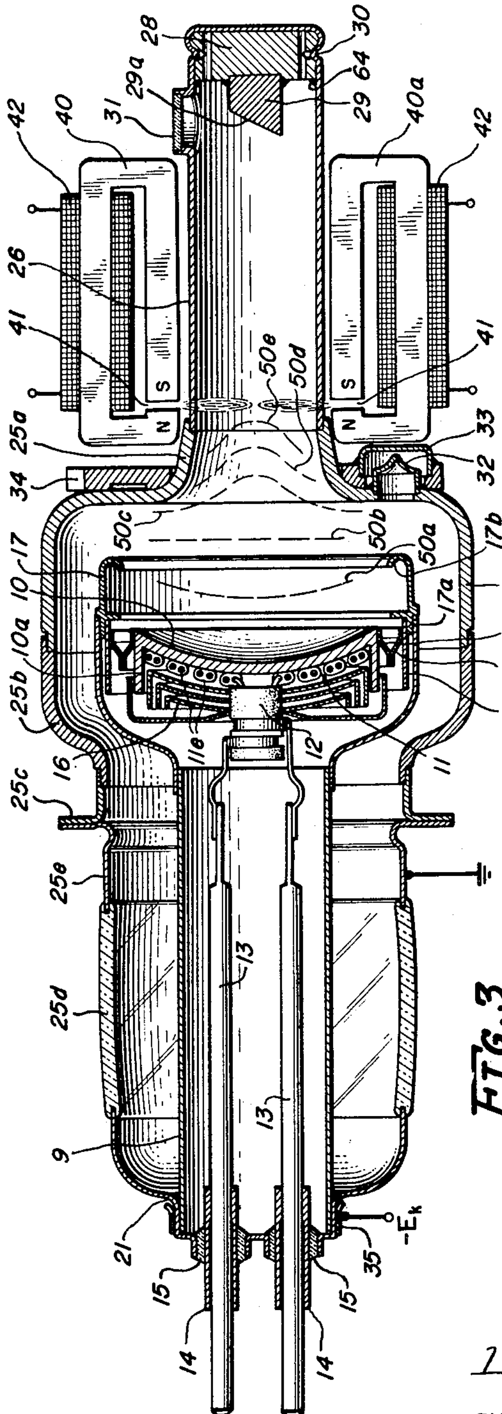
June 29, 1965 L. C. FOSTER 3,192,425

X-RAY TUBE WITH ADJUSTABLE ELECTRON BEAM CROSS-SECTION

Filed March 6, 1961 2 Sheets-Sheet 1

FIG. 1



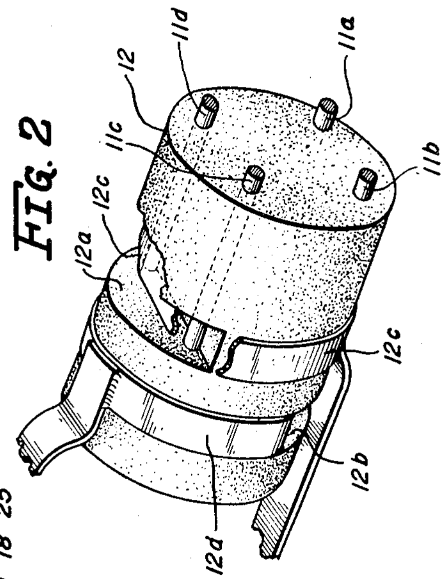
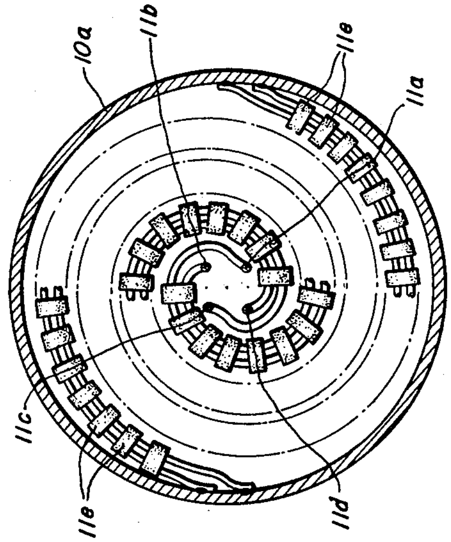


FIG. 3



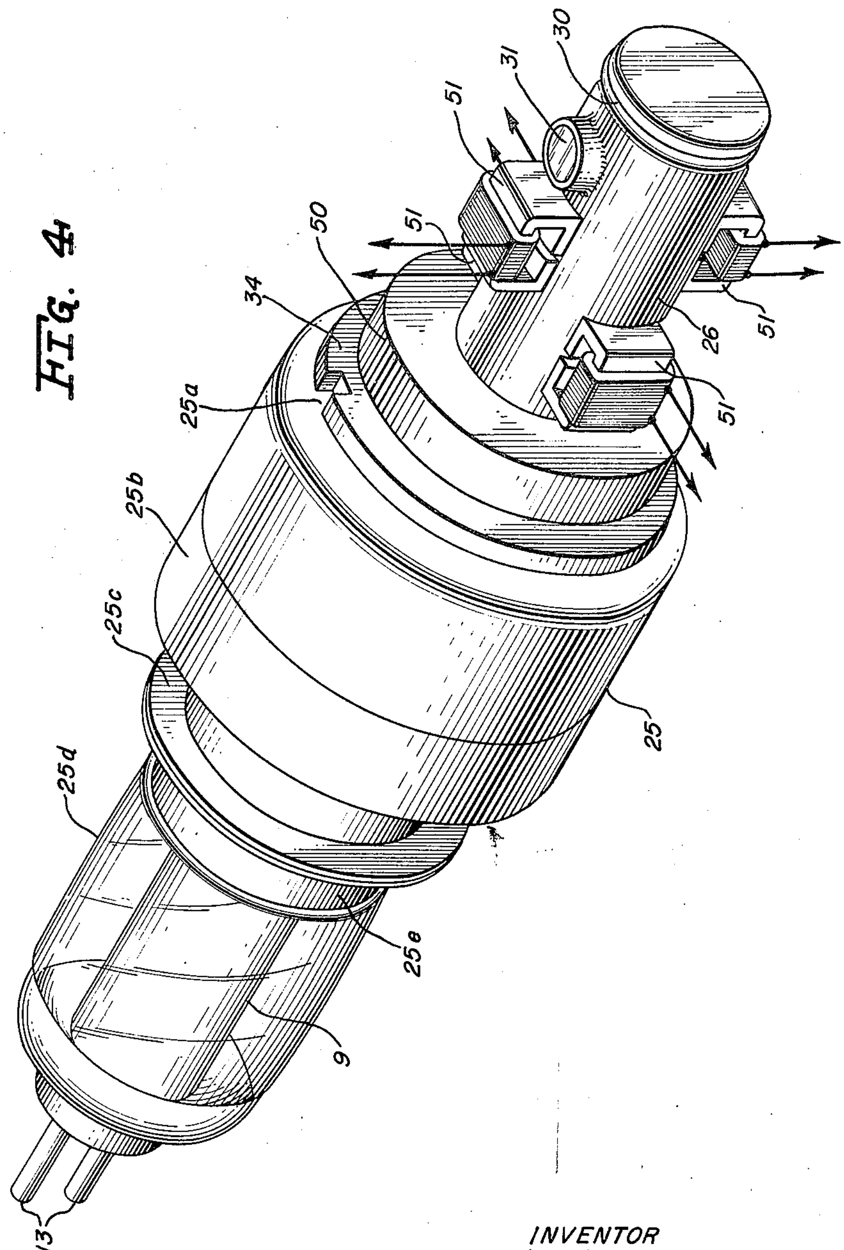
INVENTOR
Leigh Curtis Foster
BY Francis W. Crotty
ATTORNEY

June 29, 1965 L. C. FOSTER 3,192,425

X-RAY TUBE WITH ADJUSTABLE ELECTRON BEAM CROSS-SECTION

Filed March 6, 1961 2 Sheets-Sheet 2

FIG. 4



INVENTOR
Leigh Curtis Foster
BY Francis W. Crotty
ATTORNEY

United States Patent Office

3,192,425

Patented June 29, 1965

3,192,425

X-RAY TUBE WITH ADJUSTABLE ELECTRON BEAM CROSS-SECTION

Leigh Curtis Foster, Los Altos, Calif., assignor to Zenith Radio Corporation, a corporation of Delaware

Filed Mar. 6, 1961, Ser. No. 93,534
4 Claims. (Cl. 313—57)

This invention is directed to X-ray generators and pertains particularly to X-ray tubes of the space-charge limited type.

A great variety of vacuum tube structures are known for the development of X-rays; they usually comprise a temperature limited electron emissive cathode for developing electrons which are accelerated to impact a target of tungsten or the like which emits X-rays in response to electron bombardment. Usually the target is canted in respect of the path of travel of the electrons, being arranged to face a window or port through which X-rays may readily pass. The angular relation of the target face results in directing X-rays through the window toward an object which is to be exposed to X-radiation.

It is well known that the effectiveness or depth of penetration of the X-rays through object is a function of the velocity with which electrons impact the target and very often high accelerating potentials, in the order of 100 kv. or more, are employed in such generators. It is also known that, as an incident to electron bombardment of the target, atoms of tungsten may be ionized and liberated and these positive ions are accelerated in the direction of the cathode by the field gradient required to accelerate the negative electrons from the cathode to the target. Since the tungsten ion is heavy compared to the mass of an electron, the impact of the ions may rapidly destroy the cathode surface and cause additional beam loading on the energy source. This may materially shorten the tube life and, of course, is highly undesirable.

Efforts have been made to minimize this deterioration by structural arrangements which, in effect, shield the greater part of the cathode from ions originating at the target. Ion shields are more or less effective but, at any rate, add to the complexity and cost of the tube structure.

Another shortcoming which is characteristic of many prior X-ray tubes has to do with the size and shape of the electron beam as it impacts the target. Usually, the beam size and shape are fixed, being determined by the geometrical properties of the electrode structure of the tube. Added flexibility may be imparted to the generator if one may conveniently vary the size and shape of the electron beam over a wider range of dimensions. Ideally, the beam should be of such cross section that X-rays appear to originate from a point source but tube life is shortened by extremely high electron energy density on the target. For particular applications it may be quite useful to have available a variety of beam cross sections varying from an effective spot beam to one of rectangular or linear dimension. This will minimize target loading and hence deterioration, when larger beam dimensions are acceptable.

Accordingly, it is an object of the invention to provide a new and improved vacuum tube type X-ray generator.

It is a particular object of the invention to provide an X-ray tube in which the major portion of the cathode is protected against the destructive effects of ions without the need for ion shield structures.

Another salient object of the invention is to provide an X-ray tube of enhanced flexibility in that the configuration of the effective X-ray source is readily controllable.

Another specific object of the invention is to provide an

improved electrode structure for an X-ray generator of the space-charge-limited vacuum tube type.

An X-ray generator constructed in accordance with the invention comprises an electron gun for projecting an electron beam along a given path. This gun includes an electron emissive cathode located coaxially of that path and a heater for establishing the cathode at an electron emitting temperature. An anode structure is disposed axially of the path in a position spaced from the cathode. The anode structure has a conductive cylindrical portion positioned axially of the path and with an inner radius that is small compared to that of the cathode and also has a target portion constructed of a material, preferably of high density, which radiates X-rays in response to electron bombardment. The target is spaced from the anode ring in a direction away from the cathode and is disposed across or astride the beam path. The generator includes means for establishing a focusing field in the region between the cathode and the anode ring to form electrons emitted from the cathode surface into a converging beam of substantially circular cross section and focused on the target and for establishing the cylindrical portion and the target at approximately the same operating potential. The spacing of the target from the open end of the cylindrical portion is greater than the depth of penetration of the focusing field into the anode cylinder. Adjustable magnetic means are supported externally of the anode cylinder for establishing a magnetic beam shaping field about the beam path to selectively shape the beam into any of a plurality of predetermined different non-circular beam cross sections at the target.

In a preferred aspect of the invention, the anode ring and the target are maintained at approximately the same operating potential and create a relatively field-free space near the target. The dimensions of the tube result in a sufficient extent of relatively field-free space that ions emitted from the target are not accelerated to high energies toward the cathode.

In accordance with another aspect of the invention, there is also provided in the generator a beam shaping means which may take the form of one or more pairs of space-opposed magnets positioned adjacent the beam path between the anode ring and the target for shaping the beam to a desired cross sectional configuration at the target. This shaping is facilitated by arranging for independent adjustment of the ampere turns and therefore the strength of the magnetic field and hence the electron lens action of the individual beam shaping magnets.

The foregoing and other objects of the invention, together with further advantages and benefits thereof, will be more clearly understood from the following description of particular embodiments thereof taken in conjunction with the annexed drawing in the several figures of which like components are designated by similar reference characters and in which:

FIGURE 1 is a cross sectional view of a space-charge-limited vacuum tube X-ray generator embodying the present invention;

FIGURE 2 is a detailed showing of a spacer included in the tube;

FIGURE 3 is a detail of the heater structure;

FIGURE 4 represents a modification of the beam shaping arrangement of the generator.

Referring now more particularly to FIGURE 1, the structure there represented is a preferred form of X-ray generator which may be characterized as a hot cathode flash X-ray tube. It comprises an electron gun for projecting an electron beam along a given path, that path being symmetrical about the longitudinal axis of the tube structure. The electron gun has a cathode comprising an electron emitting surface 10 in the form of a sector of a sphere centrally located on the longitudinal axis of the tube. The surface **10**, customarily referred to as the cathode button, is formed of nickel and coated with sintered nickel of the commercially available type "A" or other suitable type provided with an electron emitting oxide coating.

The cathode button is maintained at a desired operating temperature, generally in the neighborhood of 825° C., by means of a heater arrangement **11**. The heater is a spiral of four tungsten wires designated **11***a*–**11***d* in the detailed view of FIGURE 2 which shows these four heater conductors and their arrangement within a heater button or spacer **12**. The heater conductors are arranged to define a square and are received in appropriately located channels of spacer **12** which, of course, is an insulator such as alumina. Spacer **12** is provided with a cut-away section **12***a* which exposes heater conductors **11***c*, **11***d* and has a similar cut-away **12***b* exposing the other heater conductors **11***a*, **11***b*. A pair of nickel bands **12***c* and **12***d* are clamped about the insulator, being received within recesses **12***a* and **12***b*, respectively. The bands clamp the heater conductors securely within insulator **12** and are spot welded thereto so that at the same time they make good electrical contact therewith to facilitate the making of connections to lead-in wires for a heater potential supply; otherwise it is very difficult to connect to the brittle tungsten heater conductors themselves.

After emerging from insulator **12**, the heater conductors are formed into helices as indicated in FIGURE 3. The pairing of these conductors, namely **11***a* and **11***b* as one pair with **11***c* and **11***d* as the other, is continued through the use of a number of alumina beads **11***e*. Each bead embraces one of the pairs of conductors and the beads are disposed along the conductor pairs with such frequency as to maintain their desired configuration while at the same time insulating them from cathode button **10**. At their free ends, the four heater conductors are mechanically and electrically secured to the rearwardly extending flange **10***a* of the cathode button which flange, of course, is not an electron emitter.

The heater structure is completed by a pair of lead-in conductors **13**, **13** each of which is circular in cross section throughout the major portion of its length for rigidity but may be flattened or otherwise formed at one end to facilitate connection with bands **12***c* and **12***d*. Each lead-in is provided with a sleeve **14**, **14** of conducting material which may be brazed to lead-ins **13** and sealed to insulator **15** which may be either glass or ceramic. The projecting terminal portions of lead-ins **13**, **13** are similar to the usual basing pins of high power vacuum tube structures.

Heater efficiency is established by a stack of concentric heat shields **16** mechanically supported from insulator **12** immediately behind the spiralled heater conductors. At least that shield which is immediately adjacent the spiral filament, and preferably all such shields, have a polished or reflecting surface for the purpose of reflecting heat in the direction of cathode button **10**. The power input to the heater, to establish the operating temperature of 825° C., is approximately 200 watts.

In addition to the electron emitting surface **10**, the specific form of electron gun illustrated includes a ring type focus electrode **17** positioned adjacent to and concentric with the cathode although being of larger diameter to, in effect, surround or encompass the outer periphery of the cathode button. The edge of electrode **17** closest to cathode **10** has a flange **17***a* which facilitates integrating the electrode and cathode structures mechanically and the opposite end of the electrode is rolled over as indicated at **17***b*. The specific configuration of the electrode is determined empirically to attain the field distribution required to achieve a desired focusing of the emitted electrons in a manner to be considered hereinafter. In constructing the tube, the shaping of the focus electrode may be readily accomplished through the use of an electrolytic tank which is a well understood practice for determining potential gradients and distribution.

To preserve heater efficiency, it is of course desirable that the mechanical support between cathode button **10** and focus electrode **17** be a poor heat conductor. Accordingly, their support is provided by inner and outer support rings **18**, **19** respectively, formed of thin stainless steel or other material that has poor heat conductivity. One end of inner ring **18** is secured to the outer periphery of button **10**. The corresponding end of outer ring **19** connects with focus electrode **17**. The rings are preformed and connected to one another at their opposite ends so that the supporting structure, as viewed between the cathode button and the focus electrode assembly, has a Y configuration as appears in FIGURE 1. It is also desirable to add a further ring **20** encompassing the supporting assembly and adding more heat shielding. As described, this support structure causes focus electrode **17** to be maintained at the same potential as cathode button **10**. This is a very practical arrangement because the desired beam forming may be accomplished quite readily with the focus electrode operating at cathode potential. However, should it be desired to have these elements maintained at specifically different potential levels, one or more components of the cathode-focus electrode support may be made of insulating material.

Still additional support for the cathode and focusing electrode assembly is provided by an element **9** formed of thin stainless steel so as to be a poor heat conductor. This element is cylindrical throughout most of its length and its diameter is chosen to be received and mechanically supported by a shoulder section **21** formed in the housing of the tube. At its opposite end, support **9** is flared outwardly into a bell shape. Its diameter at its free end matches the external diameter of the focus electrode to facilitate its receiving that electrode in nested concentric relation.

The described electron gun cooperates with an anode structure in the forming of electrons emitted from cathode button **10** into a beam of a desired cross sectional configuration. The anode structure forms a part of the envelope or housing of the tube. It is conductive, being formed of copper, and has a first or enlarged cylindrical portion **25** and a smaller elongated second cylindrical portion **26**, together defining a bell shaped envelope section. The enlarged anode section **25** surrounds and is spaced from the electron gun and its shoulder portion **25***a* which connects with anode portion **26** may be likened to an anode ring having such spaced relation to the electron gun, obtaining from the fact that the anode structure is coaxial with the gun, as to permit the desired focusing field configuration to result upon the application of operating potentials to the electrode system.

The remote end of anode portion **26** is closed and mechanically supports a block **28** of copper to which is brazed a tungsten anode or target **29** which is small in diameter compared with anode portion **26**. Preferably, anode section **26** is dimensioned to obtain a spacing of target **29** from anode ring **25***a* which is greater than the depth of penetration of the electrostatic focusing field into the anode structure in a direction beyond ring section **25***a* for a reason that will be made clear hereinafter. In mounting copper block **28** within anode cylinder **26**, it is convenient to roll in a portion of the anode cylinder as indicated at **30**. This establishes an initial mechanical line contact between the envelope and copper block which, with a suitable brazing alloy wire ring **64**, bonds and establishes a secure connection therebetween during processing of the tube at high temperatures.

Anode section **26** also accommodates an X-ray exit port **31** which usually is a window of beryllium or glass. It is spaced opposite the surface of target **29** to be impacted by electrons and that surface **29***a* is canted toward the window. Obviously, the target is constructed of a material, such as tungsten, which emits X-rays in response to electron bombardment. The angle of inclination of the target is chosen in accordance with the desired apparent dimensions of the target source as viewed through window 31. Depending on the requirements of the installation, this may vary from a line to a simulated point source.

The remainder of the tube envelope comprises a copper section 25*b* which terminates in a sealing flange 25*c*. There is an insulated envelope section 25*d* formed of glass or ceramic having at one end a metallic sealing flange 25*e* which is heliarc welded to flange 25*c*. At its opposite end the insulated segment 25*d* has a conductive cap formed to provide the shoulder or recessed section 21 which receives and mechanically supports sleeve 9 of the electron gun assembly. This cap is further part of the metal-to-glass seals 15 which complete the vacuum tube envelope. The envelope section 25 has the usual tubulation 32 through which a vacuum system may be attached to draw the desired vacuum within the envelope during processing of the tube. The vacuum condition is established, in the usual way, by pinching off this tubulation which is protected by a cap 33 fitting thereover and carried by an anode support ring 34 which is formed of non-magnetic material.

Finally, the generator has means for establishing a focus field in the region between the cathode and the anode to form electrons emitted from the cathode surface into a converging beam having a cross section determined, at least initially, by the configuration of the focus field. For the embodiment under consideration, an electric focusing field is established by connections which provide the necessary potential gradient between the electron gun on the one hand and the anode structure on the other. Preferably, the anode is operated at ground potential as indicated by the usual symbol while a negative potential $-E_k$ is applied to the electron gun through a connection 35, which may be a ring of the well-known RF contact finger structure, engaging envelope cap section 21 to establish an electrical connection therewith. The circuit connection is extended by virtue of conductive support sleeve 9 to both cathode 10 and focus electrode 17 which operate at the same potential. Since the anode structure is conductive, ring section 25*a* and target 29 operate at the same potential and the spacing of these elements causes a substantially field-free space to exist therebetween.

If the component parts of the electron gun are annular as is usually the case, the electron beam developed within the tube tends to be circular or annular in cross section but it is usually more desirable in X-ray tubes to have a point or line impact of electrons on target surface 29*a*. While more sophisticated focusing electrode arrangements may be employed in or in conjunction with the electron gun to achieve beam shaping, it is convenient to provide additional beam forming means positioned adjacent the beam path between anode ring 25*a* and target 29 in order to obtain the desired shape of the beam. Electric or magnetic beam shaping may be employed but a magnetic arrangement is represented in the drawing because of its simplicity and also because of the flexibility which it permits.

As represented, the magnetic beam forming device comprises a number of pairs of electromagnets. One pair, 40, 40*a* is shown in FIGURE 1 with the two magnet structures spaced from one another on diametrically opposed sides of the beam path and externally of anode portion 26. Another pair of magnets (not shown) is preferably used in addition, again spaced on opposite sides of the beam path externally of the anode structure and in a plane which is perpendicular to the plane of electromagnets 40, 40*a*. The larger the number of magnet pairs, the greater the control which is available for beam shaping if, as preferred, each magnet has in effect its own power supply. This does not require a completely independent power supply for each magnet but does imply that the ampere turns and polarity of flux is subject to adjustment for the individual magnets. Of course, if the number of pairs of magnets is increased to the ultimate, the structure becomes a circular magnet which, if the field strength is sufficient, tends to shape the beam into a point of small circular impact on target 29.

The core or magnet structure of each of magnets 40 and 40*a* has a gap 41 as shown in FIGURE 1. In the presence of this gap, a fringing magnetic field is created and that field projects into anode cylinder 26 to serve as an electromagnetic lens through which the electron beam passes. The strength of the lens is determined by the strength of the magnetic flux and varies with the square of the current traversing the winding 42 of each magnet. As indicated above, it is contemplated that there be individual adjustment available of the ampere turns and therefore of the flux of each such magnet.

In considering the operation of the described structure as a generator of X-rays, it will be understood that the tube is connected to the necessary power supplies including a source of heater voltage connected to heater lead-ins 13, 13 and a source of cathode potential $-E_k$ applied to RF connector 35. The anode structure is maintained at reference or ground potential. It will be assumed that the cathode potential is not applied until the heater circuit has been energized sufficiently long to bring cathode button 10 to its operating temperature. The application of cathode potential at this time results in the emission of electrons from cathode button 10 and these electrons encounter an electrostatic focusing field due to the potential gradient between the electron gun and the anode portion 25. Representative equipotential lines of this field are indicated by broken construction lines 50*a*–50*e*. In the region between the cathode surface and anode ring 25*a*, the field is predominantly a converging focusing field which causes the electrons to be converged into a beam of circular cross section focused upon target 29. As the beam traverses the space leading to target 29, it encounters the magnetic lens resulting from the fields contributed by the pairs of beam shaping magnets 40, 40*a*. Each such pair of magnets have a converging effect on the beam and, if the effective lens is sufficiently strong, the beam cross section is modified from its initial annular cross section to a substantially rectangular or linear shape as the beam impacts target surface 29*a*. The apparent dimension of the impacted area of the target is the dimension of the impacted area as seen by looking at the canted target face through exit port 31. The angle of the face is in the order of 6 or 7° and the X-rays appear to originate from a square point source which is an ideal result for the taking of certain X-ray pictures.

In the operation of the tube, heat shields 16 provide efficient heater operation and also protect insulator 25*d* from breakdown which might otherwise result because of the temperatures that can be encountered in the use of the tube as an X-ray source. The penetrating effect of the X-rays, and the depth of material through which X-ray pictures may be taken, is a function of electron velocity and therefore a function of the operating potentials of the tube. In terms of output, the yield is 0.3 roentgen per kilojoule measured at a distance of 40 inches and with an operating potential of 100 kilovolts.

The quantity of X-rays in a space charge limited type of tube, such as that under consideration, is a function of beam current which may be expressed in terms of operating voltage in accordance with the following:

$$I=kV^{3/2}$$

where k is a constant referred to as the perveance and V is the anode-cathode potential.

Ane embodiment of the invention, when operated at 100 kilovolts, had a beam current of approximately 60 amperes and at a potential of 150 kilovolts, had a beam current of approximately 125 amperes. The diameter of target 29 was approximately ½ inch, the diameter of anode ring 25*a* was 1½ inches, and the diameter of the cathode button 10 was 2⅜ inches. The spacing of the leading edge of anode ring 25a, that is the portion thereof closest to focus electrode 17, from the target was approximately 3⅞.

The described tube is particularly well suited for X-ray cineradiography. The ratio of cathode area to beam cross section as measured at target 29 is very large, being in the neighborhood of at least 2000, so that the quantity of X-rays generated is copious. When associated with a pulsed modulator, the programming is exceedingly flexible. X-rays of a fraction to several microseconds duration are easily obtainable over a variety of repetition rates. This renders the system uniquely applicable for cineradiography.

Even though large quantities of X-rays are generated, the tube exhibits extraordinary life. More than four million shots of one microsecond duration have been realized with a single tube. This is a unique feature of the tube since previous structures, wherein the cathode faces the target without an intervening ion shield or protector, suffers cathode breakdown after relatively few firings. Cathode destruction has resulted heretofore from the fact that positive ions may result during X-ray generation and, if they are developed, they may be accelerated to the cathode in the same fashion as electrons are accelerated to the target. The heavy mass of the ion causes cathode deterioration but this deficiency of prior devices is avoided in the described structure because of the relatively field-free space established between target 29 and anode ring 25a. The desired field-free characteristic is realized by so dimensioning the anode structure that the focus field which penetrates into anode portion 26 is very low in the immediate vicinity of the target. When the ions that may be developed find themselves in a field-free space, there is no accelerating force to cause them to leave the anode and hence impact upon and destroy the cathode.

It is recognized that even with this relatively field-free space, ions may occasionally be produced and move in the direction of the electron gun. If this is experienced, such ions upon reaching the focus field which has penetrated into anode cylinder 26, are subjected to a positive lens which tends to converge the ions to a vary small portion of the central region of the cathode. This focusing effect protects most of the cathode area from the deteriorating influence of impacting ions and prolongs the tube life markedly. If desired, the central portion of the cathode button may be a small island of tungsten which further protects against the damaging impact of tunsten ions.

Further protection may be achieved by pulsed operation of the tube. If the potential pulse applied to the cathode is only a microsecond in duration, for example, ions do not have sufficient time to acquire the full energy due to their mass and also due to the fact that they originate in a low electrostatic field region.

A modulating system, especially suited for exciting the described tube in the taking of X-ray pictures or for other uses, is disclosed and claimed in a copending application Serial No. 93,509 filed March 6, 1961, in the names of Leigh Curtis Foster and Pierce E. Reeves and assigned to the same assignee as the present application.

Arranging to have the target and beam in a field-free region, exposed to metal surfaces only, has other distinct advantages. The build up of surface charges, experienced when the beam is exposed predominantly to insulating surfaces, is minimized and there is little likelihood of failure of the envelope due to discharge on any such surface. Also, it is known that tungsten and other target materials tend to evaporate to some extent in the use of the device and if the vaporized metal deposits on an insulating surface, breakdown may result. This too is obviated with the anode structure of FIGURE 1.

As illustrated in FIGURE 1, the tube has a continuous small diameter section 26 formed of conductive material and maintained at a uniform potential. If desired, this portion of the anode structure may be comprised of alternate conductive and insulating cylindrical segments to increase the flexibility of the device by making possible post-acceleration or post-deceleration of the beam. The axial length of any insulating section preferably is as short as possible, compatible with the potential that the section is to hold off without breakdown.

Where successive anode segments, considered in a direction from the cathode to the target electrode, are operated at increasing positive potential levels, post-acceleration of the beam is accomplished. This is an especially convenient mechanism for attaining high energy beams without introducing the possibility of exceeding the breakdown limitation of the gun structure. For example, if beam energy corresponding to an operating potential of 500 kv. is desired, the beam would be developed by the application of potentials well within safe operating limits to the first anode segment and then succeeding ones would have increasing potentials up to the maximum of 500 kv. The successive electrodes of the anode structure provide positive lens effects and maintain the beam in focus. Of course, it is most desirable that the axial length of the final electrode section of the anode be dimensioned so that the target is in a relatively field-free space for the reasons discussed above.

In some installations it may be desirable to have a beam of the full current capabilities of the tube but at reduced voltage and this may be accomplished with the multi-section anode structure by arranging that the first anode section operate at a potential to attain full cathode emission while the final anode section operates at a reduced potential to decelerate the beam to the desired level. For example, the first anode section might operate at a potential of approximately 150 kv. to draw 120 amperes from the cathode and a final anode section may be operated at 50 kv. with respect to the cathode to the end that a 50 kv., 120 ampere beam results.

A modified form of beam-shaping arrangement is represented in FIGURE 4. In this case, there is a first beam-shaping magnet 50 located adjacent the portion of anode section 26 which is closest to the cathode. This magnet preferably is circular in cross section and the field or lens which it establishes within anode section 26 is likewise circular to reduce the beam in cross section while retaining a generally annular cross sectional configuration. Positioned next along anode section 26 are one or more pairs 51 of beam-shaping electromagnets similar to the magnets 40 and 40a in the embodiment of FIGURE 1. If one pair of magnets 51 is provided, positioned diametrically opposed to one another on the external periphery of anode section 26, the circular beam emanating from the lens established by magnet 50 may be changed to have a generally linear or rectangular cross section. If a second pair of such magnets is provided, in a plane perpendicular to the plane of the first pair, the rectangular cross section may be modified to essentially square. Also, having two pairs of magnets following annular magnet 50 but displaced from one another along anode portion 26 to have complete freedom of rotation relative to one another provides even more flexibility in shaping the beam cross section.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. An X-ray generator comprising: an electron gun for projecting an electron beam along a given path including an electron emissive cathode located coaxially of said path and a heater for said cathode; an anode structure having a conductive cylindrical portion positioned axially of said path and spaced from said cathode, having an open end facing said cathode, said cylindrical portion having

a radius small compared to that of said cathode and supporting at its end remote from said cathode a target portion, constructed of a material which radiates X-rays in response to electron bombardment, disposed across said path; means for establishing a focusing field in the region between said cathode and said cylindrical portion to form electrons emitted from said cathode surface into a converging beam of substantially circular cross section focused on said target and for establishing said cylindrical portion and said target at approximately the same operating potential, the spacing of said target from said open end of said cylindrical portion being greater than the depth of penetration of said focusing field into said anode cylinder; and adjustable magnetic means supported externally of said anode cylinder for establishing a magnetic beam shaping field about the beam path to selectively shape said beam into any of a plurality of predetermined different non-circular beam cross sections at said target.

2. An X-ray generator comprising: an electron gun for projecting an electron beam along a given path including an electron emissive cathode located coaxially of said path and a heater for said cathode; an anode structure having a conductive cylindrical portion positioned axially of said path and spaced from said cathode, having an open end facing said cathode and closed at the opposite end, said cylindrical portion having a radius small compared to that of said cathode and supporting at its closed end a target portion, constructed of a material which radiates X-rays in response to electron bombardment, disposed across said path; means for establishing a focusing field in the region between said cathode and said cylindrical portion to form electrons emitted from said cathode surface into a converging beam of substantially circular cross section focused on said target and for establishing said cylindrical portion and said target at approximately the same operating potential, the spacing of said target from said open end of said cylindrical portion being greater than the depth of penetration of said focusing field into said anode cylinder; a pair of independently adjustable magnets supported externally of said anode cylinder in space-opposed relation for establishing an adjustable magnetic beam shaping field about the beam path to selectively shape said beam into any of a plurality of predetermined different non-circular beam cross sections at said target.

3. An X-ray generator comprising: an electron gun for projecting an electron beam along a given path including an electron emissive cathode located coaxially of said path and a heater for said cathode; an anode structure forming part of the housing of the generator and having a conductive cylindrical portion positioned axially of said path and spaced from said cathode, having an open end facing said cathode, closed at the opposite end and having an X-ray exit port located near said closed end, said cylindrical portion having a radius small compared to that of said cathode and supporting adjacent said exit port a target portion with an electron beam impact surface canted to face said exit port, constructed of a material which radiates X-rays in response to electron bombardment, disposed across said path; means for establishing a focusing field in the region between said cathode and said cylindrical portion to form electrons emitted from said cathode surface into a converging beam of substantially circular cross section focused on said target and for establishing said cylindrical portion and said target at approximately the same operating potential, the spacing of said target from said open end of said cylindrical portion being greater than the depth of penetration of said focusing field into said anode cylinder; and magnetic means supported externally of said anode cylinder for establishing an adjustable magnetic beam shaping field about the beam path to selectively shape said beam into any of a plurality of predetermined different non-circular beam cross sections at said target including one which, when viewed through said exit port, simulates a point X-ray source.

4. An X-ray generator comprising: an electron gun for projecting an electron beam along a given path including a cathode having an emitting surface in the form of a sector of a sphere located coaxially of said path, a heater for said cathode, and a ring-type focus electrode positioned adjacent to and concentric with said cathode; a conductive anode structure constituting a portion of the housing of said generator having a first cylindrical portion spaced from but enclosing said focus electrode and joined with a second cylindrical portion having a radius small compared to that of said cathode surface and extending coaxially of said path, said anode structure further including a target having a beam impacting surface inclined to said path, constructed of a material which radiates X-rays in response to electron bombardment, having a radius small compared with that of said second cylindrical portion and disposed across said path at the end of said second portion remote from said cathode; said second cylindrical portion further including an X-ray exit port facing said target surface; means for establishing an electric focusing field in the region between said cathode and said second cylindrical portion of said anode to form electrons emitted from said cathode surface into a beam converged upon said target, the spacing of said target within said second cylindrical section of said anode structure exceeding the depth of penetration of said focusing field into said second cylindrical section; and adjustable magnetic means supported externally of said anode cylinder for establishing a magnetic beam shaping field about the beam path to selectively shape said beam into any of a plurality of predetermined different non-circular beam cross sections at said target.

References Cited by the Examiner

UNITED STATES PATENTS

1,657,292	1/28	Williamson	313—57.1 X
2,518,472	8/50	Heil	313—86
2,559,526	7/51	Van De Graaf et al.	313—57 X
2,683,223	7/54	Hosemann	250—99
2,944,175	7/60	Taylor	313—84.2 X
2,946,892	7/60	Bas-Taymaz	313—57 X

GEORGE N. WESTBY, *Primary Examiner.*

RALPH G. NILSON, *Examiner.*