United States Patent [19]

Gralenski et al.

[11] **3,892,989**

[45] ***July 1, 1975**

[54] **CONVERGENT FLOW HOLLOW BEAM X-RAY GUN CONSTRUCTION**

[75] Inventors: **Nicholas M. Gralenski,** Aptos; **George Wada,** Palo Alto, **David J. Bates,** Los Altos, all of Calif.

[73] Assignee: **Watkins-Johnson Company,** Palo Alto, Calif.

[*] Notice: The portion of the term of this patent subsequent to Aug. 7, 1990, has been disclaimed.

[22] Filed: **May 9, 1973**

[21] Appl. No.: **358,667**

Related U.S. Application Data

[62] Division of Ser. No. 122,065, March 8, 1971, Pat. No. 3,751,701.

[52] **U.S. Cl.** **313/59;** 313/57; 313/300

[51] **Int. Cl.** **H01j 35/14;** H01j 35/30

[58] **Field of Search** 313/59, 330, 57, 55, 76, 313/82, 86, 87, 107.5, 296, 297, 300

[56] **References Cited**

UNITED STATES PATENTS

1,715,152	5/1929	Ulrey et al.	313/59
1,717,309	6/1929	Bouwers	313/59
3,691,417	9/1972	Gralenski	313/57
3,751,701	8/1973	Gralenski et al.	313/57

Primary Examiner—John Kominski
Assistant Examiner—Darwin R. Hostetter
Attorney, Agent, or Firm—Flehr, Hohbach, Test, Albritton & Herbert

[57] **ABSTRACT**

An X-ray generating tube characterized by grid means formed with narrow annular slits which serve to isolate the cathode from being influenced by the high voltage of the anode. According to one embodiment, a target formed as a hollow conical surface of revolution closed at one end forms an X-ray window at one end of the tube. According to another embodiment, the axis of the tube remains substantially unobstructed whereby X-rays generated from a conical surface of the type noted above are emitted at the end of the tube disposed opposite the target end. Another embodiment combines the advantages of the first named and last named embodiment by utilizing concentrically oriented coaxially disposed electron beam control elements formed with a narrow annular slit for passing electrons radially into the axial region of the tube.

4 Claims, 9 Drawing Figures

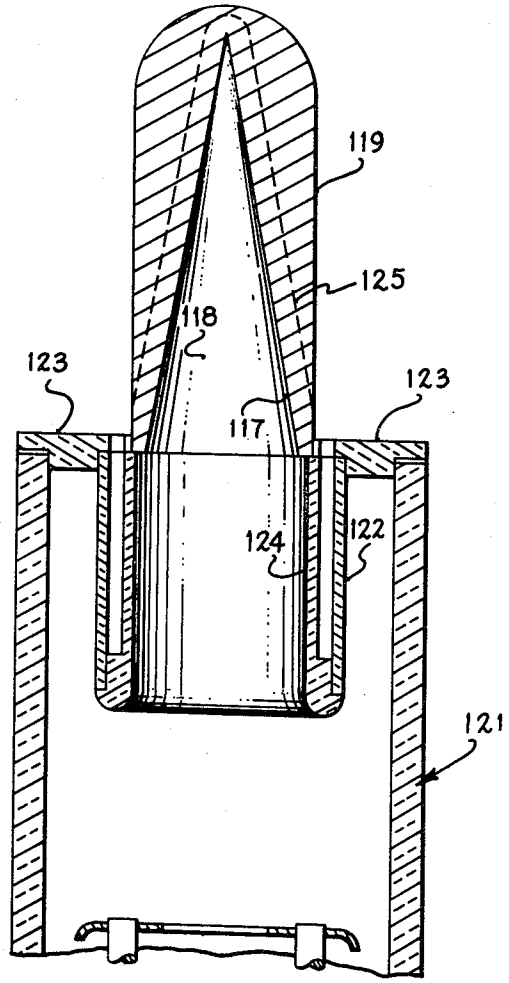
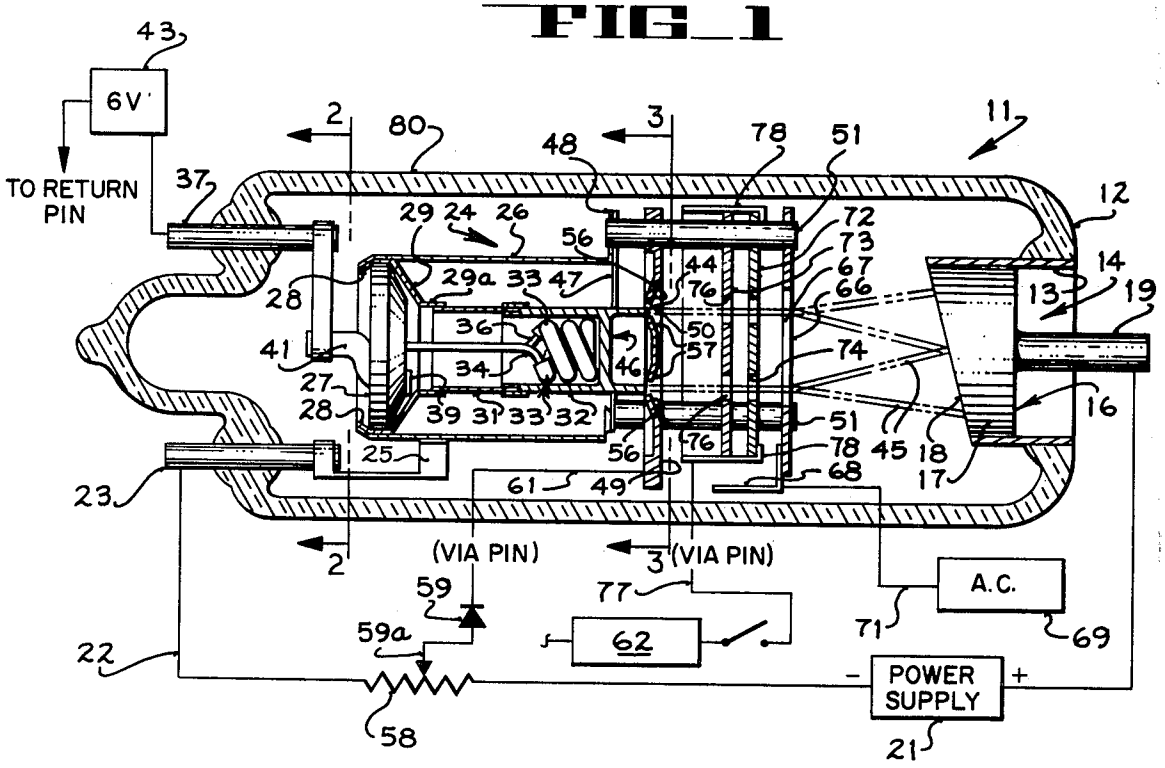


FIG_1



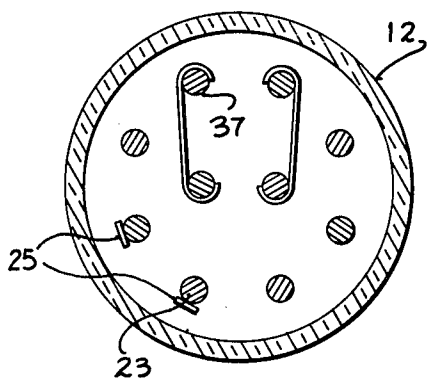


FIG_2

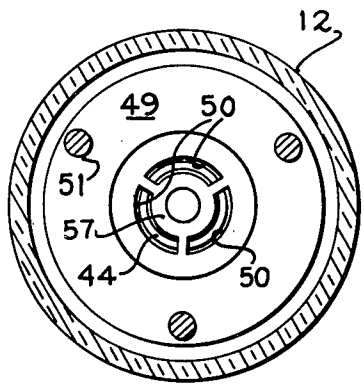


FIG_3

FIG_4

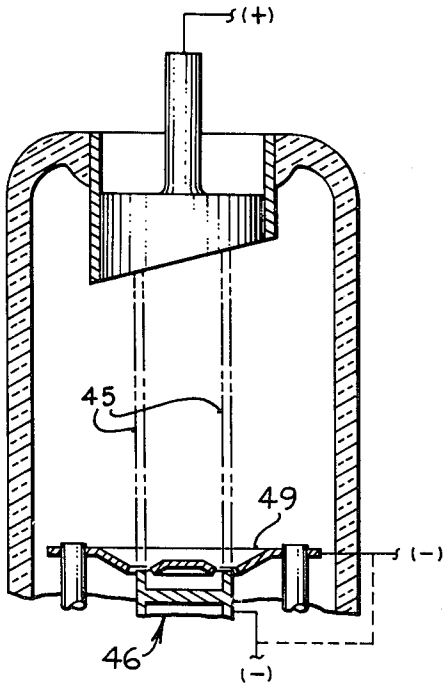


FIG_5

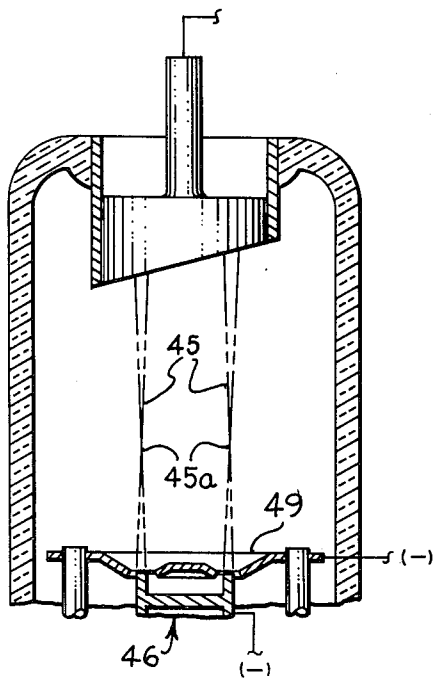


FIG_6

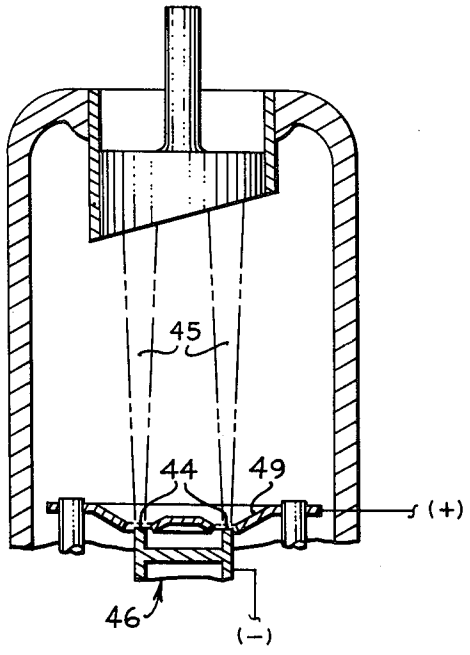
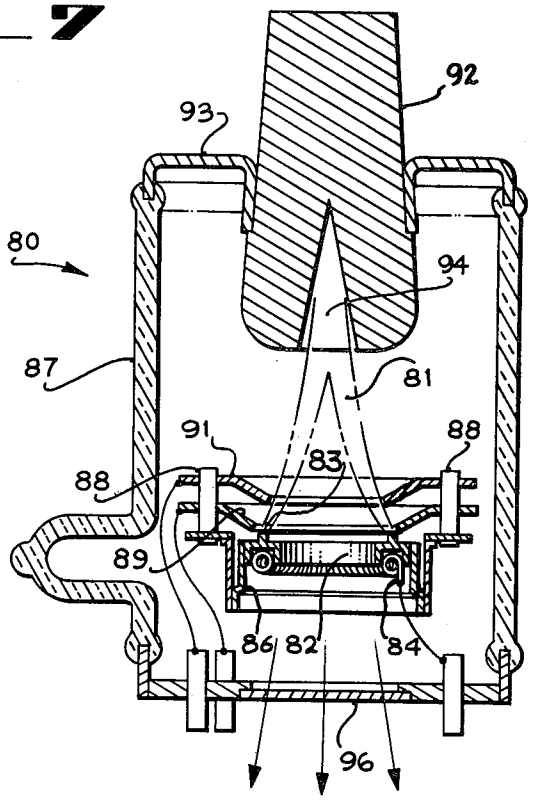


FIG_7


92
93
80
94
87
81
91
88
83
88
89
86
82
84
96

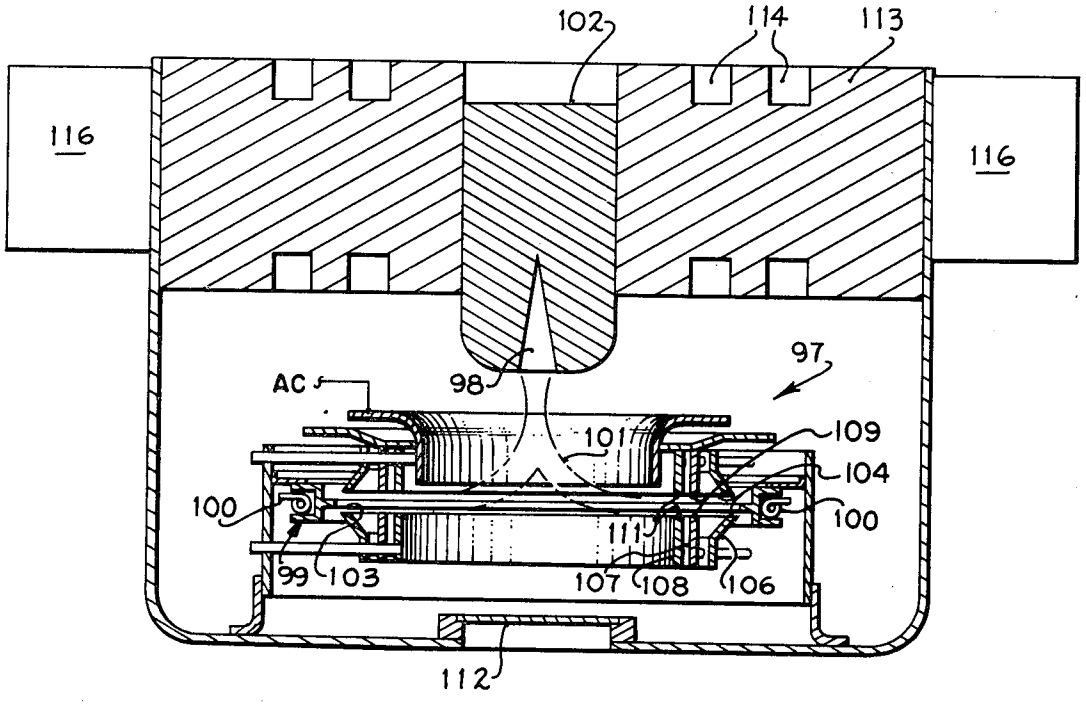
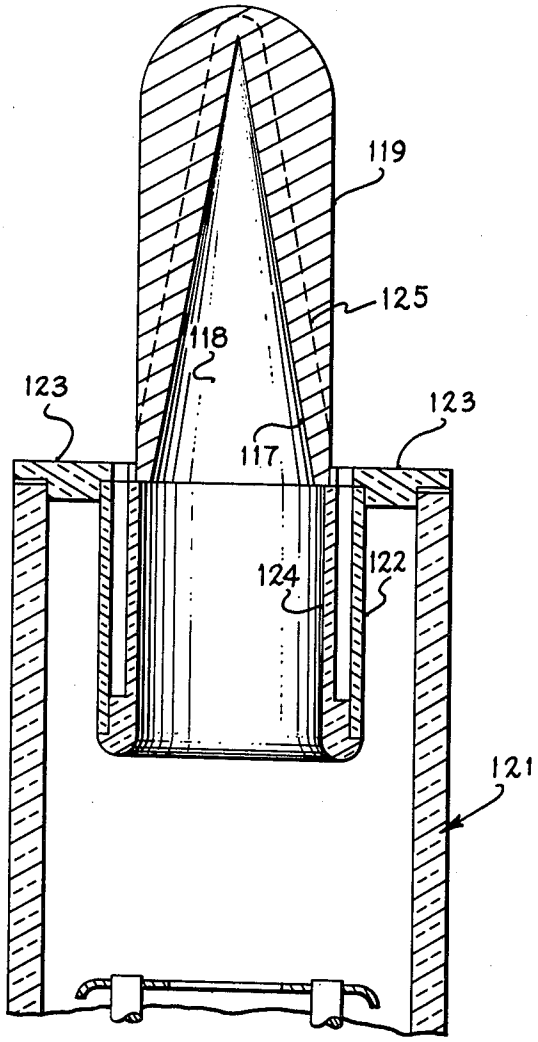

102
114
113
116
116
97
AC
98
101
109
104
100
100
111
99
103
107
108
106
112

FIG_8

FIG_9



CONVERGENT FLOW HOLLOW BEAM X-RAY GUN CONSTRUCTION

CROSS-REFERENCE TO RELATED APPLICATION

This application is a division of U.S. Ser. No. 122,065, filed Mar. 8, 1971, now U.S. Pat. No. 3,751,701, in the names of Nicholas M. Gralenski, George (NMI) Wada and David J. Bates, entitled CONVERGENT FLOW HOLLOW BEAM X-RAY GUN WITH HIGH AVERAGE POWER, and assigned to Watkins-Johnson Company, recorded March 8, 1971, Reel 2715, Frames 750–753.

BACKGROUND OF THE INVENTION

This invention pertains to an X-ray generating device or gun of a type having a beam of electrons for impinging upon a target material serving to generate X-rays within an evacuated tube. More particularly, this invention pertains to an X-ray gun having improved means for control and employment of the electron beam in such gun.

Heretofore, X-ray tubes have been known in which a hollow electron beam is directed against a target material for generating ions. In operation, such devices have typically experienced difficulty in obtaining a sufficiently small electron impact area hereafter referred to as the "spot" on the target material. By use of a tiny spot, it is possible to obtain sharper radiograms as compared to those taken with a larger spot. However, when the spot is reduced in size substantially to a point source considerable heat is immediately generated on the surface of the target and damage can be caused.

In addition, under the foregoing and other circumstances, it is usually advantageous to employ a relatively high beam intensity. The beam intensity is increased by increasing the difference in potential between the target and cathode whereby the target will appear to be quite positive with respect to the cathode. It has been observed that, in certain hollow beam X-ray tubes heretofore constructed, the presence of a substantial voltage differential between the cathode and target results in the target influencing the emissive characteristic of the cathode.

Accordingly, it is desirable that the beam intensity from the cathode be made independent of the voltage on the target.

As disclosed herein, a conically-shaped target has been provided with a hollow electron beam in a manner serving to obtain the advantages of an extremely small spot together with high beam intensity without danger of overheating the target.

In addition, as described herein, the manner of orientation of the target with respect to the cathode provides a gun arrangement with better control of secondary electrons emitted from the target in the course of bombarding the target.

SUMMARY OF THE INVENTION AND OBJECTS

In general, there is provided an X-ray generating device for a type employing a target of material disposed to be struck by high energy electrons to develop X-rays. A cathode having an electron-emitting portion is adapted to be charged negatively with respect to the target to create a flow of electrons from the cathode portion to the target. A grid means disposed adjacent the cathode and across the flow of electrons is formed

in a manner to include an annular slit therein coaxially disposed relative to the axis of the flow of electrons for passing the electrons therethrough to the target. The slit is sufficiently narrow and the cathode is spaced sufficiently behind the slit so as to inhibit the high potential of the target influencing electron emission from the cathode portion. Further, an annular control element encircles the flow of electrons and is coupled to means for varying the diameter in response to variations in the potential applied to the control element.

According to one preferred embodiment, the electron beam impinges into the interior of a closed conical surface forming the target whereby the apparent spot size is relatively small as represented by the apex of the conical surface, but the surface area constituting the electronic impact area remains relatively large and in immediate conjunction with a heat sink or other material of a type serving to readily absorb the heat of impact of the electron beam.

According to two other preferred embodiments of the invention, a window for emitting X-rays from within the tube is formed coaxially of the hollow beam, in one instance at the end of the tube opposite the target end, and in the other instance at the target end itself.

In general, it is an object of the present invention to provide an improved X-ray tube construction capable of handling high average power without sacrifice of the advantages achieved by utilization of a small spot size.

Another object of the invention is to provide an improved X-ray generating device wherein X-rays can emerge from the device from either end.

The foregoing and other objects of the invention will become more readily apparent from the following detailed description of preferred embodiments when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a diagrammatic side elevation section view of an X-ray tube according to the invention;

FIG. 2 is a transverse section view taken along the line 2—2 of FIG. 1;

FIG. 3 is a diagrammatic section view taken along the line 3—3 of FIG. 1;

FIGS. 4, 5 and 6 are a series of diagrams illustrating the functioning of apparatus of the type shown in FIG. 1;

FIG. 7 is a side elevation section view of an X-ray tube according to another embodiment of the invention;

FIG. 8 is a side elevation section view of a portion of an X-ray tube according to another embodiment of the invention; and

FIG. 9 is an enlarged detail view diagrammatically illustrating a portion of another embodiment of an X-ray tube according to the invention adapted to be used in conjunction with apparatus of a type such as shown in the embodiment of FIG. 7.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An X-ray generating tube assembly 11 comprises an elongated evacuated envelope 12 of glass or ceramic material. At one end of envelope 12 a cylindrically-shaped metallic insert 13 of a type, such as Kovar, suitable for forming a metal seal with glass or ceramic as used in envelope 12, forms a re-entrant opening 14 into

which a target terminal assembly **16** can be mounted and sealed.

Assembly **16** comprises a cylindrical body **17** or section of suitable material, such as tungsten, to be bombarded by electrons to form X-rays within envelope **12.** Body **17** is formed with a planar face **18** disposed transversely of the axis of body **17** and oriented at an angle on the order of 76° thereto.

Body **17** is brazed inside of the metallic insert **13** and a suitably sized anode terminal rod **19** is brazed to the back of body **17.** Rod **19** is preferably of a highly heat conductive material so as to quickly dissipate heat from body **17** and form a heat sink therefor.

During the glassing operation where envelope **12** is formed of glass, the thinness and poor thermal conductivity of the Kovar insert **13** prevents heat from being excessively lost to other portions of assembly **16.** At the same time, rod **19** can be highly heat conductive to allow a rapid heat drain from body **17** during tube operation. In addition, cooling fins or the like can be attached to rod **19** by suitable means, such as soldering, after assembly **11** is completely vacuum sealed.

Terminal rod **19** is adapted to be coupled to the positive terminal of a relatively high voltage source on the order, for example, of 40,000 volts or much higher so as to form target assembly as the anode of tube assembly **11.** The other side of power supply **21** is directly coupled via line **22** to a cathode terminal **23** carried in the end of envelope **12.** Cathode terminal **23** is electrically coupled to cathode assembly **24** now to be described.

A generally cylindrical metallic body **26** encloses a ceramic insulator and support plug **27.** Plug **27** is held in place within body **26** by means of a retaining lip **28** bent around the rear edge of plug **27** on one side and by means of the generally conically-shaped hollow, annular enclosure **29** on the other.

Coaxially of plug **27** a relatively thin, cylindrical metal thermally-insulating sleeve **31** is spot welded at its rear end to a projecting collar portion **29*a*** of enclosure **29** and serves, at its other end, to support a heater housing **32** encircling the coils of a heater element **33.** Heater **33** is connected by leads **34, 36** passing through plug **27** and subsequently by attachment to respective ones of pins **37, 38.** Accordingly, a rivet **39** anchors the inner end of an L-shaped support leg **41** while a connecting strap **42** extends between leg **41** and pin **37.** A 6 volt power supply **43** or other suitable low voltage source can be used to energize heater element **33.**

The inner end of cathode assembly **24** carries an electron-emitting portion adapted to be charged negatively relative to target assembly **16** to form a flow of electrons from the cathode-emitting portion to the target. The electron-emitting portion of cathode assembly **24** comprises an annular oxide-coated surface portion in the form of the edge of lip **44** of the cathode element **46.** Element **46** consists of a suitable metallic material upon which there is deposited an oxide coating of a highly electron-emitting material, such as strontium, calcium, or barium, or a mixture thereof, deposited around the edge of lip **44.** The remainder of element **46** can be made of conventional cathode nickel.

Element **46** merges with housing **32** to form a heater cavity **46*a***. A perforated triangular plate **47** is formed with a hole or circular opening encircling in a closely spaced relation the end margin of housing **32.** The outer three corners of plate **47** are secured by suitable means such as spot welding to tabs **48** formed on the end of body **26.**

As thus arranged, plate **47** provides rigidity to the distal end of housing **26** and further serves to align and retain within relatively close tolerances the position of lip **44** with its electron-emitting annular surface portions.

The edge of lip **44** forms the source of a flow of electrons from cathode assembly **24** to target assembly **16.** Thus, the electron-emitting oxide-coated surface portion of lip **44** of cathode **46** is directed toward target assembly **16** in a manner to form a hollow, annular electron beam **45.**

For additional focusing of the beam onto target assembly **16,** a grid element **49** is carried by insulators **51** attached to plate **47** and grid **49** in coaxial relation to the oxide-coated electron-emitting surface of lip **44.**

Grid element **49** includes relatively broad surface portions disposed transversely to the axis of the electron beam **45** and includes tapered surface portions serving to direct the emitted electrons as a hollow beam of electrons toward the target.

Thus, grid element **49** includes an annular opening or slit **50** comprised of three arcuate sections **52** of a circle disposed coaxially of the center of grid element **49.** Between each adjacent pair of arcuate circle sections **52,** there remains a radial support **53** serving to hold the central ion shield **54** coaxially of grid **49.**

Grid **49** influences the electron emission of beam **45** and serves to direct it as an annular, hollow beam by means of the focusing action of the surfaces of grid **49** remote from cathode element **46.** An outer annular surface **56** slopes inwardly toward the center of grid **49** at a Pierce angle, for example, on the order of 22.5°. A second annular surface **57** tapers rearwardly and radially outwardly of the center of grid **49** at a similar Pierce angle. The two surfaces **56, 57** are spaced slightly to define the circular slit **50** coaxially of grid **49** through which electrons will be emitted from cathode element **46.**

Means are provided for biasing grid **49** to cathode potential or slightly above, as desired.

Accordingly, a variable resistance **58** taps into line **22** to provide a variable voltage drop between the potential on line **22** (and hence cathode **24**) and the potential of grid **49.** The wiper **58a** is directly connected via diode **59,** poled in a direction to pass current to grid **49,** via line **61** (entering envelope **12** through one of the pins disposed through the end of the envelope). Line **61** is directly attached to grid **49** as shown.

Accordingly, it is readily evident that grid **49** can be adjusted to the potential of cathode assembly **24** or arranged to a selected bias condition by the adjusting resistor **58.**

Ideally, as shown in FIG. **4,** beam **45** will form a substantially right cylindrical hollow beam when grid **49** has been biased to cathode potential. It has been also observed, however, that (FIG. **5**) with the grid at slightly negative potential, there will be generated an electron beam with divergent sides with a cross-over point **45a** located intermediate the grid and target.

Conversely, (FIG. **6**) with grid **49** slightly positive, the electron beam **45** will be slightly divergent from each of the bounding edges of annular lip **44.**

As now to be described, means have been provided for continuously varying the potential of an annular control element encircling the beam **45** so as to cause the beam to continuously vary in diameter in response

to variations of the potential applied to the annular control element. In this way, a continuously varying convergent/divergent flow of electrons in a hollow beam gun will be maintained with high average power while avoiding problems attendant the use of high power concentrated on a small spot on the target.

Thus, an annular spot size control grid **66** is supported upon insulator rods **51** so as to align its central opening **67** coaxially of beam **45.** Grid **66** is further electrically coupled via the semi-rigid strip **68** to an AC power supply **69** connected via lead **71** passing outwardly and through the end of envelope **12** via a suitable pin connection (not shown). Power supply **69** operates at a suitable frequency whereby the electron flow of beam **45** will cyclically diverge and converge between large and small diameter annular, hollow "spots" on the face **18** of body **17** in response to variations in potential applied to grid **66.**

In addition to the foregoing, and as shown in FIG. **1,** means for inhibiting the potential of target assembly **16** from influencing the electron emission from cathode portion **44** have been provided in the form of a pair of axially spaced grids **72, 73** formed respectively with narrow annular slits **74, 76** serving to pass the flow of electrons from the cathode to the target. Slits **74, 76** are sufficiently narrow and cathode portion **44** is disposed sufficiently behind slits **74, 76** so as to inhibit the potential of target **16** from influencing electron emission from cathode portion **44** when target **16** is at high voltage.

Control grids **72, 73** may be pulsed via lead **77** coupled to pulse generator **62** so as to cause emission of electrons from cathode lip **44.** Grids **72, 73** are of suitable metallic material, such as molybdenum, providing appropriate rigidity and electrical characteristics as are well known to those skilled in the art. The refractory nature of this material serves to protect cathode surface **44** from erosion caused by ion bombardment.

Grids **72, 73** are supported within envelope **12** by insulating pins **51** carried from tabs **48.** A cylindrical open-ended electrical shield **78** is then seamed directly to grids **72** and **73** as by spot welding.

From the foregoing, it will be readily evident that the embodiment shown in FIG. **1** can serve to provide relatively high average beam power while evenly distributing the electron energy of the beam over the target assembly **16.** Accordingly, discrete locations of high intensity within the beam will be averaged out over the broad target surface so as to minimize danger of localized hot spots. The slits formed in control grids **72, 73** act to isolate the electron-emitting portions of cathode **46** from being influenced by the high voltage of target **16.** Accordingly, means have been provided both for safeguarding against overheating of target assembly **16** and for obtaining high average beam power in a hollow beam X-ray tube.

According to another embodiment of the invention as shown in FIG. **7,** the further advantage of being able to obtain a very small electron impact area or spot whereby the sharpness and definition of radiographs becomes substantially improved has been provided as now to be described.

As shown in FIG. **7,** an annular electron beam is generated from an annular cathode **82** having an electron-emissive portion **83,** the cathode **82** being heated by a heater filament **84.**

Cathode **82** and heater **84** are supported by a relatively thin metal sleeve **86** disposed coaxially of an evacuated envelope **87** by suitable means.

Insulative stud supports **88** serve to support a focusing grid **89** and control grid **91** whereby the axis of X-ray tube **80** remains substantially unobstructed to the travel of electrons, ion, X-rays, etc.

A target **92** in the form of a relatively large tungsten block is supported at one end of tube **80** by means of a Kovar or other glass sealing annular metal seal **93.** Target **92** includes a conically-shaped electron impact zone **94** formed in the shape of a closed conical surface oriented in a manner whereby the sides converge in a direction leading away from cathode **82.**

By means of a type such as shown with respect to FIG. **1,** electrical control of grid **91** can serve to provide a continuously varying diameter to the annular beam of electrons generated by cathode **82.** In this way, the electrons will strike varying portions of zone **94** and, as arranged herein, by using the closed conical zone surface, it becomes possible to generate X-rays from a very small spot on the target.

Finally, an X-ray window **96** of material suitably pervious to X-rays, such as beryllium, is disposed in the opposite end of tube **80** whereby X-rays may be discharged axially of tube **80.**

In addition to the foregoing advantage of a structure as shown in FIG. **7,** the conical target surface provides an increased efficiency in the utilization of the secondary electrons in that secondary electrons are readily generated from the conical surface of impact zone **94** so as to continue to strike other portions of zone **94** thereby generating additional X-rays.

As shown in FIG. **8,** another embodiment of an X-ray gun **97** incorporates advantages and features of embodiments described above but with additional advantages of its own.

As noted above, certain advantages are obtained by means of the construction shown in FIG. **1.** Certain additional advantages are obtained in the construction shown in FIG. **7.** The advantages of both systems may be obtained upon use of the construction shown in FIG. **8** wherein a conical electron impact zone **98** is formed with sides which converge in a direction leading away from the cathode assembly **99.** In addition, the annular electron beam **101** has been provided in a manner whereby the high voltage of target **102** will not influence the emission of electrons from cathode assembly **99.**

Thus, a cathode assembly **99** with its associated heater **100** includes an electron-emitting portion **103** disposed to project radially inwardly of cathode assembly **99** and to direct electrons through a narrow slit **104** formed between the confronting edges of the two halves of a focusing grid element **106.** In addition, control grids **107, 108** each formed with a slit **109, 111** respectively serve to function in the manner disclosed with respect to the embodiment shown in FIG. **1** whereby cathode **99** will not be influenced by a high potential on target **102.** Accordingly, slit **104** and the slits **109, 111** are all sufficiently narrow and the cathode-emissive portion **103** is sufficiently removed from the foregoing slits that cathode **99** will not be influenced by the high potential of target **102.** Suitable electrical "lead throughs" and connections are made as before.

An X-ray window **112** of suitable material pervious to the transmission of X-rays, such as beryllium is mounted coaxially of electron beam **101** and impact zone **98** whereby a relatively high voltage can be applied to target **102** and X-rays projected outwardly from essentially a very small electron impact area or spot formed on target **102.** At the same time, the heat of impact of the electrons upon target **102** is dissipated over the relatively broad conical surface of the zone **98.**

In addition, a heat conducting electrical insulating plug or seal **113** of beryllium oxide formed with annular grooves **114** at each end thereof for improved voltage control serves to dissipate heat generated by target **102.** Further, cooling fins **116** can be provided to extend radially outwardly and spaced circumferentially about the perimeter of plug **113.**

Finally, according to another embodiment of the invention, the target becomes the X-ray transmissive window. More particularly, the target comprises an X-ray productive layer of material such as a sufficiently thin layer of tungsten **117** formed within a closed conical surface forming an electron impact zone **118** whereby X-rays can pass through layer **117.** A heat sink **119** in the form of a heat conductive material having X-ray transmissive qualities, e.g., beryllium, is mechanically supported to an end of the evacuated envelope **121** and immediately adjacent the target layer **117** whereby heat generated on target layer **117** can be readily dissipated while X-rays escape through layer **117** and heat sink **119.** The dashed line **125** (FIG. 9) represents the degree of reduction in the size of heat sink **119** which may be accommodated with the reduction in beam power and target voltage as desired.

Accordingly, as shown in FIG. **9,** an envelope **121** includes a cylindrical molybdenum sleeve **122** chosen for its thermal expansion coefficient corresponding substantially to that of glass as used in the end plug **123** of envelope **121.** Sleeve **122** is suitably secured into the end of plug **123** in conventional style whereas interiorly of sleeve **122,** a metal sleeve **124** such as may be provided from Monel metal is secured at the inner end of sleeve **122** to substantially rigidly support impact zone **118** coaxially of tube **121.** As thus arranged, a suitable electron gun can be provided to generate a hollow beam for bombarding electrons upon the target surface **117** and, upon generating X-rays, the X-rays will be discharged through the relatively thin layer of target material and subsequently through the X-ray transmissive beryllium material of heat sink **119.**

In this way, the X-ray window is disposed axially of the electron beam via heat sink member **119.**

From the foregoing, it will be readily evident that there has been provided an improved X-ray generating device solving a number of problems pertaining to the overheating of target material, limitations on high average power of the electron beam as heretofore encountered and in which the high resolution advantage of obtaining a minimum diameter spot so as to produce sharp radiograph images have been obtained.

We claim:

1. In an X-ray generating device of a type employing an evacuated enclosure and a target of material disposed therein to be struck by high energy electrons to develop X-rays, the improvement comprising a cathode having an electron-emitting portion adapted to be charged negatively with respect to said target to create an annular, hollow beam of electrons for impinging upon said target, said target being formed with a closed conical surface, said surface converging in a direction leading away from said cathode, means responsive to a potential applied thereto for focusing said beam onto said surface, a control element and means coupled to said control element for continuously varying the potential thereof to cause said flow of electrons to cause said annular beam to impinge upon said surface with a varying diameter in response to variations in said potential of the last named means, and a window formed to pass X-rays out of said enclosure axially of said beam.

2. In an X-ray generating device according to claim **1** further including means forming said window via said target.

3. In an X-ray generating device according to claim **1** wherein said target comprises an X-ray transmissive layer of material supported by a heat conductive X-ray transmissive member therebehind whereby to form said window axially of said beam via said member.

4. In an X-ray generating device of a type employing a target of material disposed to be struck by high energy electrons to develop X-rays, the improvement comprising a cathode having an electron-emitting portion adapted to be charged negatively with respect to said target to create a flow of electrons from said portion to said target, said target being formed with a closed conical surface portion and converging in a direction leading away from said cathode, a focusing grid element and means for applying a potential thereto for focusing said flow of electrons primarily onto said closed conical surface, annular grid means disposed adjacent said cathode and across said flow of electrons and including a slit therearound for passing said flow of electrons therethrough to move in a path leading toward said target, said slit being sufficiently narrow and said cathode portion being spaced sufficiently therebehind so as to inhibit the potential of said target from influencing said electron emission from said cathode portion, an annular control element encircling said flow of electrons, and means coupled to said control element for varying the potential thereof to cause said focused flow of electrons to provide an annular beam impinging primarily upon said surface with a varying diameter in response to variations in said potential of said last named means, said annular grid means and control element being each comprised of an annular member coaxially disposed with respect to each other.

* * * * *