

[54] X-RAY FOCAL SPOT CONTROL SYSTEM

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[51] Int. Cl. H05g 1/10
[58] Field of Search 250/99; 313/57

[56] References Cited
UNITED STATES PATENTS

2,340,363 2/1944 Atlee 250/99
3,103,591 9/1963 Rogers 250/99

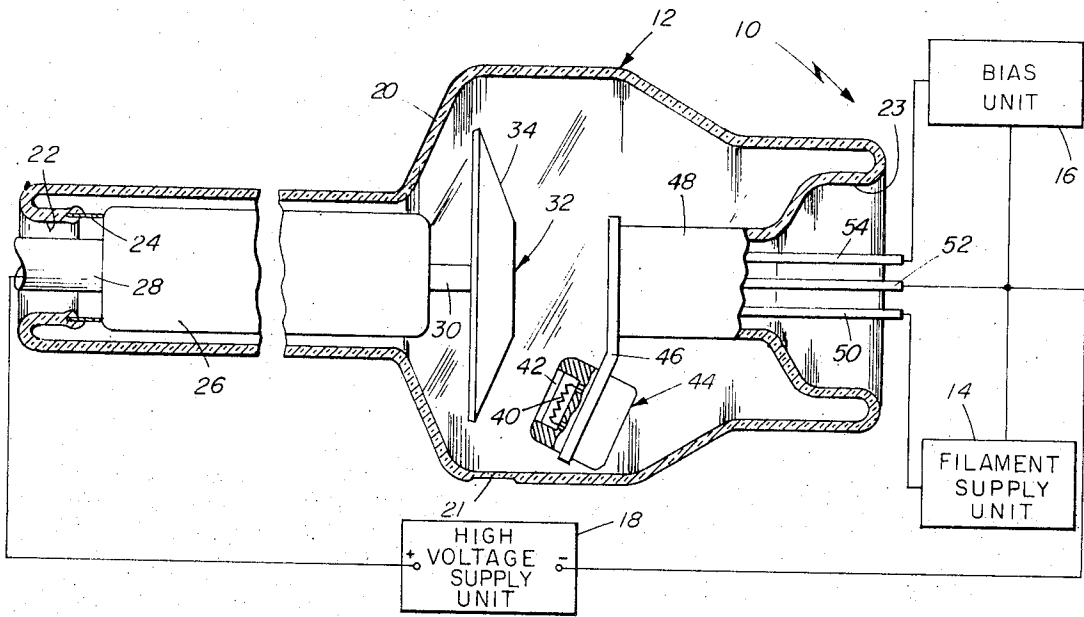
3,433,955 3/1969 Perry 250/99
2,798,963 7/1957 Saget 250/99

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[57] ABSTRACT

An X-ray generating system comprising an X-ray tube having an electron-emitting cathode disposed in spaced opposing relationship with an anode target surface and supported within a focusing cup which is provided with means for directing emitted electrons into a Gaussian distribution pattern on the target surface, such that the area of the resulting focal spot is minimized and useful X-rays radiate therefrom in a corresponding Gaussian distribution pattern.

6 Claims, 10 Drawing Figures



2 Sheets-Sheet 1

FIG. 1

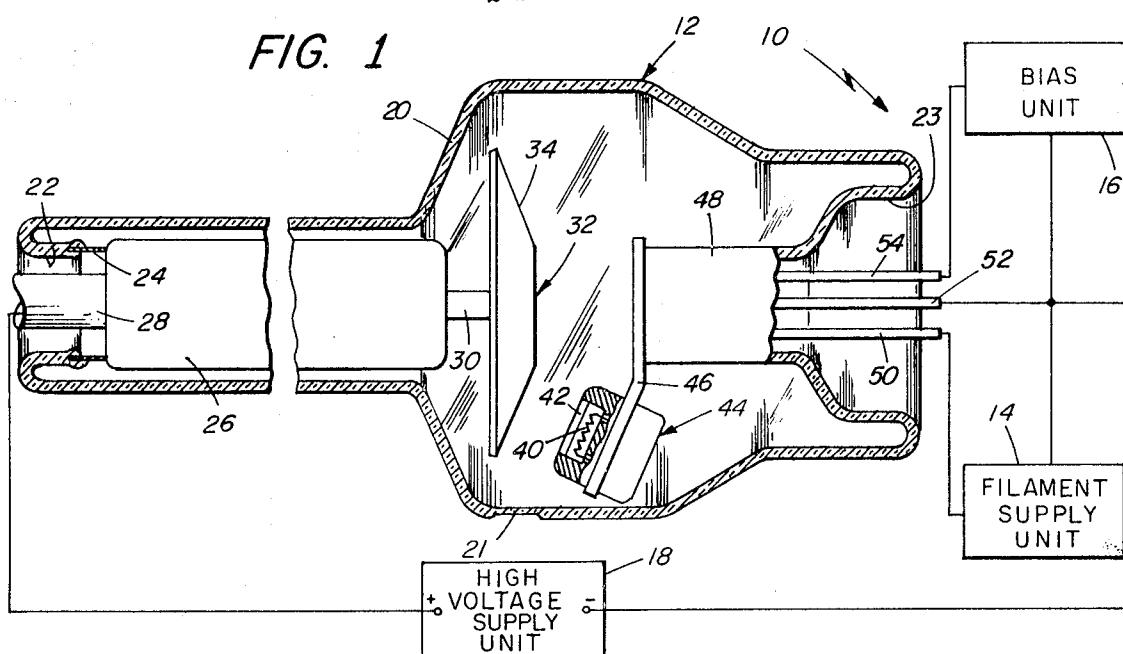


FIG. 2

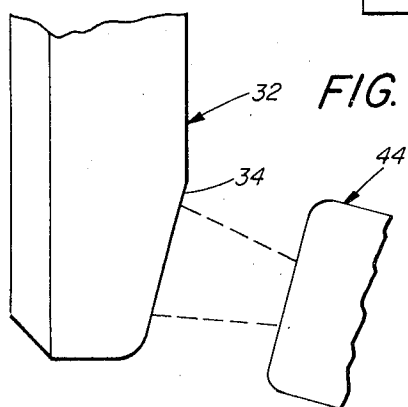


FIG. 6

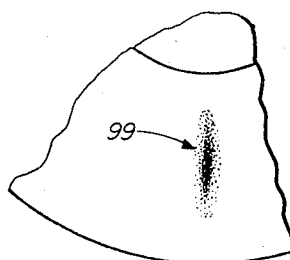


FIG. 9

FIG. 3
PRIOR ART

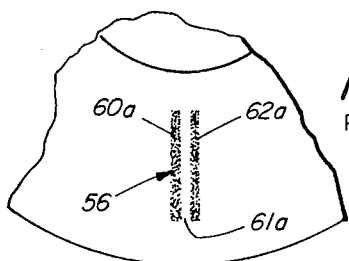


FIG. 4
PRIOR ART

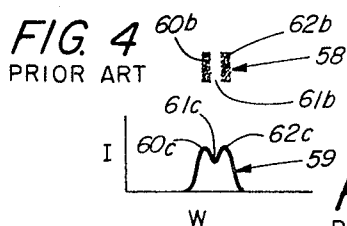


FIG. 5
PRIOR ART

FIG. 7

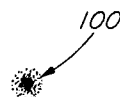
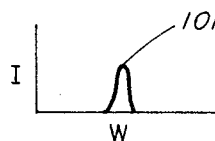


FIG. 8



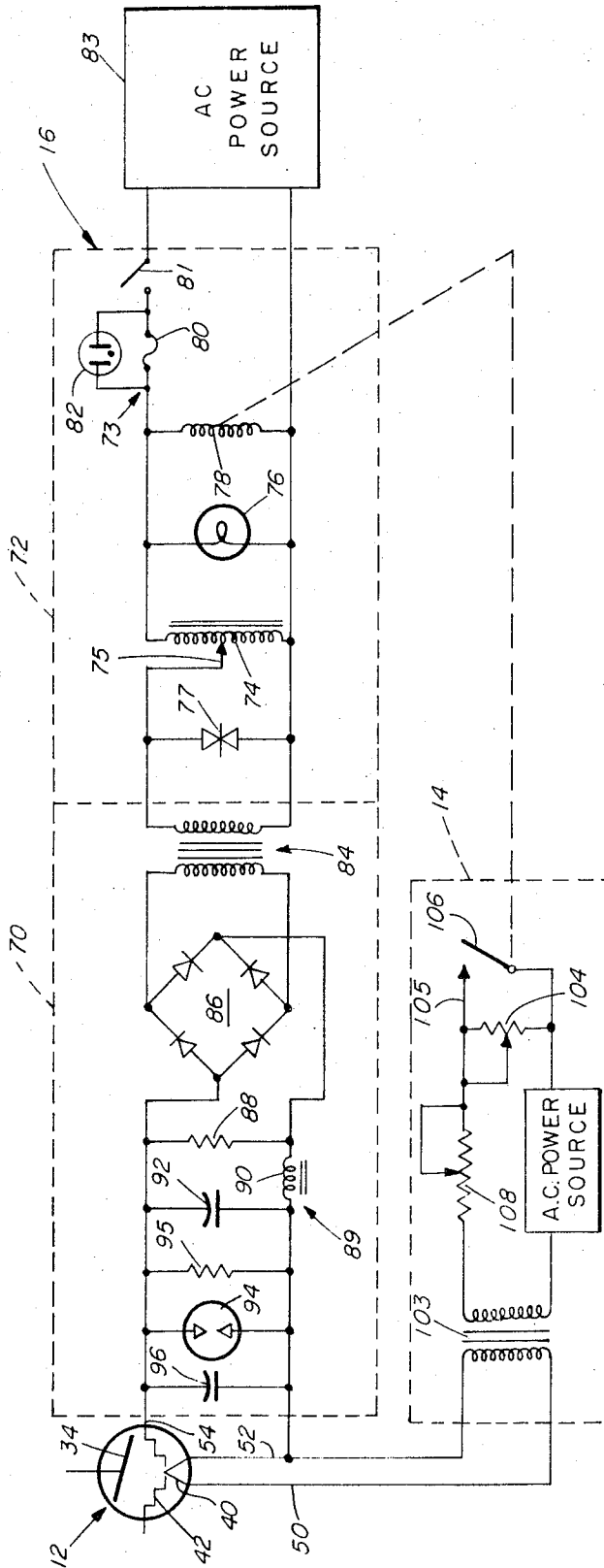


FIG. 10

X-RAY FOCAL SPOT CONTROL SYSTEM

BACKGROUND OF THE INVENTION

This invention relates generally to X-ray generating systems and is concerned more particularly with a system for producing a focal spot of minimized area from which X-rays radiate in a single-peak intensity distribution pattern.

A conventional X-ray tube basically comprises a tubular envelope wherein an electron-emitting cathode is disposed in longitudinal spaced relationship with an anode target surface. In operation, electrons emitted from the cathode are accelerated toward the anode by means of an electrostatic field established therebetween. A resulting dense stream of electrons impinges on the target surface in a particular area which is commonly called the "actual" focal spot and generally has a configuration corresponding to the incident cross section of the electron stream. Thus, accelerated electrons bombard the target with sufficient energy to generate X-rays which radiate outwardly from the "actual" focal spot area of the target surface. The useful portion of this radiation comprises those X-rays which pass out of the tube through an X-ray transparent window in the wall of the tube envelope.

An X-ray tube of the "line focusing" type generally includes means for directing electrons emitted from the cathode into a substantially flat beam which terminates at the anode. Also, the anode target surface usually is disposed at an acute angle to the longitudinal axis of the envelope and positioned in radial alignment with the X-ray transparent window. Thus, when the flat beam of emitted electrons impinges on the anode target surface, it produces a rectangular focal spot which extends linearly along the sloped target surface in the direction of the X-ray transparent window. The rectangular focal spot, when projected radially through the X-ray transparent window, forms a small square which is called the "effective" focal spot. Consequently, the useful X-rays, which pass out of the tube by way of the X-ray transparent window, appear to be emanating from the small square or effective focal spot.

Ideally, an X-ray tube of the line focusing type should provide an effective focal spot approximating a point source of radiation in order to resolve fine structural detail in radiography. Therefore, the effective focal spot should be made as small as possible and have a single peak of maximum intensity located in the minimized area of the spot. However, prior art tubes of the line focusing type generally provide an effective focal spot comprising a pair of high intensity lines which are separated by an intervening area of significantly lower intensity. Consequently, at magnifications greater than two, the spaced pair of high intensity lines act as individual, closely spaced sources of radiation which produce overlapping double images on radiographic film. As a result, the edges of fine detail structure are blurred and the purpose of higher magnification is frustrated. In order to avoid this loss of valuable information, it would be desirable to have an X-ray tube of the line focusing type which provides an effective focal spot having a minimized area and a single peak of maximum intensity centrally located therein.

SUMMARY OF THE INVENTION

Accordingly, this invention provides an X-ray generating system comprising an X-ray tube having a fila-

mentary cathode supported within a focusing cup which is opened toward a spaced anode target surface, an adjustable current means electrically connected across the filament for controllably heating the filament to a desired electron-emitting temperature, a polarized voltage means electrically connected between the filament and the anode for drawing electrons emitted by the filament toward the anode in a generally flat beam, and an adjustable biasing means electrically connected between the filament and the focusing cup for maintaining the cup at a controllable negative potential with respect to the filament such that electrons in the beam are focused onto a generally elongated focal spot area of the target surface in a Gaussian distribution pattern, both longitudinally and transversely of the spot, thereby producing an effective focal spot of minimized area from which useful X-rays radiate in a corresponding energy distribution pattern.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of this invention, reference is made to the accompanying drawings, wherein:

FIG. 1 is an axial view, partly in section, of an X-ray tube connected into an X-ray generating system;

FIG. 2 is an enlarged fragmentary view of the cathode head and anode focal surface shown in FIG. 1;

FIG. 3 is an enlarged fragmentary plan view of an actual focal spot produced by an X-ray generating system of the prior art;

FIG. 4 is a radially projected view of the actual focal spot shown in FIG. 3, as viewed as from the X-ray transparent window shown in FIG. 1;

FIG. 5 is a graphical representation of the X-ray intensity distribution pattern of the spot shown in FIG. 4;

FIG. 6 is an enlarged fragmentary plan view of an actual focal spot produced by the X-ray generating system of this invention;

FIG. 7 is a radially projected view of the actual focal spot shown in FIG. 6, as viewed from the X-ray transparent window shown in FIG. 1;

FIG. 8 is a graphical representation of the transverse intensity distribution pattern of the spot shown in FIGS. 6 and 7;

FIG. 9 is a graphical representation of a longitudinal intensity distribution pattern of the spot shown in FIG. 6; and

FIG. 10 is a schematic representation of a preferred embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring more particularly to the drawing wherein like characters of reference designate like parts throughout the several views, there is shown in FIG. 1 an X-ray generating system 10 including an X-ray tube 12 which is electrically connected to a filament supply unit 14, a bias unit 16 and a high voltage supply unit 18.

X-ray tube 12 comprises a generally tubular envelope 20 which may be made of dielectric material, such as lead-free glass, for example. One end of envelope 20 is provided with a reentrant portion 22 which is peripherally sealed to one end of a kovar collar 24. The other end of collar 24 is hermetically attached to one end of an anode rotor 26 which extends longitudinally into the tubular envelope 20.

The rotor 26 is made of conductive material, such as copper, for example, and is provided with an external

stem 28 which is electrically attached to the positive terminal of the high voltage supply unit 18. Extending longitudinally from the other end of rotor 26 and in electric communication therewith is a conductive shaft 30 which is preferably made of refractory material, such as molybdenum, for example. A perpendicularly disposed disk 32 is fixedly attached to the inner end of shaft 30 and has a frusto-conical inner surface for the purpose of providing a sloped annular target surface 34 adjacent the outer periphery of the disk 32. Thus, the target surface 34 is disposed at an angle to the longitudinal axis of the tube 12 and to a radially aligned window 21 which is made of x-ray permeable material, such as glass, for example. The target surface 34 is made of a material, such as tungsten, for example, which readily emits X-rays when bombarded by high energy electrons. However, the remainder of the anode disk 32 may be made of a suitable refractory material, such as molybdenum, for example.

Although the anode disk 32 is rotatable, a radial portion of the target surface 34 always is positioned in spaced opposing relationship with a helically wound filament 40. The filament 40 is insulatingly supported within a conventional focusing cup 42 comprising a metallic block having a planar face wherein there is disposed an elongated recess or series of communicating cavities, each having a generally rectangular configuration. The filament 40 and the cup 42 comprise component parts of a cathode head 44 which is fixedly mounted on an angled end of a transversely extending support arm 46. Arm 46 is hollow and is attached at the other end to the inner end of cathode support cylinder 48 which is circumferentially sealed to another reentrant portion 23 of the envelope 20.

Electrical leads 50, 52 and 54 extend insulatingly through cathode cylinder 48, within support arm 46 and into the cathode head 40 where the leads 50 and 52 are electrically attached to respective opposite ends of the filament 40 and the lead 54 is electrically connected to the focusing cup 42. The lead 54 is electrically connected to an output terminal of bias unit 16 and the lead 50 is electrically connected to an output terminal of the filament supply unit 14. The lead 52 which is electrically connected to the other output terminal of the filament supply unit 14 and to the other output terminal of the bias unit 16 also, is electrically connected to the negative output terminal of the high voltage supply unit 18.

One well-known type of X-ray generating system includes an X-ray tube 12 having a focusing cup 42 which is connected directly to the filament 40. Thus, the cup 42 is biased at cathode potential and exerts a slight focusing effect on electrons emitted from the filament. This prior art type of system usually is brought to a condition of readiness by having a moderate flow of current passing through the filament thereby heating it to a low electron-emitting temperature. However, the emitted electrons are not accelerated toward the anode disk 32 because, at this time, an electrostatic field is not established between the filament 40 and the anode.

The described prior art system may be set into active operation by actuating a timing switch which results in a large increase in current flowing through the filament 40 thereby heating it up to a high electron-emitting temperature. Shortly thereafter, a high voltage supply, such as 18, for example, impresses a high positive voltage with respect to ground on the anode disk 32 and a

correspondingly low negative voltage with respect to ground on the filament 40. As a result, there is established between the filament and the rotating anode disk a strong electrostatic field which accelerates the emitted electrons, at very high velocity, toward an aligned portion of the target surface 34, as shown in FIG. 2. The generally flat electron beam, thus formed, impinges on the target surface 34, as shown in FIG. 3, in a generally rectangular area 56 which is commonly called the "actual" focal spot area and has a configuration corresponding to the incident cross section of the beam. The accelerated electrons bombard the target material with sufficient kinetic energy to generate X-rays which radiate from the actual focal spot area 56 in all directions. The useful portion of these X-rays leave the tube 12 through the X-ray transparent window 21.

It is worth noting that the length dimension of the rectangular area 56 is transversely disposed on the sloped target surface 34 and radially aligned with the X-ray transparent window 21. Consequently, the rectangular area 56 when projected radially through the window 21 forms a small square 58, as shown in FIG. 4. As a result, the useful X-rays passing through the window 21 appear to be emanating from the small square area 58 which is commonly referred to as the "effective" focal spot area. Thus, the smaller an effective focal spot is the closer it approximates a point source of radiation and the greater resolution it provides when taking radiographic exposures of fine structural detail. In order to approximate a point source of radiation, however, the effective focal spot also must have a single peak of maximum intensity.

Generally, X-ray generating systems of the prior art provide effective focal spots having non-uniform intensity distribution, as shown in FIG. 5, for example, where the intensity I is plotted across the width W of the effective focal spot 58. The resulting distribution curve 59 has a pair of spaced peaks 60c and 62c, respectively, of maximum intensity which are separated by an intervening trough 61c of relatively lower intensity. A comparison of the curve 59 in FIG. 5 with the effective focal spot 58 in FIG. 4 discloses that the spaced peaks 60c and 62c are associated with respective marginal lines 60b and 62b of maximum intensity which are separated by an interposed line 61b of relatively lower intensity. A further comparison with the actual focal spot 56 shown in FIG. 3 indicates that the marginal lines 60b and 62b are associated with respective marginal areas 60a and 62a of maximum electron bombardment which are spaced apart by an intermediate area 61a of minimum electron bombardment. Thus, the underlying cause of the non-uniform distribution of X-ray intensity shown in FIG. 5 is traceable to the non-uniform bombardment of the actual focal spot area 56 by the electron beam emanating from the filament 40.

The present invention provides an x-ray generating system 10 which overcomes this problem of non-uniform electron bombardment. As shown in FIG. 10, connected electrically between the focusing cup 42 and the filament 40 is a bias unit 16 comprising a bias supply unit 70 and a bias control 72. The bias control unit 72 is connected across the output terminals of an AC power source 83 via control switch 81 and includes a powerstat auto-transformer 74 having its input leads connected across a pilot light 76 which, in turn, is connected across a relay coil 78. One end of the relay coil 78 is connected through an overload indicating means

73, such as a fuse 80 and parallel connected fuse indicator 82, for example, to one side of an energizing switch 81. The other side of switch 81 is connected directly to an output terminal of the AC power source 83. The other end of the relay coil 78 is connected directly to the other side of the AC power source 83.

The auto-transformer 74 has its output terminals, one of which is connected to the movable tap 75 of the transformer secondary, connected across a transient suppressor 77 which, in turn, is connected across a primary winding of an isolation transformer 84 located in the bias supply unit 70. The secondary of the transformer 84 is connected across the input of a full wave, bridge-type rectifier 86 which has a polarized output connected across a load resistor 88 of an LCR filter network 89. One end of resistor 88 is connected to the negative side of a filter capacitor 92 and the other end is connected to one end of a choke coil 90. The other end of coil 90 is connected to the positive side of capacitor 92. Capacitor 92 is connected across a bleeder resistor 95 and also may be connected across a parallel array of protective devices, such as spark gap 94 and surge capacitor 96, for examples. The negative side of the filter capacitor 92 is connected directly to the focusing cup 42, and the positive side of capacitor 92 is connected directly to the filament lead 52. Thus, the bias unit 16 maintains the focusing cup 42 at a negative potential with respect to the filament 40 even during active operation of the X-ray tube 12. This negative bias potential impressed on the focusing cup 42 may be adjusted by moving the tap 75 of the auto-transformer 74.

The X-ray generating system 10, shown in FIG. 1, may be operated in accordance with the prior art by connecting the lead 54 directly to the filament lead 52, as by throwing the switch 81 in bias control unit 72 to the "off" position, for example. With the bias unit thus bypassed, the focusing cup 42 will be maintained at the potential of the filament 40; and the tube 12 will produce an actual focal spot having a generally rectangular configuration, such as 56 in FIG. 3, for example. Consequently, the effective focal spot will be generally square, such as 58 in FIG. 4, for example; and the resulting X-ray intensity distribution will be non-uniform, as shown in FIG. 5, for example. Then, the X-ray generating system 10 may be switched to operate in accordance with this invention by throwing the energizing switch 81, in bias control unit 72, to the "on" position. As a result, a negative potential with respect to the filament 40 will be applied to the focusing cup 42, as described.

It has been found that by adjusting the negative potential on the longitudinal side walls of the focusing cup 42, the marginal areas 60a and 62a shown in FIG. 3 may be moved laterally toward one another. At an optimum value of negative potential, the areas 60 and 62a will merge to produce, as shown in FIG. 6, an actual focal spot 99 of minimized area having centrally located therein a single area of maximum electron bombardment. The simultaneous change in negative potential on the transverse end walls of the cup 42 causes the opposing ends of the rectangular focal spot 56, shown in FIG. 3, to become rounded and moved slightly toward one another. As a result, the actual focal spot 99 has a generally elliptical configuration which, when projected radially through the X-ray transparent window 21, forms an effective, focal spot 100 having a gen-

erally circular configuration, as shown in FIG. 7. Thus, the useful X-rays passing through the window 21 appear to be emanating from the circular focal spot 100 which closely approximates a point source of radiation.

When the intensity of electron bombardment is plotted across the width of the actual focal spot 99, a Gaussian distribution curve having a characteristic single peak of maximum intensity, as indicated by the curve 101 shown in FIG. 8, will be obtained. Also, when the intensity of electron bombardment is plotted along the length of the actual focal spot 99, a Gaussian distribution curve having the single peak of maximum intensity, as indicated by the curve 102 shown in FIG. 9, will be obtained. Thus, when the intensity of useful X-rays radiating from the effective focal spot 100 is plotted in orthogonal directions corresponding to the width and length dimensions of the actual focal spot 99, Gaussian distribution curves similar to the curves 101 and 102, respectively, are obtained. Therefore, the effective focal spot 100, because of its single peak of maximum intensity and its minimized area, approximates a point source of radiation more closely than an effective focal spot 58 of the prior art, as shown by a comparison of FIGS. 4 and 7. Consequently, the X-ray generating system of this invention will provide greater resolution, particularly when making exposures of fine structural detail, than will X-ray generating systems of the prior art.

X-ray intensity is controlled by the number of electrons emitted from the filament 40. Consequently, when the focusing cup 44 is biased negatively with respect to the filament 40, the resulting decrease in the number of electrons leaving the filament 40 is accompanied by a corresponding decrease in the intensity of X-ray energy emanating from the effective focal spot 100. This problem may be solved, as shown in FIG. 10, by connecting a variable resistor 104 in series with the primary of a transformer 103 which supplies energy to filament 40. The resistor 104 may be connected across a normally open contact 105 and contact arm 106 which is operated by the relay coil 78 in the bias control unit 72. Thus, when the bias control unit 72 is energized, the relay coil 78 will close the contact arm 106 thereby shorting out the resistor 102 and increasing the flow of current through the filament. As a result, the emitting temperature of the filament 40 will be increased to compensate for the reduction in electron emission caused by the negative bias potential impressed on the focusing cup 44. In this manner, the X-ray intensity generated by the tube may be maintained substantially constant while achieving the desired effective focal spot having a Gaussian distribution of intensity.

Similarly, when increasing the negative bias on focusing cup 42 by means of tap 75 on auto-transformer 74, the number of electrons leaving the filament 40 is reduced thereby decreasing the intensity of useful X-ray energy emanating from the effective focal spot 100. In order to counteract this undesirable effect, a second variable resistor 108 is connected in series with the filament 40, as shown in FIG. 10. Thus, when the tap 75 is adjusted to increase the negative potential on the focusing cup 42, the resistor 108 may be varied correspondingly to increase the current through filament 40. In this manner, an effective focal spot having a generally circular configuration and the desired X-ray intensity emanating therefrom may be obtained.

Thus, there has been disclosed herein a novel X-ray generating system including an X-ray tube having an electron emitting filament supported within a focusing cup, the focusing cup being provided with means for biasing it negative with respect to the filament during operation of the tube and the filament being provided with compensating means for controlling the rate of electron emission. Although this invention has been illustrated with high tension primary tuning control operated equipment, it also may be used with pulse operated equipment, the essential feature being that the initiating pulse should not drive the focusing cup or grid-type of electrode into the positive direction with respect to the filament. Rather, the initiating pulse after driving up from a cutoff bias potential should still leave the necessary negative bias potential on the gated electrode for focusing purposes in accordance with this invention. Furthermore, although this invention has been illustrated herein with the use of a rotating anode type of X-ray tube, it will operate equally well with other types of X-ray tubes, such as X-ray tubes of the stationary anode type, for example.

From the foregoing, it will be apparent that all of the objectives of this invention have been achieved by the structures shown and described herein. It will also be apparent, however, that various changes may be made by those skilled in the art without departing from the spirit of the invention as expressed in the appended claims. It is to be understood, therefore, that all matter shown and described is to be interpreted as illustrative and not in a limiting sense.

We claim:

1. An X-ray generating system for producing an x-ray focal spot having a minimized area and a Gaussian distribution of X-radiation, said system comprising:

- an X-ray tube including:
 - an envelope,
 - a focusing electrode supported within the envelope and having a recess therein,
 - an electron-emitting cathode supported insulantly within the recess,
 - an anode having a target surface supported within the envelope opposite said recess;

first means for impressing on the anode a positive voltage with respect to the cathode;

second means for heating the cathode to an electron-emitting temperature; and

biasing means for maintaining the focusing electrode at a negative potential with respect to the cathode during active operation of the tube and directing emitted electrons into a Gaussian distribution pattern on a minimized area of the target surface;

said biasing means including a pulsating voltage source and an electrical circuit connecting the source to the tube, the circuit having control means and means for converting pulsating voltage to a steady-state voltage.

2. An X-ray generating system as set forth in claim 1 wherein the voltage converting means includes a voltage filtering network having polarized output terminals, the negative output terminal being connected to the focusing electrode and the other output terminal being connected to the filament.

3. An X-ray generating system as set forth in claim 2 wherein the voltage converting means includes a rectifying means having input terminals connected through the control means to the output of the pulsating voltage source and output terminals connected to the input of the voltage filtering network.

4. An X-ray generating system as set forth in claim 1 wherein the control means includes switching means for applying a negative potential to the focusing electrode when desired and adjustable means for varying the magnitude of the negative potential when desired.

5. An X-ray generating system as set forth in claim 4 wherein the control means includes means for increasing the electron emitting temperature of the cathode when the negative potential is applied to the focusing electrode.

6. An X-ray generating system as set forth in claim 5 wherein the second means includes means for adjusting the electron-emitting temperature of the cathode in accordance with the magnitude of the negative potential applied to the focusing electrode.

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