a plane. The arrow indicates the direction of the deflectron axis. The line $a—a$ passing through the tips of the zig-zag interleaved elements 51, 52 defining the x and y plates provides a reference line parallel to the deflectron axis. FIG. 4 shows the same pattern after twisting. The line $a—a$ has become the line $a'—a'$, which is still straight, but which is inclined relative to the axis of the deflectron 48. The change is caused by the displacement of each point of the pattern cirucmferentially in a direction perpendicular to the deflectron axis through a distance which is directly proportional to the distance of that point longitudinally from the end of the deflectron nearest the electron source. When the pattern of FIG. 4 is rolled into a cylinder as shown in FIG. 5, the line $a'—a'$ describes a helix on the surface of the cylinder, and points at the end of the deflectron 48 near the target will have been rotated away from corresponding points at the opposite end through an angle θ_e, which is defined as the electric twist angle. Intermediate points will be rotated through an angle equal to $(Z/L)\theta_e$, where Z is the longitudinal distance of the point from the end of the deflectron nearest to the electron source. A similar result would ensue if both ends of a conventional deflectron of FIG. 3, which is rolled into a cylinder, were grasped and twisted in opposing directions.

Twisted deflectrons now known have a twist given by $\theta_e = \pi/2$ radians or 90°. However, other angles are possible.

It will now be shown that if the magnetic field is adjusted to the correct value as determined by the amount of twist, a previously unsuspected new mode of operation will result. To accomplish this, the equations of motion of the electrons in the crossed electric and magnetic fields within the FPS cavity 24 of FIGS. 1 and 2 will be derived and solved. Then it will be required that shading error be zero, and from this requirement, a restriction on admissible values of magnetic field strength will be derived.

First it is necessary to establish a system of coordinates. With reference to FIGS. 6a and 6b, the origin of the coordinates is taken on the axis at the point where the electron beam enters the deflectron. The tube envelope axis coincides with the Z axis, with the unit vector $\hat{z}$ directed toward the target. Taken together, the unit vectors $\hat{x}$, $\hat{y}$ and $\hat{z}$ form the basis of a right-handed, orthogonal coordinate system.

The electric field of a conventional cylindrical deflectron has $E_z = 0$, since the electric vector $\vec{E}$ is perpendicular to the Z axis. The strength of $\vec{E}$ and its orientation in the $x—y$ plane are controlled by the application of appropriate voltages to the deflectron in a known manner. Without loss of generality, take $E_x = 0$ and $E_y = -E_o$, where E_o is the length of the electric vector $\vec{E}$. Thus, $\vec{E}$ lies along the negative y axis and produces an electric force $-e\vec{E}$ in the positive Y direction. Since the deflectron is not twisted, the electric field is everywhere of the same magnitude and direction. FIG. 6a illustrates the nature of the electric vector in a conventional deflectron. The deflectron volume is sectioned by planes at longitudinal intervals of $\Delta Z = L/4$, and the $x—y$ orientation of $\vec{E}$ is shown in each plane.

The electric field of a twisted deflectron can be shown to be substantially perpendicular to the $\vec{Z}$ axis. However, the orientation of the electric vector $\vec{E}$ does not remain fixed from one end of the deflectron to the other. Rather, it rotates through the electric twist angle θ_e at a uniform rate with axial distance from the origin. The x and y components of electric field are given by

$$E_x = E_o \sin(\theta_e Z/L) \qquad (1)$$

$$E_y = -E_o \cos(\theta_e Z/L) \quad (2)$$

$$E_z \cong 0 \quad (3)$$

Equation (3) is not true exactly. However, if the condition $\theta_e R_o/L << 1$ is satisfied, where k is deflection sensitivity to be defined below, and R_o is the maximum deflection of the electron beam, then the disturbing effedts of E_z will be small. Here, it is assumed, without loss of generality, that the initial direction of the electric vector is along the negative y axis to agree with the conventional case of FIG. **6**a. The twisted case is illustrated in FIG. **6**b. In both FIGS. **6**a and **6**b, the magnetic field is directed along the z axis, so that $B_x = B_y = 0$, and $B_z = B_o$, may be either positive or negative.

The equations of motion can be written as

$$\ddot{X} = -\omega \dot{Y} - a \sin(\theta_e Z/L) \quad (4)$$

$$\ddot{Y} = +\omega \dot{X} + a \cos(\theta_e Z/L) \quad (5)$$

$$\ddot{Z} = 0, \quad (6)$$

with the cyclotron frequency being $\omega = \eta B_o$ and the electric acceleration $a = \eta E_o$. The ratio of charge to mass for the electron is η. Equation (6) is assumed to be exactly true and states that the z component of velocity $\dot{Z}$ does not change, and is equal to its initial value $\dot{Z}_o = \sqrt{2\eta V_a}$, as shown in FIGS. **6**a and **6**b. Also, it is to be assumed that the electron enters the deflectron with no x or y velocity, so that $\dot{X}_o = \dot{Y}_o = 0$. Since $\dot{Z} = \dot{Z}_o$, the axial position is

$$Z = \dot{Z}_o T, \quad (7)$$

where T is the time elapsed since the electron entered the deflectron at $Z = 0$.

It is convenient to measure time in units of the transit time T_L for traversal of the deflectron defined by $T_L = L/\dot{Z}_o$, and distance in units of $R = aT_L^2/(2\pi)^2$. This results in the dimensionless normalized variables $x = X/R$, $y = Y/R$, $z = Z/R$ and $t = T/T_L$. Also, following the teaching of Schlesinger, the magnetic dwell angle θ_m is defined as $\theta_m = \omega T_L$.

With these definitions, equations (4) and (5) become

$$\ddot{x} = -\theta_m \dot{y} - (2\pi)^2 \sin(\theta_e t) \quad (4a)$$

$$\ddot{y} = +\theta_m \dot{x} + (2\pi)^2 \cos(\theta_e t) \quad (5a)$$

The solutions of (4a) and (5a) for x, y, $\dot{x}$ and $\dot{y}$ as functions of t can be written as

$$x(t) = (2\pi)^2 [\sin \theta_m t/\theta_m(\theta_m - \theta_e) - \sin \theta_e t/\theta_e(\theta_m - \theta_e)] \quad (8)$$

$$y(t) = (2\pi)^2 [\cos \theta_e t/\theta_e(\theta_m - \theta_e) - \cos \theta_m t/\theta_m(\theta_m - \theta_e) - 1/\theta_m\theta_e] \quad (9)$$

$$\dot{x}(t) = (2\pi)^2 [\cos \theta_m t/(\theta_m - \theta_e) - \cos \theta_e t/(\theta_m - \theta_e)] \quad (10)$$

$$\dot{y}(t) = (2\pi)^2 [\sin \theta_m t/(\theta_m - \theta_e) - \sin \theta_e t/(\theta_m - \theta_e)] \quad (11)$$

It is now required that the shading error be zero. Therefore, at the exit to the deflectron where $t = 1$, the x and y velocity components must vanish so that the electron will strike the target at right angles thereto. When this condition is applied to equations (10) and (11) with $t = 1$, the following result is obtained:

$$\theta_m = \theta_e t\ 2\pi n, \quad (12)$$

where n is any positive or negative non-zero integer. Equation (12), which may be referred to as the zero-shading condition, states that the magnetic dwell angle must be limited to values differing only by integer multiples of 2π radians from the electric twist angle if zero-shading error is to be achieved. Since θ_m is proportional to the magnetic field, equation (12) implies that only certain magnetic field values are permitted. It can be shown that as θ_e exceeds 2π or $|n|$ becomes large, the deflection sensitivity becomes small. Therefore, further discussion will be limited to the cases where $0 \leq \theta_e \leq 2\pi$ and $n = \pm 1$, since the other modes are generally impractical, or at least offer no advantages. Also, the various zero-shading modes will be labeled herein by the valves of θ_e and n which apply, since equation (12) fully defines θ_m, given θ_e and n. For example, the mode $[\pi/2, -1]$has an electric twist of $\pi/2$ radians and a magnetic dwell of $-3\pi/2$ radians. The negative sign indicates that the magnetic field is oriented along the negative z axis. The value of θ_e is always positive so that it has the conventional counter clockwise polarity. The mode $[\pi/2, +1]$ has the same electric twist angle of $\pi/2$ but has the magnetic dwell angle $+5\pi/2$ thereby indicating that the corresponding magnetic field is of positive z polarity. This illustrates a general result: for each value of θ_e, with $|n| = 1$, there are two values of θ_m which give zero shading, and, hence, two values of magnetic field. FIG. **7** illustrates the variation of θ_m with θ_e for $n = \pm 1$.

If normalized speed V in the x–y plane is defined by

$$V = \sqrt{\dot{x}^2 + \dot{y}^2}/(2\pi)^2,$$

where $(2\pi)^2$ is the velocity at $t = 1$ for a deflectron with $\theta_e = \theta_m = 0$, equations (**10**) and (**11**) lead to the result

$$V = |1/\pi n \sin \pi n t|, \quad (13)$$

which is plotted in FIG. **8** for $|n| = 1$. This illustrates the way in which the speed in the x–y plane falls to zero at $t = 1$, thus ensuring normal landing at the target. FIG. **8** applies to all values of θ_e for $n = \pm 1$.

The projections of the electron trajectories onto the x-y plane are shown in FIGS. 9 and 10 for $\theta_e = 0, \pi/2, \pi, 3\pi/2, 2\pi$. FIG. 9 shows trajectories for $n = -1$, while FIG. 10 illustrates trajectories for $n = +1$.

To compare the deflectron sensitivities obtainable in the various modes of the invention, the deflection sensitivity k is defined as the ratio of deflection for the mode in question to the deflection for an untwisted deflectron of the same diameter and length which is operated without a magnetic field. It can be shown from equations (8) and (9), subject to equation (12), that k can be expressed in the form

$$k(\theta_e,n) = |(4 \sin (\theta_e/2)/\theta_e(\theta_e + 2\pi n)| \tag{14}$$

That is, the values of θ_e and n are sufficient to determine k. Equation (14) is plotted in FIG. 11 for $n = \pm 1$. It is clear from FIG. 11 that, in general, the highest values of k are obtained for $n = -1$. The highest possible value of k occurs at $\theta_e = \pi$, where $k = 4/\pi^2$.

The Schlesinger shading-free mode appears here as the two special cases for $\theta_e = 0$: [0, +1] and [0, −1]. The deflection sensitivity of both modes is $1/\pi$. Thus, all modes of the invention for $n = -1$ give deflection sensitivity greater than or equal to that of the Schlesinger shading-free mode, which is actually two modes in this analysis.

If the scan rotation angle θ_r is defined as the angle between the positive y axis and the final deflected direction in the x–y plane, with θ_r counted positive in the counterclockwise direction, then $\tan \theta_r = -x/y$. Again, using equations (8) and (9) subject to (12), the result for $|n| = 1$ is:

$$\theta_r = (\theta_e/2) + (\pi/2),\ n = +1 \tag{15a}$$

$$\theta_r = (\theta_e/2) - (\pi/2),\ n = -1 \tag{15b}$$

Equations (15a) and (15b) are plotted in FIG. 12. For $\theta_e = \pi$ and $n = -1$, $\theta_r = 0$, indicating that no scan rotation occurs. This can also be seen from FIG. 9.

FIGS. 7 through 12 and their corresponding equations describe the operation of the electron beam deflection means of the invention. In considering the electron beam focusing means of the invention, it will become evident that the two are closely interrelated.

It is well known to those skilled in the art that, in reference to FIG. 1, the drift space 22 of length A and the FPS cavity 24 of length L containing a substantially uniform magnetic field oriented axially, taken in combination, form an electron lens. As remarked above, an additional separation may be interposed between the deflectron and the target means. This is within the scope of the invention. However, the resolution will be reduced thereby, since the obtainable demagnification of the electron lens will be reduced.

Referring again to FIG. 2, a practical embodiment of the lens comprises the anode cup 42 with the beam-limiting aperture 44, the barrel 45, the deflection shield 46 and the solenoid 25. The solenoid is assumed to have a length substantially the same as the deflectron length L. It is to be assumed that the barrel is operated at anode potential so that the space 22 is a field-free drift space.

Well-known theory predicts that this lens will form an image of aperture 44 at the target 50 if the magnetic dwell angle θ_m, the distance A and the length L are related according to

$$(A/L) = -\tan(\theta_m/2)/(\theta_m/2). \tag{16}$$

When the restriction of θ_m by equation (12) is applied the result is

$$A(\theta_e, n)/L = -\tan(\theta_e/2)/(\theta_e/2 + \pi n). \tag{17}$$

Therefore, once the values of θ_e and n are given, the permissible value of A/L is strictly defined. FIG. 13 is a graph of equation (17) for $n = \pm 1$.

The magnification of the lens is known to be

$$M = |\cos(\theta_m/2)|. \tag{18}$$

Application of equation (12) leads to

$$M = |\cos(\theta_e/2)|. \tag{19}$$

Equation (19) is plotted in FIG. 14. This result is independent of the value of n. The calculated value of M falls to zero at $\theta_e = \pi$. In practice, $M = 0$ is not attainable, since space-charge effects and lens aberrations not considered here will limit the minimum beam size at the target, as will the influence of the required auxiliary lens. However, substantial demagnification can be achieved, because the condition $M \leq 1$ is true everywhere.

Since the distance A can become infinite or negative, as is evident from FIG. 13 and equation (17), it is sometimes necessary to make use of the auxiliary electrostatic lens 23 of FIG. 1. In the practical embodiment of FIG. 2, the lens barrel 45 would be operated at a voltage other than anode voltage V_a.

A negative value of A/L indicates that the apparent source of electrons must lie on the target side of the entrance end of the delfectron, rather than on the electron beam source side. An infinite value of A/L indicates that the electron beam must be collimated when the beam enters the solenoid. These requirements can be satisfied by operating the prefocus lens so as to produce a virtual source of electrons at the correct distance. The resulting magnification will depend in part on the focal length and position of the prefocus lens.

In general, it will be preferable to limit θ_e to the range $0 < \theta_e < 3\pi/4$, in order to avoid excessive twist and the complications of a strong electrostatic lens. In this range, A/L is less than about 1.23 if $n = -1$. This will limit the maximum overall length from beam aperture to target to about twice the deflectron length L, without using a strong auxiliary prefocus lens. However, the lens barrel potential should be variable to provide fine adjustment of focus without changing the preset magnetic field.

For special applications, larger values of θ_e may be desirable. For example, as noted above, for the mode [π, −1] there is no rotation of the image. This result is obtained without the use of the multiple-winding solenoid required for the same purpose according to the teaching of U. S. Pat. No. 3,319,110 to Schlesinger. The deflection sensitivity of this mode is the highest possible for this invention.

Furthermore, for the mode [2π, −1], zero shading is obtained without the use of a magnetic field, because

$\theta_m = 0$ in this case. This mode is an electrostatic analog to the Schlesinger zero-shading mode, which is the special case $[0, \pm 1]$, or zero-twist mode. The modes $[2\pi, -1]$ and $[0, \pm 1]$ have the same deflection sensitivity. The mode $[2\pi, -1]$ requires an electrostatic lens for focusing.

In any case, it is generally desirable to utilize the modes with $n = -1$ rather than $n = +1$, since the former have higher deflection sensitivity than the latter.

It is essential to practice the invention with the correct value of magnetic field as specified by equation (12) if the highest performance is required. An incorrect magnetic field will introduce shading error. If β is the angle to the target normal for landing, then the shading factor s can be defined by

$$\tan \beta = s\ [R_b/L], \tag{20}$$

where R_b is the distance of the beam from the axis at the target measured in unnormalized units. It can be shown that

$$s = \sqrt{\dot{x}^2 + \dot{y}^2 / x^2 + y^2}, \tag{21}$$

where the right-hand side is evaluated at $t = 1$. The quantity s is connected with the landing angle, and hence is an indicator of shading error.

FIG. **15** shows s as a function of θ_m for the case $[\pi/2, -1]$. The correct value of θ_m is $-3\pi/2$, at which value s vanishes. However, s rapidly increases if θ_m departs from $-3\pi/2$. For example, it has been found in practice for the case $(\pi/2, -1)$ that a change of approximately 0.3 percent in the solenoid current, and hence in θ_m, produces a detectable increase in the amount of shading. From FIG. **15** or equation (21) it can be inferred that this corresponds to a change in shading factor s of more than 0.014. Thus, in practicing the invention, it is essential that the magnetic field be adjusted to the correct value if the best possible shading performance is to be achieved.

It can be shown that the use of a conical rather than a cylindrical deflectron increases the shading factor. The conical deflectron produces an electric field, the magnitude of which varies from one end of the deflectron to the other. FIG. **16** illustrates the relationship between the shading factor s and the taper ratio m, which is defined as the ratio between the large diameter and the small diameter of the conical deflectron. Thus, $m = 1$ corresponds to a cylinder. Curves are shown for various values of electric twist angle θ_e for $n = -1$. Again referring to the case $(\pi/2, -1)$, it can be inferred from FIG. **16** that an increase in m from $m = 1$ to approximately $m = 1.02$ will cause s to increase from 0 to 0.014, which is known to be a detectable degradation of shading performance. Therefore, it is essential in practicing the invention to provide electric field means capable of producing an electric field of substantially constant magnitude within the deflectron.

The curves of FIG. **16** were calculated by numerical integration of the equations of motion in the conical FPS system using a computer, because no exact solution is known for the conical cases.

Thus, by combining the FPS system with an extension of the 90° twisted deflectrons to an arbitrary angle of twist and operating the resulting modified FPS system at one of a number of strictly specified magnetic field values, a series of new shading-free modes of the FPS system is produced, in which higher deflection sensitivity, better resolution and lower solenoid power than in the previously known shading-free modes can be attained simultaneously.

The focus projection and scanning system of the invention may be used in many cathode ray devices and for a number of applications. For example, the FPS System of the invention may be employed in high beam intensity microspot tubes, monochrome or color television projection systems, vidicon or image orthicon tubes, X-ray tubes or high-power focused-beam tubes for electron machining, welding or contour drilling.

Many modifications of the invention will occur to those skilled in the art. For example, various arrangements of the electrostatic lens may be used; the length of the solenoid may be extended past the target to reduce the fringing fields of the solenoid; the deflectron may be made slightly conical to permit easier fabrication on mandrels; the value of θ_e may be taken to be negative, thus interchanging the positive and negative values of n; or the solenoid may be operated at a slightly incorrect current. All these changes, and many other which may appear, are within the scope and spirit of this invention.

The invention is claimed in accordance with the following:

1. An electron tube comprising:

a vacuum envelope having a longitudinal axis;

a cathode in said envelope for emitting an electron beam;

anode means in said envelope spaced from said cathode and having a beam-limiting aperture therein through which said electron beam passes;

target means in said envelope spaced from said anode means;

means along said envelope between said target means and said anode means for generating an electric field, said electric field being substantially perpendicular to said longitudinal axis and having an orientation displaced substantially uniformly with distance along said longitudinal axis for producing an electric force on said electron beam, said electric field at any given instant having a substantially uniform strength therealong; and

means along said envelope including said electric field for producing a magnetic field, the beginning of said magnetic field being spaced from a plane containing said beam-limiting aperture a specified distance, said magnetic field being of substantially uniform specified strength along said horizontal axis for creating a magnetic force acting in conjunction with said electric force thereby producing a resultant helical motion of said electron beam causing the electrons of said electron beam to impinge on said target means at a substantially normal direction thereto.

2. An electron tube according to claim **1** wherein said means for producing said magnetic field comprises a solenoid surrounding said means for generating said electric field.

3. An electron tube according to claim **1** wherein said means for generating said electric field comprise an electrostatic yoke coincident with said means for producing said magnetic field.

4. An electron tube according to claim **3** wherein said electrostatic yoke is twisted at a predetermined angle from one end to the other.

5. An electron tube according to claim 3 wherein deflector shield means is disposed adjacent an entrance to said coincident means for generating said electric field and for producing said magnetic field.

6. An electron tube according to claim 1 wherein the area between said anode means and said deflector shield means defines a drift space.

7. An electron tube according to claim 3 wherein electrostatic yoke is cylindrical.

8. An electron tube according to claim 5 wherein the area between said anode means and said deflector shield means includes prefocus lens means, said lens means being energized to focus a virtual image of said beam-limiting aperture at a specified distance from an entrance to said electric and magnetic fields.

9. An electron tube comprising:

a vacuum envelope having a longitudinal axis;

a cathode in said envelope for emitting an electron beam;

anode means in said envelope spaced from said cathode and having a beam-limiting aperture therein through which said electron beam passes;

deflector shield means spaced from said anode means and having an opening therein through which said electron beam passes;

target means in said envelope spaced from said deflector shield means;

means along said envelope between said target means and said deflector shield means for generating an electric field, said electric field being substantially perpendicular to said longitudinal axis and having an orientation displaced substantially uniformly with distance along said longitudinal axis for producing an electric-force on said electron beam, said electric field at any given instant having a substantially uniform strength therealong; and

means along said envelope including said electric field for producing a magnetic field, the beginning of said magnetic field being spaced from a plane containing said beam-limiting aperture a specified distance, said magnetic field being of substantially uniform specified strength along said horizontal axis for creating a magnetic force acting in conjunction with said electric force thereby producing a resultant helical motion of said electron beam causing the electrons of said electron beam to impinge on said target means at a substantially normal direction thereto.

10. An electron optical system for focusing and deflecting an electron beam comprising:

vacuum envelope means;

magnetic means for generating a substantially uniform magnetic field of specified magnitude within and along an axis of said envelope means;

electric field means for generating a variable electric field of substantially uniform magnitude within said envelope means thereby causing deflection of the electron beam along two coordinates of said system, said electric field being generated substantially orthogonal to said magnetic field;

electron beam generating means disposed in said envelope means;

means including beam-limiting aperture means disposed in said envelope means adjacent said electron beam generating means and disposed at a specified distance from an entrance to said electric and magnetic fields;

target means disposed in said envelope means adjacent an exit to said electric and magnetic fields; and

said electric field means causing said magnetic and electric fields to cross within said envelope means thereby forming a focus projection and scanning cavity for simultaneously projecting a focused beam of electrons onto said target means at a substantially normal direction thereto and scanning said focused beam of electrons across said target means.

11. An electron optical system according to claim 10 wherein said electric field means is twisted a specified amount from one end to the other.

12. An electron optical system according to claim 11 wherein said electric field is twisted from 0° to 360°.

13. An electron optical system according to claim 10 wherein said target means includes mesh means at an exit of said electric and magnetic fields.

14. An electron optical system according to claim 10 wherein deflector shield means having an opening therethrough is disposed at said entrance.

15. An electron optical system according to claim 10 wherein prefocus lens is disposed between said electron beam generating means and said entrance, said lens means being energized to form a virtual image of said beam-limiting aperture at a specified distance from said entrance of said cavity.

16. An electron optical system according to claim 10 wherein said magnetic means comprises solenoid means surrounding said cavity.

17. An electron optical system according to claim 10 wherein said electric field means comprises electrostatic yoke means surrounding said cavity.

18. An electron optical system according to claim 17 wherein said electrostatic yoke means is cylindrical.

19. An electron optical system according to claim 10 wherein the area between said beam-limiting aperture means and said entrance defines a drift space.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,796,910 Dated March 12, 1974

Inventor(s) EDWARD F. RITZ, JR.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 6, Equation (12), "$\theta_m = \theta_e t\ 2\ \ n$" should be --$\theta_m = \theta_e + 2\ \ n$--

Col. 6, Equation (13), "$V = \left| 1/\pi n \sin \pi n t \right|$" should be

--$V = \left| (1/\pi n) \sin \pi n t \right|$--

Col. 9, Equation (21), "$s = \sqrt{\dot{x}^2 + \dot{y}^2/x^2 + y^2}$" should be

--$s = \sqrt{(\dot{x}^2 + \dot{y}^2)/(x^2 + y^2)}$--

Signed and Sealed this

fifth **Day of** *August 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,796,910

DATED : March 12, 1974

INVENTOR(S) : EDWARD F. RITZ, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 10 and 11, delete "k is deflection sensitivity to be defined below, and"

Signed and Sealed this

twenty-third **Day of** *December 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks