United States Patent

Naruse et al.

[15] **3,686,525**

[45] **Aug. 22, 1972**

[54] **CATHODE RAY TUBE HAVING SHADOW MASK APERTURES ALIGNED ALONG CURVED HORIZONTAL AND VERTICAL LINES**

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[73] Assignee: **Sony Corporation,** Tokyo, Japan

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[30] **Foreign Application Priority Data**

May 31, 1969 Japan 44/42142

[52] **U.S. Cl.** ....**313/92 B,** 313/85 S

[51] **Int. Cl.**.......**H01j 29/30,** H01j 25/06, H01j 31/20

[58] **Field of Search**..................313/92 B, 85 S, 70 C

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[57] **ABSTRACT**

In a cathode ray tube having a curved phosphor screen, a shadow mask having bored therein apertures and electron beam generating means for generating three in-line electron beams aligned in a horizontal direction, the apertures of the shadow mask are aligned along barrel-shaped lines extending in a horizontal direction and are aligned along pin-cushioned lines extending in a vertical direction and the diameter distribution of the apertures is arranged so that the distribution of the electron beam transmission factor of the mask is concentric about the center of the mask.

4 Claims, 16 Drawing Figures

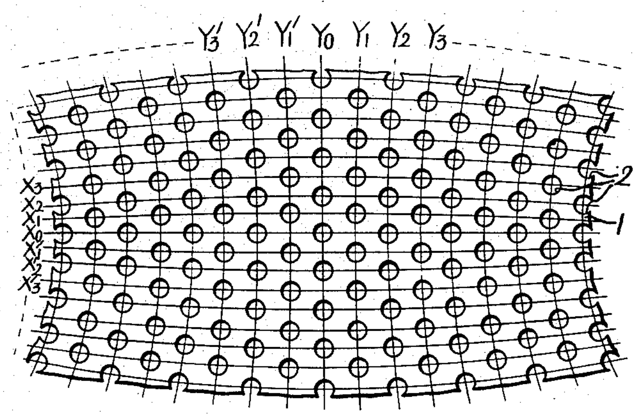

Fig. 1

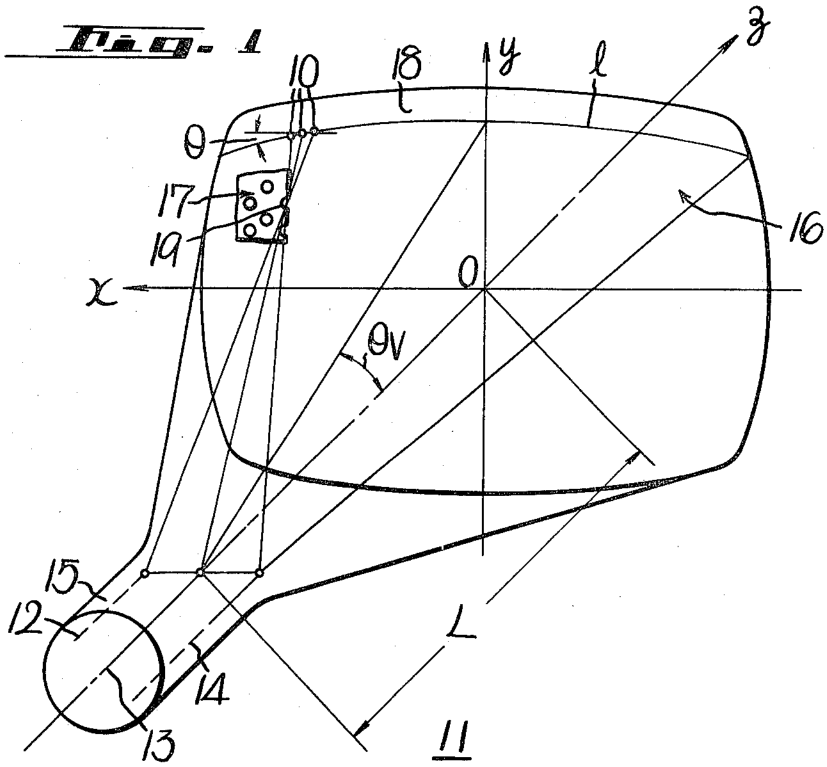

Fig. 2

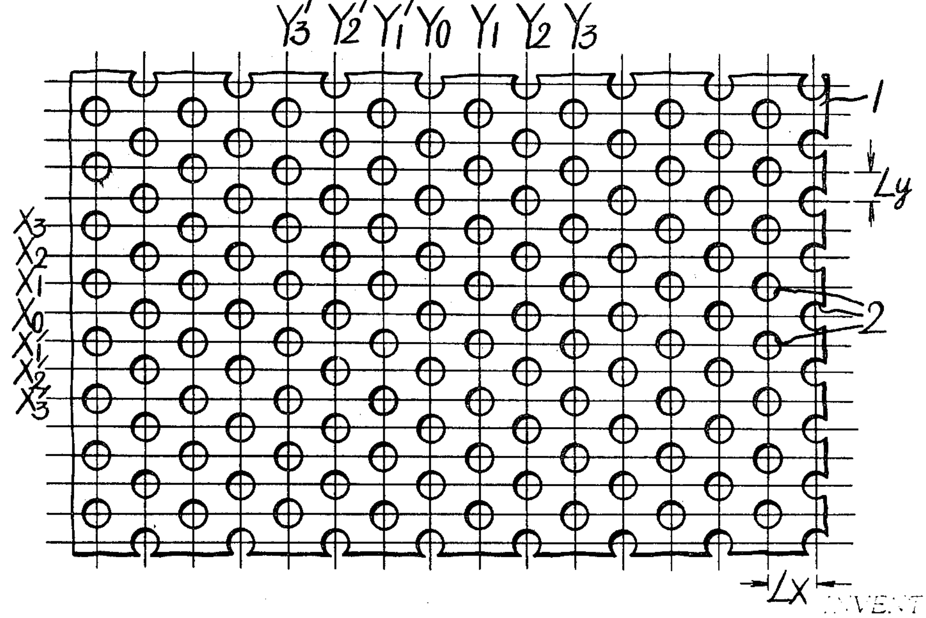

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Fig. 3A

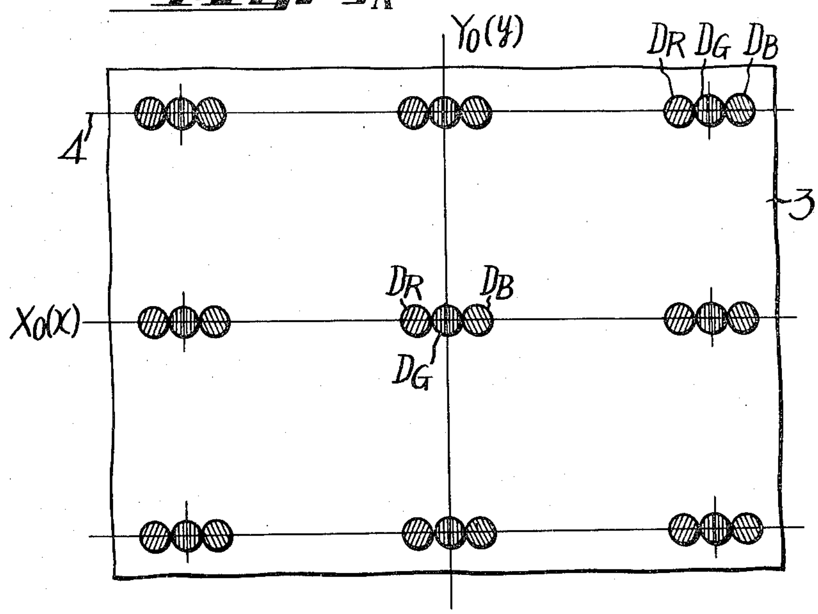

Fig. 3B

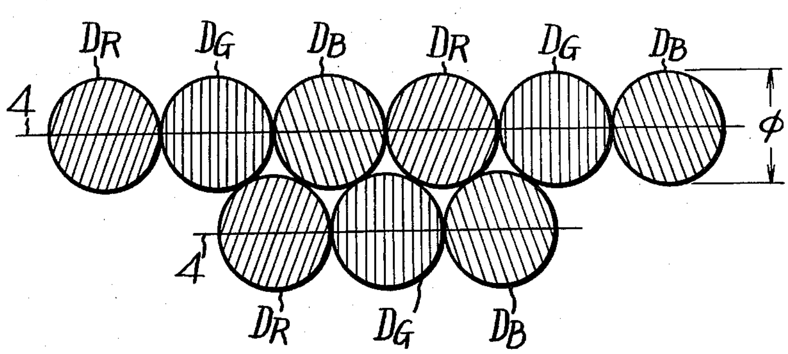

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Fig. 4

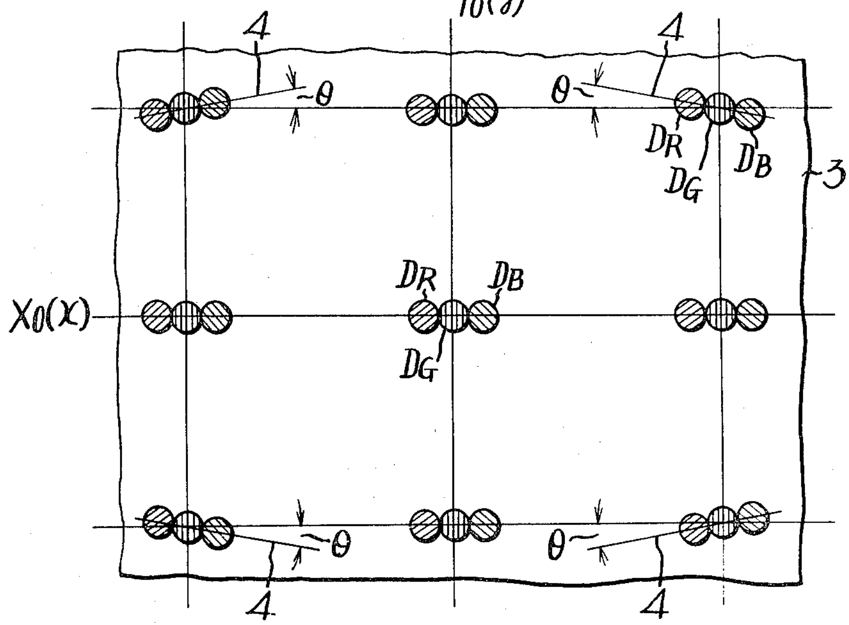

Fig. 7

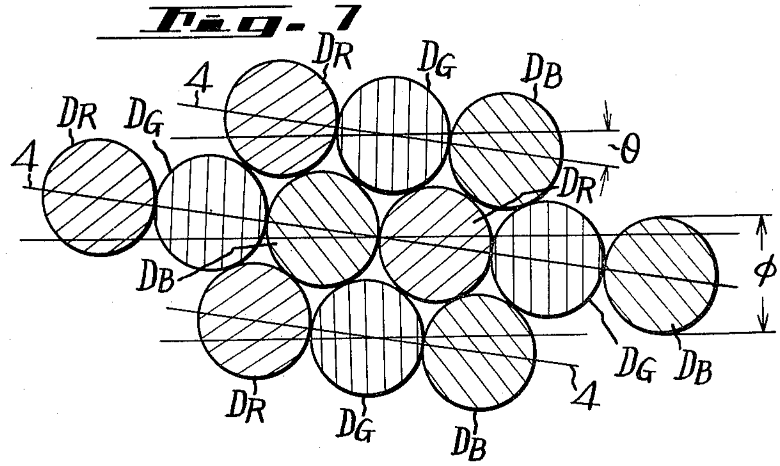

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Fig. 5A

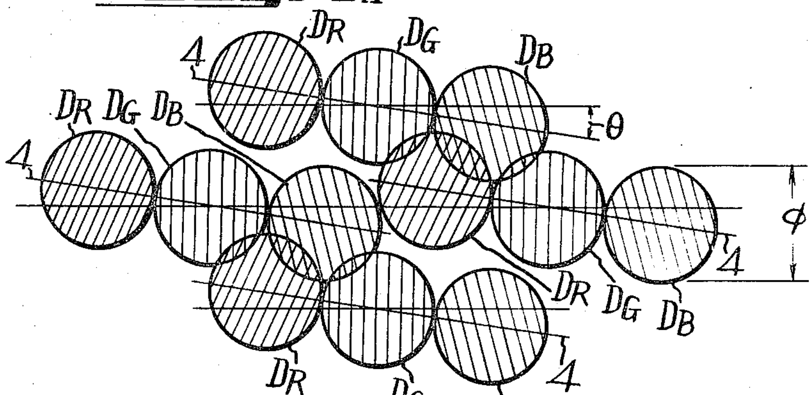


Fig. 5B

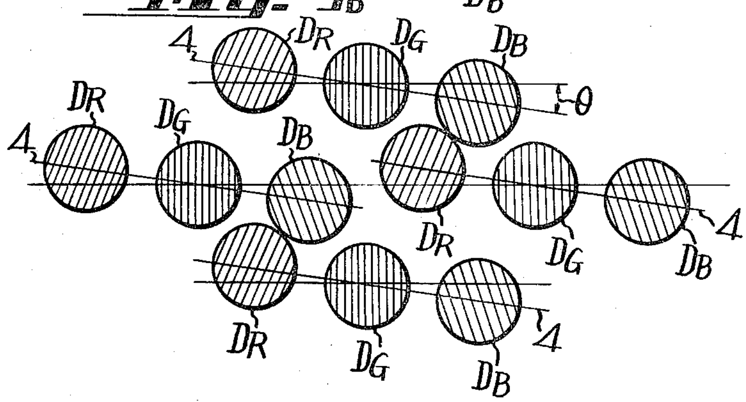
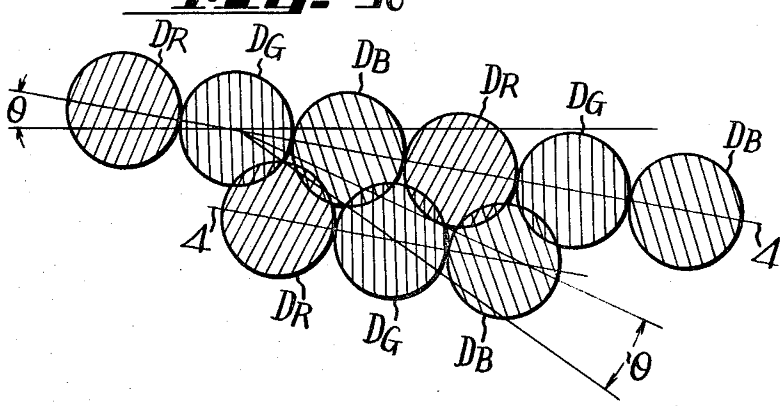


Fig. 5C



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Patented Aug. 22, 1972 3,686,525

7 Sheets-Sheet 5

Fig. 6

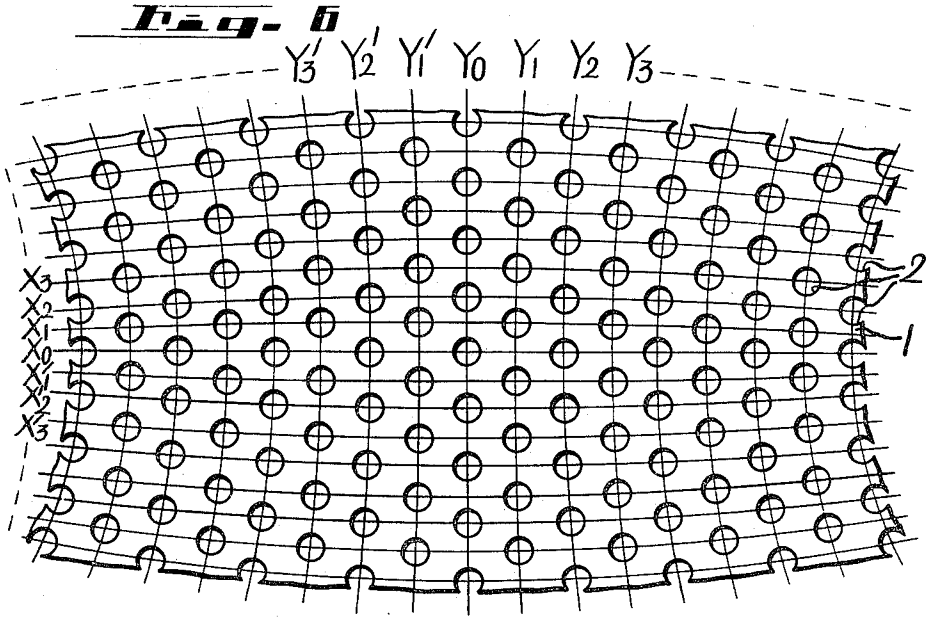
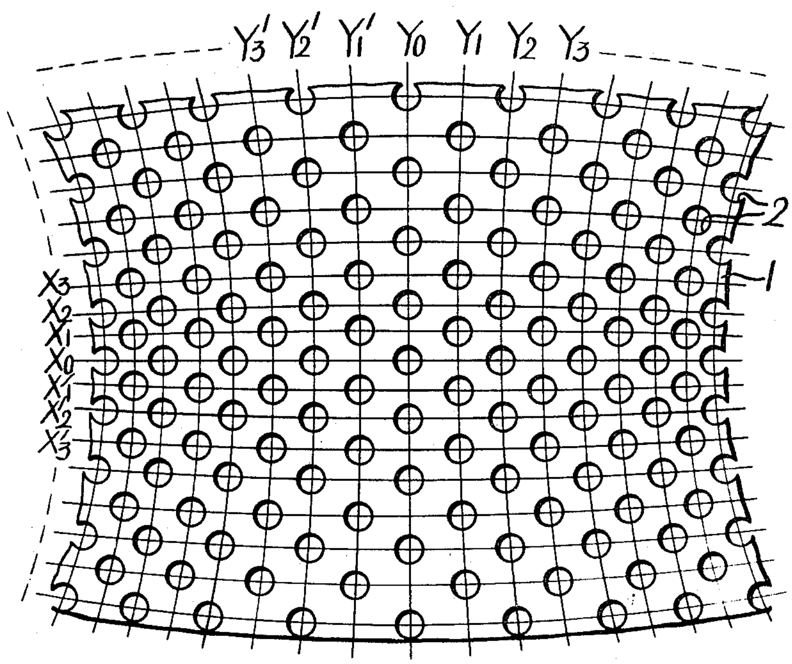


Fig. 8



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Patented Aug. 22, 1972

3,686,525

7 Sheets-Sheet 6

Fig. 9

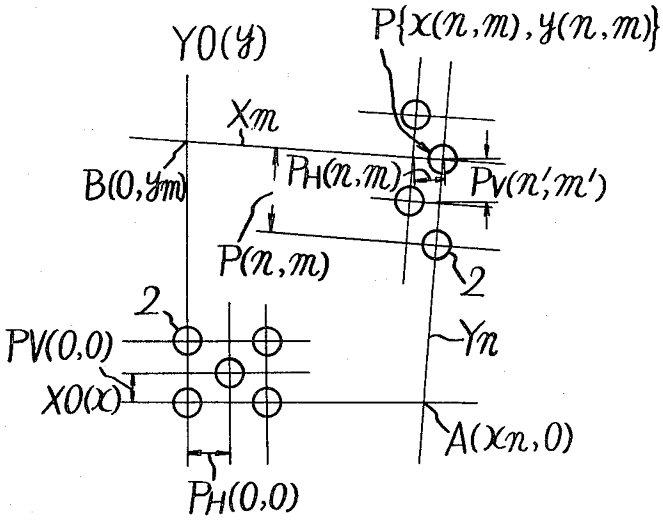
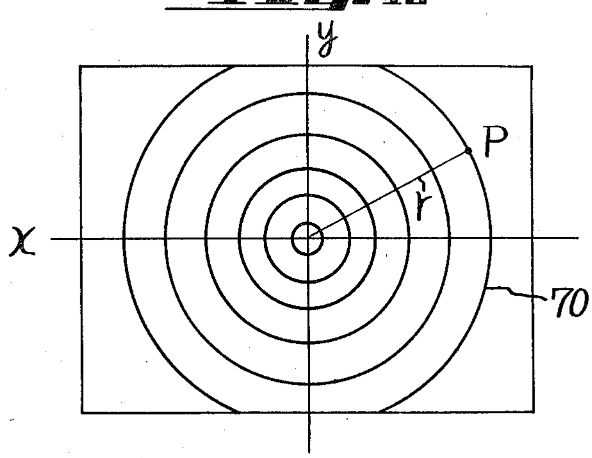


Fig. 10



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Patented Aug. 22, 1972 | 3,686,525

7 Sheets-Sheet 7

Fig. 11A

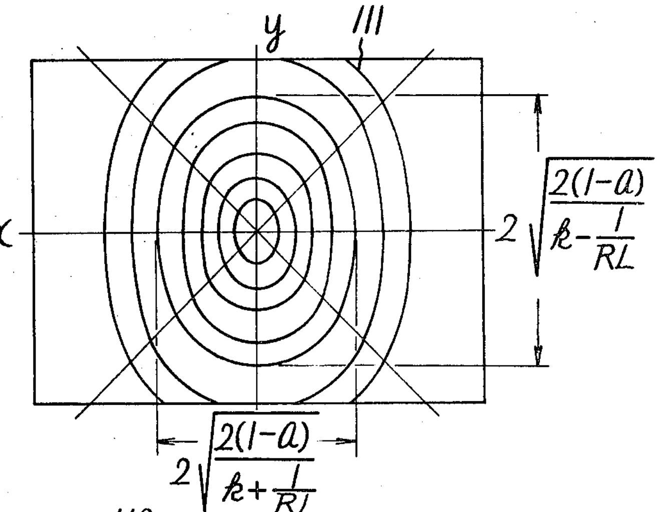


Fig. 11B

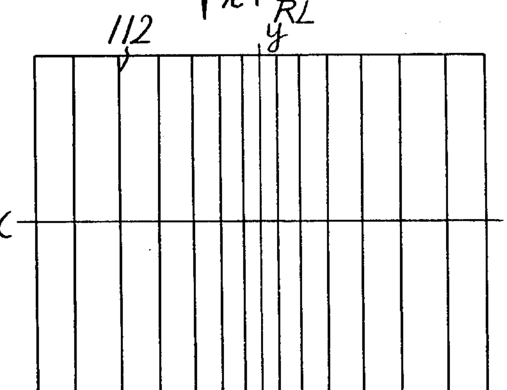
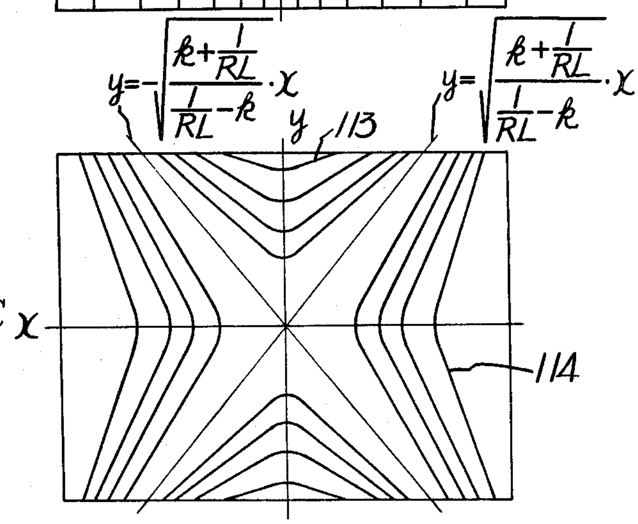


Fig. 11C



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CATHODE RAY TUBE HAVING SHADOW MASK APERTURES ALIGNED ALONG CURVED HORIZONTAL AND VERTICAL LINES

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an improved shadow mask, and more particularly to a color cathode ray tube in which an improved shadow mask is used to ensure that an electron beam strikes exactly on a color dot of the tube.

2. Description of the Prior Art

Conventional types of color cathode ray tubes comprise an electron gun for emitting an electron beam, a color screen and a shadow mask or aperture grill for beam selection, in which each of the apertures perforated in the mask or grill exactly corresponds to each of the color dots instead the beam precisely on to predetermined color dots for reproducing a color picture. However, the beam separation is not carried out accurately due to certain causes that introduce improper separation and or misconvergence. This is especially noticeable in the peripheral areas of the screen.

SUMMARY OF THE INVENTION

The present invention is directed to a shadow-mask type color cathode ray tube in which a plurality of electron beams are deflected horizontally and vertically while being kept aligned in a common plane and are caused to scan an outwardly projecting screen having a spherical or cylindrical curvature or the like. To reach the screen the beams pass through a shadow mask and the transmission factor of the mask is increased to provide for enhanced brightness in the reproduced picture.

Accordingly, one object of this invention is to provide an improved shadow mask.

Another object of this invention is to provide an improved shadow mask in which a plurality of apertures are arranged in a particular pattern.

Another object of this invention is to provide a novel color cathode ray tube in which an electron beam impinges exactly on a predetermined color dot.

Another object of this invention is to provide a color cathode ray tube which is bright and free from color misregistration.

Another object of this invention is to provide a color cathode ray tube which employs an in-line gun.

Still another object of this invention is to provide a color cathode ray tube employing an improved shadow mask having a plurality of apertures bored therethrough in a particular pattern and color dots on the screen closely packed on the peripheral portion of a screen.

Other objects, features and advantages of this invention will become apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view, partly cut away, showing a cathode ray tube;

FIG. **2** is a schematic diagram of a shadow mask used in a conventional shadow-mask type color cathode ray tube;

FIGS. **3A** and **3B** are schematic diagrams showing the relative arrangement of picture elements on the screen perpendicular to the central axis of a cathode ray tube employing the shadow mask depicted in FIG. **2**;

FIG. **4** is a schematic diagram showing the relative arrangement of the picture elements on a spherical screen used in conjunction with the shadow mask shown in FIG. **2**;

FIGS. **5A**, **5B** and **5C** are enlarged schematic diagrams showing the relative arrangement of the picture elements on the screen in accordance with this invention;

FIG. **6** is an exaggerated depiction of one example of a shadow-mask according to this invention;

FIG. **7** shows an enlargement of the relative arrangement of the picture elements on a spherical screen in the case of using the mask exemplified in FIG. **6**;

FIG. **8** is a schematic diagram illustrating another example of a mask according to this invention;

FIG. **9** shows the relationship between co-ordinates and the pitches of aperture alignment lines of the mask according to this invention;

FIG. **10** is a graph showing desirable equi-transmission factor curves of electron beams obtained by plotting those points on the mask of equal electron beam transmission factors therethrough; and

FIGS. **11A**, **11B** and **11C** are a series of graphs showing equi-diameter lines of the apertures of the mask of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For a better understanding of this invention, a description will be given first of a shadow mask color cathode ray tube **11** in FIG. **1**, which has three electron beams **12**, **13** and **14** arranged in line in a common horizontal plane **15**. The beams are deflected by deflecting means (not shown) horizontally and vertically across a surface **16** perpendicular to the central axis of the tube and are thereby caused to pass through a shadow mask **17** and scan an outwardly curved spherical screen **18**. The screen **18** is covered with phosphor dots, and the relationship between apertures **19** of the shadow mask **17** and phosphor dots on the screen **18** is of prime importance.

The relationship between mask apertures and screen dots of shadow mask **1** depicted in FIG. **2**, in which assumed horizontal and verticals lines ... X_3, X_2, X_1, X_0, X_1', X_2', X_3', ... and ... Y_3, Y_2, Y_1, Y_0, Y_1', Y_2', Y_3',... are drawn on the shadow mask **1**, which is viewed from the z-axis direction. The shadow mask **1** is of the type having apertures **2** located at intersections of even-numbered horizontal and verticals lines ... X_2, X_0, X_2', ... and ... Y_2, Y_0, Y_2', ... and at the intersections of odd-numbered horizontal and vertical lines ... X_3, X_1, X_3', ... and Y_3, Y_1, Y_3', ...

With such an arrangement, if the phosphor screen **3** is a plane perpendicular to the central axis of the tube and if the red, green and blue phosphor dots D_R, D_G and D_B on the screen **3** are formed by the usual light or electron beam printing method employing a light or electron beam passing through the horizontal and vertical deflection centers of the beams, the phosphor dots D_R, D_G and D_B of a diameter ϕ, which form triplets of picture elements for each aperture 2 of the mask 1, are sequentially arranged on the horizontal lines ..... X_3, X_2, X_1, X_0, X_1', X_2', X_3', ... in the form of horizontal rows of triplets as shown in FIGS 3A and 3B. In view of the requirement for closely packed hexagonal arrays of the phosphor dots D_R, D_G and D_B on the phosphor screen 3, the pitch Lx of adjacent vertical columns of apertures of the shadow mask 1 is selected to be $\sqrt{3}$ times the pitch Ly of adjacent horizontal rows of apertures.

In a shadow mask tube 11 (FIG. 1) having a spherical screen and using an in-line gun, the beam triplets 10 which strike the screen 18 in line, pass through individual apertures 19 tilted relative to the original line of alignment of the three beams as shown in FIG. 4. This phenomenon is referred to as the twist of the in-line beam triplets. The twist phenomenon is a purely geometrical effect caused by the combination of in-line alignment of three beams and a spherical screen. Considering the coordinate system illustrated in FIG. 1, the three beams 12, 13 and 14 passing through the aperture 19 of the shadow mask 17 form the flat plane 16 which is parallel to the x-axis of the tube and which makes and angle of θ_V (the angle of vertical deflection) to the x-z plane. This flat plane 16 intersects the spherical screen 18 which has the center 0 on the z-axis. The in-line beam triplet 10 thus strikes intersection line l, which is an elliptical arc when viewed from the z-axis direction and is expressed as follows.

$$x^2+\left(1+\frac{1}{\tan^2\theta_V}\right)y^2+\frac{2(R-L)}{\tan\theta_V}y+L^2-2RL=0 \qquad \text{(Eq. 1)}$$

where R is the radius of curvature of the spherical screen 18 and L is the distance from the deflection center of the beams to the center of the screen. This is the cause of the twist of a landing in-line beam triplet. This mathematical expression of the angle of twist is obtained by differentiating the Equation (1) and using the relation of $\tan\theta_V = y / (\sqrt{R^2-x^2-y^2} - R + L)$. Thus, it follows that

$$\tan\theta=\frac{dy}{dx}=-\frac{xy}{R^2-x^2-(R-L)\sqrt{R^2-x^2-y^2}} \qquad \text{(Eq. 2)}$$

where θ is the angle of twist measured counter-clockwise from the positive x-axis. The approximate form of the Equation (2) is $\tan\theta = -(xy/RL)$ (Eq. 3)

With the arrangement described, in which the diameter of the phosphor dots D_R, D_G and D_B is selected to be ϕ the same as described in FIG. 3 the phosphor dots corresponding to one of the horizontal rows of apertures 2 overlap those of adjacent horizontal rows of apertures. This is due to the fixed relative arrangements of adjacent apertures, as depicted in FIG. 5A. To avoid this overlap, the diameter of the apertures of the shadow mask is selected to be small in accordance with the angle θ, and the diameter ϕ of the phosphor dots on the screen 3 is selected correspondingly. Thus, in a conventional shadow mask with an in-line gun, the beam impact allowance considerably decreases as a consequence of the twist phenomenon of the landing beam triplets (FIG. 5A).

To avoid this, the present inventors have previously proposed in the copending U.S. Pat. application, Ser. No. 877,183, filed Nov. 17, 1969, a shadow mask of the type in which the horizontal alignment lines of the apertures were "barrel-shaped" and the vertical alignment lines of the apertures were "pin-cushioned". In addition, the horizontal and vertical alignment lines of the apertures were orthogonal to each other and the apertures were located at the intersections of the horizontal and vertical alignment lines. The primary object of this shadow mask was to compensate the twist phenomenon completely. The philosophy of the shadow mask of our previous invention was to make fit the alignment of the apertures for the geometrical twist of the beam triplets striking the screen. This meant that a horizontal row of the aligned apertures on the spherically-pressed shadow mask and the line passing through the deflection centers of the three electron beams had to be included on a single flat plane.

Considering the fact that the radius of the spherically pressed shadow mask is nearly equal to the radius R of the panel inner surface, and neglecting the length of the gap between the shadow mask and the panel inner surface as compared with L, the horizontal alignment lines of the apertures must be the arcs of the ellipses given by the Equation (1) which is the solution of the differential equation of the geometrical twist. A conversion of the integral constant θ_V in Equation (1) yields the following expression.

$$x^2+\frac{R^2+(R-L)^2-2(R-L)\sqrt{R^2-y_0^2}}{y_0^2}y^2-2\frac{(R-L)^2-(R-L)\sqrt{R^2-y_0^2}}{y_0}y+L^2-2RL=0 \qquad \text{(Eq. 4)}$$

where, $y \gtrless 0$ for $y_0 \gtrless 0$,

y_0 is a parameter which is the intercept of the y-axis by the curve. The group of arcs of ellipses (eq. 4) form a "barrel-shaped" group of curves...X_3, X_2, X_1, X_0, X_1', X_2', X_3', ... as shown in FIG. 6. The vertical alignment lines of the apertures must be made "pin-cushioned" so as to be orthogonal to the horizontal alignment lines throughout the shadow mask plane.

The vertical alignment lines can be obtained by solving the following differential equation which is the inverse, and has the opposite sign, of the equation of geometrical twist (Eq. 2).

$$\frac{dy}{dx}=\frac{R^2-x^2-(R-L)\sqrt{R^2-x^2-y^2}}{xy} \qquad \text{(Eq. 5)}$$

The solution of the Equation 5 is obtained as follows.

$$x=x_0\left\{\frac{R^2-(R-L)\sqrt{R^2-x^2-y^2}}{R^2-(R-L)\sqrt{R^2-x_0^2}}\right\}^{\left(\frac{R}{R-L}\right)^2} \times \exp\left\{\frac{\sqrt{R^2-x^2-y^2}-\sqrt{R^2-x_0^2}}{R-L}\right\} \qquad \text{(Eq. 6)}$$

where x_0 is a parameter which is the intercept of the x-axis by the curve. Thus, curves obtained from Equation (6) make right angles to the group of curves obtained from Equation (4) throughout the whole shadow mask plane. Equation (6), however, has the following approximate form which causes and error of ±1° at most, in the orthogonality between the horizontal and vertical alignment lines.

$$x = \frac{RL}{x_0} \mp \sqrt{\left(\frac{RL}{x_0} - x_0\right)^2 - y^2} \qquad \text{(Eq. 7)}$$

for $x_0 \gtrless 0$ This is the "pin-cushioned" group of circular arcs ... Y_3, Y_2, Y_1, Y_0, Y_1', Y_2', Y_3', ... as shown in FIG. 6. Equations (4), (6) and (7) were derived on the basis of the spherically pressed shadow mask. These equations relate to the alignment lines of the apertures on the spherically pressed shadow mask when viewed from the z-axis direction. However, considering the experimental result that when a flat shadow mask is pressed into a nearly spherical surface, the displacement of the aperture position occurs almost only in the z-direction and the displacement in the x-y plane is negligibly small. These equations can be interpreted to mean the alignment lines of the apertures on the flat (pre-pressed) shadow mask.

The foregoing description has been the based on spherical phosphor screen 3. The same principles apply in the case in which the screen is a cylindrical surface extending in a vertical direction. In this case, however, the relationship of the inclination angle of the horizontal row of the triplet of the phosphor dots D_R, D_G and D_B to the horizontal line for each aperture 2 of the mask 1 is as follows.

$$\tan \theta = \frac{dy}{dx} = -\frac{xy}{R^2 - x^2 - (R-L)\sqrt{R^2 - x^2}} \qquad \text{(Eq. 8)}$$

corresponding to Equation (2).

Accordingly, in this case the horizontal alignment lines of the apertures are made "barrel-shaped;" and the vertical alignment lines of the apertures are made "pin-cushioned" so as to be orthogonal to the horizontal alignment lines throughout the shadow mask plane. The apertures are positioned at the intersections of the horizontal and vertical alignment lines. The curve of the horizontal alignment lines is obtained by solving the differential equation (Eq. 8) to obtain an equation corresponding to Equation (4) and by satisfying the resulting equation. The curve of the vertical alignment lines is obtained by solving the following differential equation which is the inverse and has the opposite sign of Equation (8):

$$\frac{dy}{dx} = \frac{R^2 - x^2 - (R-L)\sqrt{R^2 - x^2}}{xy} \qquad \text{(Eq. 9)}$$

to obtain an equation corresponding to the Equation (4) and by satisfying resulting equation. Thus, the same results as the aforementioned can be obtained as the aforementioned.

Although the foregoing discussion has described the shadow mask of the aforementioned copending application in connection with the case where the electron beams respectively corresponding to red, green and blue colors enter the position of the horizontal and vertical deflection means while being aligned in a common horizontal plane, the mask is also applicable to the case where these electron beams enter the position of the deflection means while being aligned in a common vertical plane. In this case it is necessary, of course, to form the apertures at intersections of the horizontal alignment lines made "pin-cushioned" and the vertical alignment lines made "barrel-shaped" and to exchange the curves of the horizontal and vertical alignment lines.

The pitches of the apertures 2 on the horizontal and vertical alignment lines X_0 and Y_0 on the mask 1 are respectively x_{00} and y_{00} ($x_{00} = \sqrt{3y_{00}}$) peculiar to the x- and y-axis and the apertures on each line are arranged at regular intervals and the pitches of the apertures 2 of the vertical alignment lines are gradually increased according to the distance from the center of the mask 1, while the pitches of the apertures 2 of the horizontal alignment lines are gradually decreased according to the distance from the center of the mask 1. However, this does not provide the aforementioned relationship that the pitch Lx of adjacent vertical columns of apertures of the mask 1 be $\sqrt{3}$ times the pitch Ly of adjacent horizontal rows of apertures at places remote from the center of the mask 1.

Consequently, the horizontal rows of the triplets of the phosphor dots D_R, D_G and D_B laid down on the screen 3 at places remote from the center of the mask 1 tilt against the horizontal lines and do not overlap adjacent dots as depicted in FIG. 7. The vertical spacings of the phosphor dots are reduced as compared with the vertical spacing at the center of the screen and the horizontal spacings of the dots are enlarged as compared with the horizontal spacing at the center. This does not fully satisfy the requirement for closely packed hexagonal arrays of the phosphor dots and introduces the possibility of deterioration of color purity resulting from overlapping of the phosphor dots of adjacent horizontal rows of the triplets at places more remote from the center of the screen than the abovementioned ones as shown in FIG. 5C.

In view of the foregoing, the present invention has for its object the improvement of the shadow mask of the type depicted in FIG. 6 for use with a shadow mask color cathode ray tube of the type in which the red, green and blue electron beams, aligned in a common horizontal plane, are deflected by deflection means horizontally and vertically, still in a common plane, and are thereby caused to scan an outwardly curved spherical screen through a shadow mask. The shadow mask of this invention is featured first in that the pitches of the apertures are enlarged at both ends of the vertical alignment lines and the pitches of the apertures are reduced at both ends of the horizontal alignment lines so that the pitches of the horizontal and vertical alignment lines of the apertures at the corner regions of the mask are substantially equal to those at the center of the mask.

The shadow mask of the present invention is further arranged so that the diameters of the apertures of the shadow mask vary to provide equi-transmission-factor curves of the electron beams through the shadow mask. As shown in FIG. 10, such curves may be circles 70, which are concentric substantially about the center of the shadow mask 1. The transmission factors of the apertures are reduced from the center of the mask to the peripheral portion thereof. There are several reasons why the equi-transmission-factor curves of the electron beams are in the form of circles substantially concentric about the center of the shadow mask. One reason is that respective portions of the color cathode ray tube are usually formed chiefly with parts symmetrical about the axis of the tube. Especially when the screen and the shadow mask are spherical, substantially the entire construction of the cathode ray tube is symmetrical about the axis thereof. Deterioration of color purity on the screen varies concentrically outward from the center of the screen due to errors in the mechanical precision of the parts and their arrangements, thermal deformation of the shadow mask, the influence of earth magnetism and so on. As a result, it is convenient to make the equi-transmission-factor curves of the shadow mask for the electron beam in the form of circles concentric about the center of the mask for compensation of deterioration of the color purity. Even if the luminance distribution on the screen is concentrically circular about its center when the equi-transmission-factor lines of the shadow mask for the electron beam, substantially no appreciable change in vision is caused in the reproduced picture as compared with the cases where the luminance distribution is not concentrically circular.

A description will be given of the respective enlargement and reduction of the pitches of the horizontal and vertical alignment lines of the apertures from the center of the mask toward both ends of the horizontal and vertical center alignment lines. The method for obtaining the varying values of the pitches for such pitch distribution has been proposed in the aforementioned U.S. Pat. application, Ser. No. 877,183, filed Nov. 17, 1969 but will also be described below.

In FIG. **9** horizontal and vertical alignment lines running across the aperture **2** at a desired point P on the mask **1**, respectively based upon the aforementioned Equations (4) and (6) are respectively designated by the intersecting point of the line Xm with the y-axis (Yo) is and the intersecting point of the line Xm with the y-axis (Y_0) is indicated by B(0, y_m) and the intersecting point of the line $Y_n$with the x-axis is identified by A (x_n, 0).

Assume that the co-ordinate of the point P is $\{x(n, m), y\ (n, m)\}$. Since the point P is the intersecting point of the alignment lines Xm and Yn, the aforementioned Equations (4) and (6) are expressed as follows, by substituting y_m and x_n for y_0 and x_0 in Equations (4) and (6), respectively, and by approximately solving simultaneous equations derived therefrom.

$$x(n, m) \doteqdot \left(1+\frac{ym^2}{2RL}\right) x_n \qquad (10)$$

$$y(n, m) \doteqdot \left(1-\frac{x_n^2}{2RL}\right) y_m \qquad (11)$$

The solution of the simultaneous equations derived from the equations (**4**) and (**6**) results in a power series of variables such as x^2/R^2, y^2/R^2, xy/R^2, x^2/RL, y^2/RL, xy/RL, ... whose numerators are terms of second order with respect to a length on the shadow mask plane and whose denominators are terms of second order with respect to the length of the radius of curvature R of the sphrical screen or the distance from the deflection center of the screen or both of them. The higher order terms are neglected in the approximation for obtaining Equations (10) and (11), since the aforementioned variables are less than 0.2 in practice.

Accordingly, if the pitches of vertical and horizontal alignment lines of the apertures in the vicinity of the point P are taken as $P_V(n, m)$ and $P_H(n, m)$ respectively, they are given by the following equations.

$$P_H(n, m) = x(n, m) - x(n-1, m) = \left(1+\frac{y_m^2}{2RL}\right)(x_n - x_{n-1}) \qquad (12)$$

$$P_V(n, m) = y(n, m) - y(n, m-1) = \left(1-\frac{y_m^2}{2RL}\right)(y_m - y_{m-1}) \qquad (13)$$

In this case $(x_n - x_{n-1})$ is the pitch of the vertical alignment lines on the x-axis (X_0) and may be expressed by $P_H(n, 0)$, while $(y_m - y_{m-1})$ is the pitch of the horizontal alignment lines on the y-axis (Y_0) and may be expressed by $P_V(0, m)$. Consequently, the Equations (12) and (13) are respectively given by the following Equations (14) and (15).

$$P_H(n,m) = \left(1+\frac{y_m^2}{2RL}\right) P_H(n, 0) \qquad (14)$$

$$P_V(n,m) = \left(1-\frac{x_n^2}{2RL}\right) P_V(0, m) \qquad (15)$$

With a line $y = \gamma x$ joining the center of the shadow mask **1** with its peripheral region being expressed in the form of a functional equation, the pitches of the vertical and horizontal alignment lines of the apertures $P_H(n, m)$ and $P_V(n, m)$ on the line $y = \gamma x$, which are obtained by the above Equations (14) and (15), are selected equal to those $P_H(0, 0)$ and $P_V(0, 0)$ at the center of the mask **1**. This implies fulfilment of the requirement for a closely packed array of the apertures.

Accordingly, if $P_H(n, m)$ and $P_V(n, m)$ on the line $y = \gamma x$ by the Equations (14) and (15) are respectively expressed as $P_H(n', m')$ and $P_V(n', m')$, it is sufficient only to satisfy the following equations.

$$P_H(n', m') = P_H(0,0) \qquad (16)$$

$$P_V(n', m') = P_V(0,0) \qquad (17)$$

Calculated by using the above relations from Equations (14) and (15),

$P_H(n, 0)$ and $P_V(0, m)$ are given by the following equations.

$$P_H(n,0) = \frac{P_H(n', m')}{1+\frac{y_m^2}{2RL}} = \frac{P_H(0, 0)}{1+\frac{y_m^2}{2RL}} \qquad (18)$$

$$P_V(0,m) = \frac{P_V(n', m')}{1-\frac{x_n^2}{2RL}} = \frac{P_V(0, 0)}{1-\frac{x_n^2}{2RL}} \qquad (19)$$

From Equations 10 and 11 the following relation is obtained:

$$\frac{y_m}{x_n} = \frac{y(n, m)/\left(1-\frac{x_n^2}{2RL}\right)}{x(n, m)/\left(1+\frac{y_m^2}{2RL}\right)} \qquad (20)$$

Considering $y=\gamma x$, Equation 20 is expressed as follows:

$$\frac{y_m}{x_n}=\frac{y(n',m')/\left(1-\frac{x_n^2}{2RL}\right)}{x(n',m')/\left(1+\frac{y_m^2}{2RL}\right)} \tag{21}$$

The relation $y=\gamma x$ is given by the following equation.

$$y(n', m')=\gamma x(n', m') \tag{22}$$

Accordingly, the following equation is obtained from Equations 16 and 17:

$$\frac{y_m}{x_n}=\gamma\frac{\left(1+\frac{y_m^2}{2RL}\right)}{\left(1-\frac{x_n^2}{2RL}\right)} \tag{23}$$

Equation (23) is expressed approximately as follows:

$$\frac{y_m}{x_n}=\gamma\left\{1+\frac{1}{2RL}(y_m^2+x_n^2)\right\} \tag{24}$$

Further, Equations (18) and (19) are respectively expressed as including y_m and x_n. Equation (22) may be substituted into the aforementioned Equations (10) and (11) and approximation similar to that for obtaining Equations (10) and (11) carried out to express Equation (18) as including only x_n and Equation (19) as including only y_m. $P_H(n, 0)$ and $P_V(0, m)$ are then given by the following equations.

$$P_H(n, 0)=\frac{P_H(0, 0)}{1+\gamma^2\frac{x_n^2}{2RL}}\doteqdot P_H(0, 0)\left(1-\gamma^2\frac{x_n^2}{2RL}\right) \tag{25}$$

$$P_V(0, m)=\frac{P_V(0, 0)}{1-\frac{y_m^2}{\gamma^2 2RL}}\doteqdot P_V(0, 0)\left(1+\frac{y_m^2}{\gamma^2 2RL}\right) \tag{26}$$

The Equations (25) and (26), thus obtained, respectively represent the pitches of the vertical and horizontal alignment of the apertures on the x- and y-axis when $P_H(n, m)$, and $P_V(n, m)$ at the point P on the line $y=\gamma x$ on the mask plane, are equal to $P_H(0, 0)$ and $P_V(0, 0)$ at the center of the mask.

The Equations (25) and (26) are expressed as including γ used in the line $y=\gamma x$. If the vertical and horizontal alignment lines of the apertures at the desired point P on the mask plane, given by the Equations (14) and (15), are expanded by substituting Equations (25) and (26), Equations (14) and (15) are then expressed by the following equations.

$$P_H(n, m)=P_H(0, 0)\left(1+\frac{y_m^2}{2RL}\right)\left(1-\gamma^2\frac{x_n^2}{2RL}\right) \tag{27}$$

$$P_V(n, m)=P_V(0, 0)\left(1-\frac{x_n^2}{2RL}\right)\left(1+\frac{y_m^2}{\gamma^2 2RL}\right) \tag{28}$$

Accordingly, if γ used in the line $y=\gamma x$ is selected to be equal to 1, the following relation is obtained from Equations (27) and (28).

$$\frac{P_H(n, m)}{P_V(n, m)}\doteqdot\frac{P_H(0, 0)}{P_V(0, 0)} \tag{29}$$

The Equations (25) and (26) are respectively expressed by the following equations for x_n and y_m.

$$\begin{aligned} x_n&=\sum_{k=1}^{n}P_H(k, 0)\\ &=nP_H(0, 0)-P_H(0, 0)\sum_{k=1}^{n}\frac{x_k^2}{2RL} \end{aligned} \tag{30}$$

$$\begin{aligned} y_m&=\sum_{k=1}^{m}P_V(0, k)\\ &=mP_V(0, 0)+P_V(0, 0)\sum_{k=1}^{m}\frac{y_k^2}{2RL} \end{aligned} \tag{31}$$

By substituting the x_n and y_m into the aforementioned Equations (25) and (26) and performing approximation similar to that for obtaining the aforementioned Equations (10) and (11), the following equations are obtained.

$$P_H(n, 0)=P_H(0, 0)\left(1-\frac{\{P_H(0, 0)\}^2}{2RL}n^2\right) \tag{32}$$

$$P_V(0, m)=P_V(0, 0)\left(1+\frac{\{P_V(0, 0)\}^2}{2RL}m^2\right) \tag{33}$$

Although x_n and y_m are expressed in the following forms based upon the Equations 30 and 31

$$x_n=\sum_{k=1}^{n}P_H(k, 0)$$

$$y_m=\sum_{k=1}^{m}P_V(0, k)$$

they may be expressed approximately as follows:

$$x_n=\sum_{k=1}^{n}P_H(k, 0)=\int_0^n P_H(k, 0)dk \tag{34}$$

$$y_m = \sum_{k=1}^{m} P_V(0, k) = \int_0^m P_V(0, k)\,dk \qquad (35)$$

Substituting k's in the Equations (34) and (35) for n and m, respectively and calculating the equations by using the relations of the Equations (32) and (33), the following equations are obtained.

$$x_n = nP_H(0, 0)\left(1 - \frac{\{P_H(0, 0)\}^2}{6RL} n^2\right) \qquad (36)$$

$$y_m = mP_V(0, 0)\left(1 + \frac{\{P_V(0, 0)\}^2}{6RL} m^2\right) \qquad (37)$$

Since

$$\alpha = \frac{\{P_H(0, 0)\}^2}{6RL} \text{ and } \beta = \frac{\{P_V(0, 0)\}^2}{6RL},$$

the following equations result.

$$x_n = nP_H(0, 0)(1 - \alpha n^2) \qquad (38)$$

$$y_m = mP_V(0, 0)(1 + \beta m^2) \qquad (39)$$

Based upon the foregoing, the shadow mask of this invention is of such a construction, as depicted in FIG. 8, in which the pitches of the horizontal and vertical alignment lines of the apertures on the vertical and horizontal alignment lines passing through the center of the mask are respectively increased and decreased as both side edges of the mask are approached from its center, in a manner to satisfy the aforementioned Equations (25) and (26) or (38) and (39).

The foregoing has described one feature of this invention and the following will hereinafter describe the second feature of this invention such that the equi-transmission-factor curves of the electron beams through the shadow mask are circles substantially concentric about the center of the mask as indicated by **70** in FIG. **10**. A description will be given of the manner for obtaining the diameters of the apertures for this purpose.

As previously described in connection with FIG. **9**, the coordinate of the desired point P on the mask **1** is taken as P $\{x(n, m), y(n, m)\}$ the pitch of the horizontal alignment lines of the apertures in the vicinity of the point P is $P_V(n, m)$ and the distance between adjacent apertures **2** on the alignment line Yn near the point P is $P(n, m)$. In such a case, as previously described in connection with the construction of the mask of FIG. **6**, the horizontal alignment lines are inclined at an angle θ to the horizontal line (the x-axis X_0), as expressed in the aforementioned Equation (2), so that the vertical alignment lines are also inclined at an angle θ to the vertical line (the y-axis Y_0). Accordingly, P n, m) is given by the following equation.

$$P(n, m) = \frac{2P_V(n, m)}{\cos\theta} \qquad (40)$$

By the way,

$$\cos\theta = \frac{1}{\sqrt{1 + \tan^2\theta}} \qquad (41)$$

and $\tan\theta$ is given by Equation (2) but this Equation (2) may be rewritten as follows, by approximation neglecting terms higher than second order as was done in obtaining the Equations (10) and (11).

$$\tan\theta \doteqdot -\frac{xy}{RL} \qquad (42)$$

Accordingly, the following equation is obtained by substituting Equation 42 into 41

$$\cos\theta = \frac{1}{\sqrt{1 + \left(\frac{xy}{RL}\right)^2}} \doteqdot 1 - \frac{1}{2}\left(\frac{xy}{RL}\right)^2 \qquad (43)$$

since $\sqrt{1-u}$ $1 - u/2$ when u is selected to be a desired small number. Neglecting $(xy/RL)^2$ in the right side of the equation (43) by approximation similar to the above-described one, it follows that

$$\cos\theta = 1 \qquad (44)$$

Therefore, the Equation (40) is rewritten as follows:

$$P(n, m) = 2P_V(n, m) \qquad (45)$$

While, $P_V(n, m)$ is expressed by the following Equation (15) previously mentioned,

$$P_V(n, m) = \left(1 - \frac{x_n^2}{2RL}\right) P_V(0, m) \qquad (15)$$

and $P_V(0, m)$ in the Equation 15 is given by the following Equation 26 previously referred to,

$$P_V(0, m) = \frac{P_V(0, 0)}{1 - \frac{y_m^2}{\gamma^2 2RL}} \qquad (26)$$

If γ used in $y = \gamma x$ in the Equation (26) is selected as **1** as previously described, the Equation (26) can be rewritten as follows:

$$P_V(0, m) = \frac{P_V(0, 0)}{1 - \frac{y_m^2}{2RL}} \qquad (46)$$

Here, the following equations are respectively obtained from the Equations 10 and 11,

$$x_n \doteqdot \frac{x(n, m)}{1 + \frac{y_m^2}{2RL}} \doteqdot \left(1 - \frac{y_m^2}{2RL}\right) x(n, m) \qquad (47)$$

$$y_m \doteqdot \frac{y(n, m)}{1 - \frac{x_n^2}{2RL}} \doteqdot \left(1 + \frac{x_n^2}{2RL}\right) y(n, m) \qquad (48)$$

Accordingly, by approximation similar to the aforementioned one, Equations 15 and 16 are respectively rewritten as follows:

$$P_V(n, m) \doteqdot \left\{1 - \frac{(x(n, m))^2}{2RL}\right\} P_V(0, m) \qquad (49)$$

$$P_V(0, m) \doteqdot \frac{1}{1 - \frac{(y(n, m))^2}{2RL}} P_V(0,0) \qquad (50)$$

Consequently, the following equation is obtained from the above Equations 49 and 50,

$$P_V(n,m) \doteqdot \frac{1 - \frac{(x(n, m))^2}{2RL}}{1 - \frac{(y(n, m))^2}{2RL}} P_V(0,0)$$

$$\doteqdot \left\{1 + \frac{(y(n, m))^2 - (x(n, m))^2}{2RL}\right\} P_V(0,0) \qquad (51)$$

Substituting Equation 51 into the Equation 45,

$$P(n,m)=\left\{1+\frac{(y(n,m))^2-(x(n,m))^2}{2RL}\right\}2P_V(0,0 \quad (52)$$

Since $P_V(0, 0)$ is the pitch of the horizontal alignment lines of the apertures at the center of the shadow mask, $2P_V(0, 0)$ is the distance between adjacent apertures on the vertical alignment lines at the center of the mask. Accordingly, if this distance between adjacent apertures is taken as $P(0, 0)$,

$$P(0, 0) = 2P_V(0, 0) \quad (53)$$

Further, if $P(n, m)$, $x(n, m)$ and $y(n, m)$ in Equation (52) are respectively expressed as $P(x, y)$, x and y, Equation (52) is rewritten as follows:

$$P(x, y)=\left(1+\frac{y^2-x^2}{2RL}\right)P(0,0) \quad (54)$$

Thus, the distance $P(n, m)$ between adjacent apertures on the alignment lines Yn near the point P is obtained as $P(x, y)$ by the Equation (54). A description will be given of the distribution of the diameters of the apertures each spaced apart from adjacent ones the distance given by Equation (54).

Where the equi-transmission-factor curves of the shadow mask for the beams are circles concentric about the center of the mask as shown in FIG. 10, if the distance from the center of the mask to a desired point thereon is taken as r, the beam transmission factor at the desired point may be expressed by the following equation in the form of a function $T(r)$ of r (:)

$$T(r)=T(0)(1-kr^2) \quad (55)$$

Where $T(0)$ is the transmission factor of the mask at its center and k is a constant.

If the diameter of the aperture 2 at the position where the distance between adjacent aperture is expressed by $P(x, y)$, namely at the coordinate P, is taken as $D(x, y)$ and if the transmission factor at the co-ordinate P, considered as the ratio of the sum of the areas of the adjacent three apertures to the areas of an approximate equilateral triangle defined by the adjacent three apertures, is taken as $T(x, y)$, the transmission factor $T(x, y)$ is given by the following equation.

$$T(x, y)=\frac{\sqrt{3}\pi}{6}\left\{\frac{D(x, y)}{P(x, y)}\right\}^2 \quad (56)$$

While, since $r^2=x^2+y^2$ from the Equation (55), $T(r)$, that is, $T(x, y)$ can be expressed as follows:

$$T(x, y) = T(0, 0)\{1 - k(k^2 + y^2)\} \quad (57)$$

Accordingly, $D(x, y)$ is given by the following equation from equations (56) and (57).

$$D(x, y)=\sqrt{\frac{6T(0, 0)}{\sqrt{3}\pi}\{1-k(x^2+y^2)\}}\cdot P(x, y) \quad (58)$$

Generally, when u is selected to be a desired small number and

$$\sqrt{1-u}\doteqdot 1-\frac{u}{2}$$

so that Equation 58 can be expressed as follows:

$$D(x, y)\doteqdot\sqrt{\frac{6T(0, 0)}{\sqrt{3}\pi}}\left\{1-\frac{k}{2}(x^2+y^2)\right\}P(x, y) \quad (59)$$

Since Equation (59) is based upon Equation (55) which is true in the case where the equi-transmission-factor distribution is in the form of circles concentric about the center of the mask, it will be apparent that the distribution of the aperture diameters can be obtained by substituting into Equation (59) Equation (54) representing the distribution of the distances between the apertures. Accordingly, the following equation is derived from Equations (54) and (59).

$$D(x, y)=\left\{1-\frac{k}{2}(x^2+y^2)\right\}\left\{1+\frac{y^2-x^2}{2RL}\right\}\cdot\sqrt{\frac{6T(0, 0)}{\sqrt{3}\pi}}P(0, 0) \quad (60)$$

If the diameter of the aperture at the center of the mask is taken as $D(0, 0)$,

$$D(0, 0)=\sqrt{\frac{6T(0)}{\sqrt{3}\pi}}P(0, 0) \quad (61)$$

since $D(0, 0)$ is the value when $x=y=0$ in Equation 60. Therefore, expressed by using Equation 60, Equation 61 is given by the following equation.

$$D(x, y)=\left\{1-\frac{k}{2}(x^2+y^2)\right\}\left(1+\frac{y^2-x^2}{2RL}\right)D(0, 0) \quad (62)$$

This is the equation representing the distribution of the diameters of the apertures.

The following description will be made of the equi-diameter lines of the apertures. The equi-diameter lines of the apertures are those loci at points where the ratio of the aperture diameter $D(x, y)$ at any point on the mask to the diameter $D(x, y)$ at the center of the has a constant value (referred to as a), namely those loci satisfying the following equation

$$a=\frac{D(x, y)}{D(0, 0)} \quad (63)$$

Accordingly, by substituting Equation (63) into Equation (62), the equi-diameter lines of the apertures in this invention is given by the following equation.

$$\left\{1-\frac{k}{2}(x^2+y^2)\right\}\left(1+\frac{y^2-x^2}{2RL}\right)=a \quad (64)$$

Generally, in the shadow mask the beam transmission factor at the peripheral region is usually reduced by 30 to 40 percent as compared with that at the center, so that a maximum value of $k(x^2+y^2)$ in the Equation (57) is expressed by 0.3 to 0.4, while a maximum value of (x^2+y^2) is nearly equal to the square of the shortest distance L from the electron beam deflection center of the screen and hence can be given by the following equation.

$$k(x^2+y^2).kL^2=0.4\sim 0.3 \quad (65)$$

Further, the radius of curvature R of the screen is usually two to three times as long as the distance L and k has a value nearly equal to $1/RL$. Therefore,

the term $\frac{k}{2}(x^2+y^2)$. The facto$_r$ $\frac{y^2-x^2}{2RL}$

can be neglected when the Equation (64) has been expanded and Equation (64) can then be expressed as follows:

$$1+\frac{y^2-x^2}{2RL}-\frac{k}{2}(x^2+y^2)=a \qquad (66)$$

Rearranging Equation 66, the following equation is obtained.

$$\left(k+\frac{1}{RL}\right)x^2+\left(k-\frac{1}{RL}\right)y^2=2(1-a) \qquad (67)$$

This is the equation for the equi-diameter lines of the apertures.

Thus, the equi-diameter lines of the apertures in this invention can be obtained. As will be seen from the equation (**67**), when

$$k > 1/RL \qquad (68)$$

the equi-diameter lines form ellipses substantially about the center of the mask **1**, as indicated by reference numeral **111** in FIG. **11**A. Each of these ellipses has a longer

diameter

$$2\sqrt{\frac{2(1-a)}{k-\frac{1}{RL}}}$$

and a shorter diameter

$$2\sqrt{\frac{2(1-a)}{k+\frac{1}{RL}}}$$

and the

diameters of the apertures are reduced as the peripheral region of the mask is approached from its center. In the case of k having the following value

$$k=1/RL \qquad (69)$$

the equi-diameter lines are straight lines parallel with the y-axis, as indicated by **112** in FIG. **11B**, such that the diameters of the apertures are reduced as they go away from the y-axis. In the case of k having the following value $k > 1/RL$ (70)
the equi-diameter lines of those apertures having larger diameters than that of the aperture at the center of the mask form hyperbolas about the y-axis, obtained by calculating a from Equation (63) as indicated by reference numeral **113** in FIG. **11C**. Each has an asymptote

$$y=\pm\sqrt{\left(\frac{1}{RL}+k\right)}x\sqrt{\left(\frac{1}{RL}-k\right)}$$

and the diameters of the apertures are increased as they go away from the center of the mask, while the equi-diameter lines of the apertures having smaller diameters than that of the aperture at the center of the mask form hyperbolas about the x-axis, such as indicated by reference numeral **114** in FIG. **11C**, each of which has an asymptote is similar to the aforementioned and diameters of the apertures are reduced as they go away from the center of the mask.

With the present invention above described, the transmission factor of the electron beams through the shadow mask is enhanced to provide the reproduced picture with brightness and the equi-transmission-factor curves which are circles substantially concentric about the center of the shadow mask readily compensate deterioration of the color purity, thus ensuring a color picture of good quality.

It will be apparent that many modifications and variations may be effected without departing from the scope of the novel concepts of this invention.

We claim as our invention:

1. A cathode ray tube comprising a curved screen having deposited thereon a plurality of phosphor dot triplets emitting light in a plurality of colors, means for generating a plurality of electron beams, the deflection centers of the electron beams being aligned in a common plane, and a shadow mask having a curvature similar to that of said screen and located between the screen and the beam generating means, the shadow mask having a plurality of apertures therethrough and a transmission-factor at each elemental area, said transmission-factor being related to the location of said elemental area and being is proportional to the diameter of said apertures in said elemental area and inversely proportional to the spacing between said apertures in said elemental area, and in which said apertures are located at the intersecting points of horizontal and vertical curved lines, the spacing of the horizontal curved lines increases and that of the vertical curved lines decreases as the periphery of the shadow mask is approached and said transmission-factor varies from one of said elemental areas to another of said elemental areas to form equi-transmission-factor lines in a family of concentric circles substantially symmetrically disposed about the center of the shadow mask, each of said apertures having a diameter determined by the location of that aperture on said mask such that apertures of equal diameter lie along one curve of a family of curves selected from the families consisting of ellipses, straight lines perpendicular to said common plane, and hyperbolas.

2. A cathode ray tube as claimed in claim **1** wherein said apertures of equal diameter lie along ellipses, at least one of the axes of each of the ellipses being horizontal.

3. A cathode ray tube as claimed in claim **1** wherein said apertures of equal diameter lie along substantially parallel straight lines in a vertical direction.

4. A cathode ray tube as claimed in claim **1** wherein said apertures of equal diameter lie along hyperbolas formed about a vertical and a horizontal line.

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