June 23, 1970 G. A. LEAVITT 3,517,195

HIGH INTENSITY X-RAY TUBE

Filed July 2, 1968

Fig. 1.

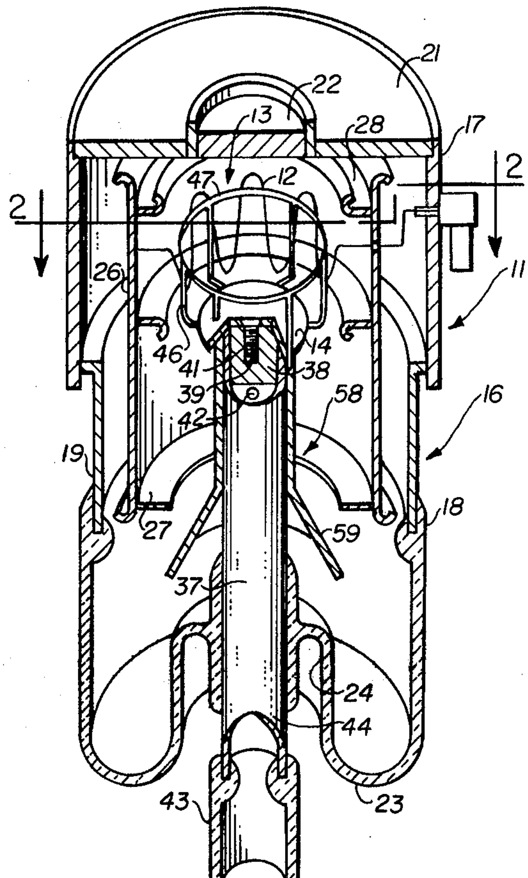


Fig. 2.

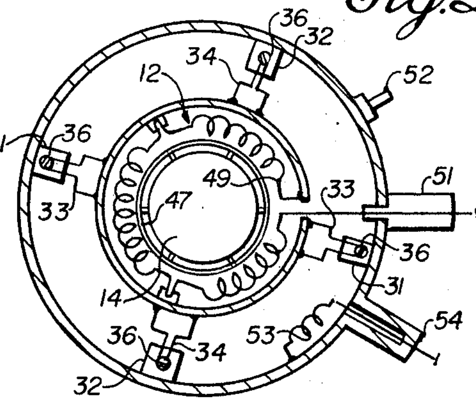
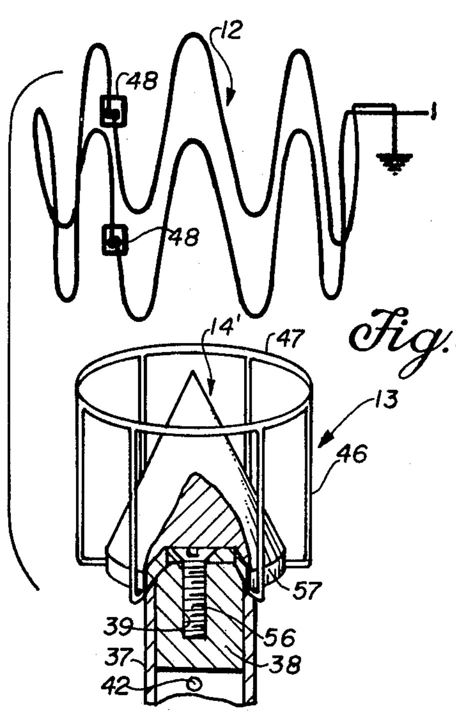


Fig. 3.



INVENTOR.
GEORGE A. LEAVITT

BY Roland A. Anderson

ATTORNEY

United States Patent Office 3,517,195
Patented June 23, 1970

3,517,195

HIGH INTENSITY X-RAY TUBE

George A. Leavitt, Livermore, Calif., assignor to the United States of America as represented by the United States Atomic Energy Commission

Filed July 2, 1968, Ser. No. 742,090
Int. Cl. H01j *35/18, 35/20*
U.S. Cl. 250—90 10 Claims

ABSTRACT OF THE DISCLOSURE

A tube for generating relatively high intensity, uniform density beams of X-rays having, for example, currents of tens of amperes for hundreds of microseconds. The beam may be uniformly dispersed over a relatively large diameter, and if desired the large diameter beam may be collimated into many closely spaced clustered small spots having nearly comparable lesser intensities. The clustered spots facilitate X-ray sampling at locations of much closer spacing than is obtainable with a cluster of small X-ray tubes due to the limitations imposed by their physical size. Alternatively, the tube may be employed to produce a very intense X-ray beam of small spot size.

BACKGROUND OF THE INVENTION

This invention was evolved in the course of, or under, Contract W–7405–ENG–48 with the United States Atomic Energy Commission.

X-ray tubes have long been employed as diagnostic tools in a variety of applications. Commercially available tubes are typically of either the very high current-short time interval flash variety productive of X-ray beam currents of the order of kiloamperes for time intervals of the order of fractions of microseconds, or the low current-long time interval standard type of tube productive of beam currents of the order of milliamperes for nearly continuous operation. Tubes operable in the area between these two categories, i.e., capable of producing medium beam currents of the order of tens of amperes for relatively long time intervals of the order of hundreds of microsoeconds have not been heretofore available. It is desirable that tubes of an intermediate category be provided since it would then be possible to obtain an X-ray suited to nearly any diagnostic requirement. In one application there is required a relatively long duration medium current X-ray beam uniformly dispersed over a relatively large beam diameter, e.g., 1½ inches, which may be collimated to form a plurality of clustered closely spaced small beam spots substantially equal in intensity to each other. The collimated spots are employable for X-ray sampling of locations of much closer spacing, and therefore with much higher resolution, than has been previously possible. More particularly, the usual practice has been to cluster a plurality of miniature X-ray tubes to thereby provide a cluster of small beam spots for viewing by a correspondingly clustered array of detectors. Although semiconductor X-ray detectors of extremely small size are available which may consequently be clustered in very closely spaced relationship, limitations are imposed on the closeness of the spacing by the physical size of the clustered X-ray tubes producing the beam spots viewed by the detectors. The problem may be readily overcome by collimating a uniform relatively large diameter medium intenity beam from a single tube into a cluster of very closeyl spaced beam spots matching the attainable closeness of the spacing of the semiconductor detectors.

Various previous attempts to provide an X-ray tube having the advantageous characteristics noted hereinbefore were unsuccessful. The flash type of X-ray tube is

not suited to modification for operation at reduced currents and materially increased pulse lengths due to limitations imposed by the field emission cathode employed in this type of tube for current generation. Even when operated at medium currents, the cathode quickly fails by melting of the field emission points when the pulse length is increased to the extent desired. Modification and scaling up of the conventional low current-long time interval type of tube for pulsed operation with increased currents was also an unsatisfactory approach to the problem for several reasons. The thermionic emission employed in such tubes is limiting upon the quantity of electrons available for X-ray production. Consequently, in a conventional tube geometry employing a disc cathode coaxially spaced from a disc anode inclined to the tube axis, a relatively large diameter cathode is required to provide a sufficient electron emission density. It was found that the necessary emission densities could not be obtained with practicable associated heater designs and values of heater power. Moreover, it was found that the electron beam did not expand sufficiently in a practicable distance between the cathode and anode to produce an X-ray beam having the desired relatively large diameter. Furthermore, the intensity of the X-ray beam generated with the inclined anode geometry was not uniform across the beam diameter. Accordingly, in order to provide an X-ray tube having the desired characteristics of medium beam current, relatively long pulse duration, and uniform intensity across a preferably large beam diameter, it was necessary to depart from conventional design.

SUMMARY OF THE INVENTION

The present invention relates to an X-ray tube having a novel electrode geometry capable of producing a medium current, relatively long pulse length X-ray beam, preferably uniformly dispersed over a relatively large beam diameter, although the beam may be alternatively concentated into a more intense spot of smaller diameter. The invention is particularly well suited to the production of an X-ray beam having, for example, a 90 ampere beam current for a 120 microsecond pulse length and uniformly distributed across a diameter of 1½ inches. As an important feature of the invention, the electrode geometry is capable of being scaled up to produce beam currents of hundreds of amperes.

In the accomplishment of the foregoing, an X-ray tube with novel electrode geometry in accordance with the present invention generally includes an anode coaxially disposed within an evacuated tube envelope in opposed spaced relationship to an X-ray transparent window thereof, and an annular directly heated cathode filament and concentric inwardly spaced annular electron accelerating grid coaxially disposed outwardly of the anode on the window side thereof. With heating current applied to the cathode filament to effect electron emission, and a positive potential applied to the anode and grid, electrons are accelerated radially inward from the filament and turned towards the anode for impingement uniformly over the surface thereof. The decelerative collisions of the electrons with the anode produce X-rays which are beamed coaxially through the window and have the desirable characteristics noted hereinbefore. The filament is preferably of sinewave configuration formed around a right cylindrical surface, while the grid is preferably provided as a cage of circumferentially spaced wires disposed parallel to the filament axis in order to insure that a sufficient quantity of electrons impinge the anode uniformly over its entire surface to produce an X-ray beam having the desired current and uniformity. The anode is preferably in the form of a circular disc in instances where a large beam diameter is desired. A conical anode is best employed in applications where a more intense beam of small spot size is required.

In accordance with a further important aspect of the invention, means are incorporated in the tube to prevent breakdown between external electrode terminals thereof due to ionization of air at the external surface of the envelope by the emitted X-rays.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view, with portions broken away, of an X-ray tube in accordance with the present invention, as arranged to produce an X-ray beam of relatively large diameter.

FIG. 2 is a sectional view taken at line 2—2 of FIG. 1.

FIG. 3 is an exploded perspective view, with portions broken away, of the electrode geometry of the tube as modified to produce an X-ray beam of relatively small diameter.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Considering now the invention in detail with reference to the illustrated forms thereof in the drawing, there will be seen to be provided an X-ray tube **11** including cathode filament **12**, accelerating grid **13**, and anode **14** arranged in a novel electrode geometry within an evacuated envelope **16** to produce an X-ray beam having a medium current of the order of tens of amperes and relatively long pulse duration of the order of hundreds of microseconds. The envelope is preferably of enlongated cylindrical configuration including a cylindrical cupped metallic can **17** at one end, a cylindrical cupped glass insulating member **18** at the opposite end, and an intermediate annular metallic coupling **19** coaxially interconnecting the open ends of the can insulating member in hermetically sealed relationship. The end wall **21** of the can is provided with a central circular window **22** of beryllium, or equivalent material that is transparent to X-rays. The end wall **23** of the insulating member is formed with a coaxially reentrant cylindrical indentation **24** for purposes subsequently described.

Within the can **17** and annular coupling **19** there is mounted a tubular cylindrical open ended metallic ground plane and heat shield **26** in close inwardly spaced coaxial relation thereto. The shield is formed with inwardly flared annular flanges **27** and **28** adjacent its opposite ends and extends longitudinally between a transverse plane substantially adjacent the sealed joint between insulating member **18** and coupling **19**, and a transverse plane adjacent the end wall **21** of the can. The shield is additionally provided with an inwardly flared annular flange **29** at a location intermediate its ends encompassed by the peripheral wall of the can.

To facilitate mounting of the heat shield, a pair of diametrically opposed metallic lugs **31** are secured to the interior surface of the peripheral wall of the can **17** to project radially inward therefrom adjacent the end wall **21**. A second pair of diametrically opposed lugs **32** similarly project radially inward from the peripheral wall of the can adjacent the joint between the can and the coupling **19** at positions circumferentially spaced 90° from the lugs **31**. First and second pairs of diametrically opposed clips **33** and **34** are secured to the periphery of the heat shield at positions corresponding to the lugs **31** and **32**. The clips are formed with eyes receiving screws **36** threadably engaging tapped bores provided in the lugs to thereby secure the heat shield coaxially within the envelope in the previously noted position. The clips and lugs also serve to electrically connect the heat shield to the can.

Considering now the novel electrode geometry of the X-ray tube **11** in detail, it is to be noted that the anode **14** is disposed within the envelope **16** in coaxially spaced relation to the window **22**. More particularly, in one embodiment of the invention for producing an X-ray beam of relatively large diameter, the anode is of circular disc configuration and concentrically disposed within the intermediate flange **29** of heat shield **26** in inwardly spaced relation, as shown in FIG. 1. Mounting of the anode in position is preferably accomplished by means of an elongated metallic sleeve **37** which coaxially traverses the indentation **24** of the insulating member **18** in hermetically sealed relation thereto and extends into the envelope to a location adjacent the flange **29**. The proximal end of the sleeve relative to the flange is formed with a plug **38** having a central tap **39** extending thereinto. The tap is engaged by a threaded stud **41** coaxially projecting from the disc anode to thereby secure same in place. The sleeve serves as a pump out conduit, as well as an electrical terminal for applying high voltage to the anode. More particularly, at least one aperture **42** extends radially through the wall of the sleeve to communicate the sleeve bore with the interior of the envelope. A tubular member **43** of glass, or equivalent insulating material, is hermetically secured to the exterior end of the sleeve in spaced relation to the sealed joint between the sleeve and insulating member **18** such that an annular band **44** of the sleeve surface encompassed by the indentation **24** is exposed. The insulating tubular member **43** facilitates insulated communicable connection of the sleeve to a pump whereby the interior of the envelope may be evacuated to high vacuum dimensions. The exposed band **44** of the sleeve defines an electrical terminal for high voltage energization of the anode **14**.

In further respect to the novel electrode geometry, the cathode filament **12** is directly heated and disposed in an annular region of space coaxially outward of the anode on the proximal side thereof relative to the window **22**. The accelerating grid **13** is annular and concentrically disposed inwardly of the filament in coaxial outwardly spaced relation to the anode. The grid is electrically connected to the anode and is consequently at the same potential.

The filament is preferably of sinewave configuration formed around a right cylindrical surface such that the cycles of the sinewave are parallel to the axis of the envelope **16** and repeat in the circumferential direction. The sinewave filament provides an extended electron emissive surface capable of emitting copious quantities of electrons requisite to the production of X-ray beams of relatively high currents.

The grid is preferably provided as a cage of circumferentially spaced wires **46** extending longitudinally from the periphery of disc anode **17** towards the window **22**. The free ends of the wires are best secured to an interconnecting ring **47** to prevent sagging of the wires into the filament during operation.

Support of the filament in operative position is best facilitated by means of insulated fastening elements **48** secured to the heat shield **26** at circumferentially spaced positions thereof to project radially inward into securance with the filament. The filament is provided with an opening so as to define a pair of ends for facilitating energization with heater current. In this regard, one end is preferably electrically connected to the heat shield, as indicated at **49**. The other end of the filament is led through the heat shield, in insulated relationship thereto, into electrical connection with the conductor of a filament input terminal **51** mounted on the exterior of the can **17**. A ground terminal **52** is also conductively mounted on the can exterior. Thus, the terminal **52** may be connected to ground and a filament supply (not shown) connected between the terminals **51** and **52** to ground the can and heat shield and energize the filament with heater current, thereby resulting in the thermionic emission of electrons therefrom.

The X-ray tube **11** further includes a getter **53** preferably connected at one end to the interior surface of can **17**, and at the other end to the conductor of a getter input terminal **54** mounted on the can exterior. Thus, a power supply may be connected between the terminals **52** and **54** to energize the getter, whereupon same functions in the usual maner to establish high vacuum conditions in the envelope **16**.

In the overall operation of the X-ray tube **11**, the envelope **16** is first evacuated to establish a high vacuum therein. This is accomplished by connecting the tubular insulating member **43** at the exterior end of the sleeve **37** to a vacuum pump capable of pumping the envelope interior to rough vacuum dimensions. The getter **53** is momentarily energized to deposit some of the getter material on the interior surface of the envelope for the purpose of adsorbing residual gas and thereby establishing the desired high vacuum. A high voltage pulsed power supply is connected to the exposed band **44** of sleeve **37** to apply high voltage pulses to the anode **14** and grid **13**. Terminal **52** is connected to ground to thereby place the can **17** and heat shield **26** at ground potential. A filament supply is connected between terminals **51** and **52** to energize the filament **12** with heater current and thereby effect the generation of copious quantities of electrons. The electrons are accelerated from the filament radially inward and downward to impinge the anode **14** with a uniform distribution over its entire surface due to the electric field established by each pulse of positive potential on the grid and anode. The electrons suffer decelerative collisions with the anode productive of X-rays which are preferentially emitted in a slowly diverging relatively large diameter beam directed coaxially through the window **22**. By virtue of the substantial quantity of electrons emitted from the extended surface of the filament, and their uniform distribution over the anode surface, the X-ray beam has a relatively high current which is substantially uniformly distributed across the beam diameter.

The X-ray tube **11** may be modified to produce a more intense beam of reduced diameter, in which case a conical anode **14'** is employed in place of the disc anode **14**, as shown in FIG. 3. More particularly, the anode **14'** is secured to the end of sleeve **37** in inwardly spaced coaxial relationship to the grid **13** with the apex of the cone even with, or short of the ring **47**. Securance of the conical anode **14'** to the sleeve is preferably accomplished in a manner similar to that of the disc anode **14**. A threaded stud **56** projects coaxially from the base of the conical anode for engagement in the tap **39**. Although the grid wires **46** may be secured to the base of the anode **14'**, such wires are preferably secured to a washer **57** traversed by the stud **56** to thereby secure the grid structure in place.

As in the case of the disc anode **14**, electrons emitted from the filament impinge the conical anode **14'** with a uniform distribution over the surface thereof. However, the emission pattern of the conical anode is such as to concentrate the X-rays into an intense beam of small spot size transmitted coaxially through the window **22**.

It is to be noted that a relaitvely long insulated path exists across member **18** between the exposed band **44** of sleeve **37**, which is at high positive potential, and the metallic coupling **19**, which is at ground potential. Still, there would normally be a tendency for breakdown to occur across the exterior surface of insulating member **18** due to ionization of a surface film of air by a portion of the X-rays emanating from the anode being directed through the insulating member. However, in accordance with another important feature of the present invention the foregoing problem is obviated by the provision of means for masking the insulating member from X-ray emission at the anode. More particularly, an inverted funnel shaped metallic collar **58** is preferably concentrically mounted upon the sleeve **37** at a position wherein the outwardly flared conical portion **59** of the collar is disposed in radially inwardly spaced relation to the rim of flange **27** of heat shield **26**. In addition, the base edge of conical portion **59** is disposed within the insulating member **18** at a greater radius than that of the rim of flange **27**. Thus, the collar **58** in cooperation with the flange **27** block line-of-sight paths between the anode and insulating member while permitting free communication between the interiors of the heat shield and insulating member. Since the line-of-sight paths are blocked, the insulating member is masked from X-ray mission, and ionization breakdown between the coupling **19** and anode terminal band **44** is prevented. The collar also functions as a heat shield for protecting the seal between the sleeve **37** and indentations **24** of insulating member **18** against heat damage.

I claim:

1. An X-ray tube comprising an evacuated cylindrical envelope having an X-ray transparent window coaxially disposed in an end thereof, an anode disposed within said envelope in coaxially spaced relation to said window, an annular directly heated cathode filment coaxially disposed outwardly of said anode on the proximal side thereof relative to said window, filament supply means coupled to said filament for energizing same with heating current to thereby effect the emission of electrons therefrom, and means coupled to said anode for establishing an electron accelerating electric field extending between said filament and anode, whereby said electrons are accelerated to said anode for decelerative collisions therewith productive of X-rays directed coaxially through said window.

2. An X-ray tube according to claim **1**, further defined by said filament being of sinewave configuration formed about a right cylindrical surface disposed coaxially outward from said anode.

3. An X-ray tube according to claim **1**, further defined by said means for establishing an electron accelerating electric field comprising a tubular cylindrical metallic ground plane and heat shield coaxially mounted within said envelope in outwardly spaced encompassing relation to said filament, an annular accelerating grid concentrically disposed inwardly of said filament in coaxial outwardly spaced relation to said anode, means for applying ground potential to said ground plane and heat shield, and means for applying positive potential to said anode and said grid.

4. An X-ray tube according to claim **3**, further defined by said filament being of sinewave configuration formed about a right cylindrical surface disposed coaxially outward from said anode, and said grid comprising a plurality of circumferentially spaced longitudinally extending wires electrically connected to said anode.

5. An X-ray tube according to claim **4**, further defined by said anode being of circular disc configuration.

6. An X-ray tube according to claim **4**, further defined by said anode being of conical configuration and disposed with its apex substantially flush with the proximal ends of said grid wires relative to said window.

7. An X-ray tube according to claim **5**, further defined by said envelope including a cupped cylindrical metallic can having said window centrally of the end wall thereof and a cupped cylindrical insulating member, said can and insulating member having their open ends coupled in coaxially opposed thermetically sealed relationship, said insulating member having a coaxially reentrant cylindrical indentation formed in the end wall thereof, means electrically connecting said ground plane and heat shield to said can and coaxially mounting said ground plane and heat shield within said can to extend between a transverse plane adjacent the coupling between said can and insulating member and a transverse plane adjacent said end wall of said can, a metallic sleeve coaxially traversing said indentation of said insulating member in hermetically sealed relation thereto and extending into said ground plane and heat shield to an intermediate position thereof, said sleeve having an exterior end portion encompassed by the peripheral wall of said indentation in inwardly spaced relation thereto, means securing said anode and grid in electrically conducting relation to the interior end of said sleeve, said exterior end portion of said sleeve defining a terminal for connection of a positive potential supply thereto and thereby comprising said means for

applying positive potential to said anode and said grid, and means disposed within said envelope for blocking line-of-sight paths between said anode and insulating member to thereby mask the insulating member from X-ray emission at said anode and prevent ionization breakdown between said terminal and said can.

8. An X-ray tube according to claim 7, further defined by said filament being of sinewave configuration formed about a right cylindrical surface disposed coaxialy outward from said anode and inwardly from said ground plane and heat shield, and said grid comprising a plurality of circumferentially spaced longitudinally extending wires secured in electrically conducting relation to said anode and having their free ends interconnected by a ring.

9. An X-ray tube according to claim 7, further defined by said means for blocking line-of-sight paths between said anode and insulating member comprising an inwardly flared annular metallic flange of said ground plane and heat shield substantially in said transverse plane adjacent the coupling between said can and insulating member, said flange being coaxially spaced from said anode in the direction of said insulating member, and an inverted funnel shaped metallic collar concentrically mounted upon

said sleeve, said collar having an outwardly flared conical portion traversing the opening of said flange in radially inwardly spaced relation to the rim thereof with the base edge of said conical portion disposed within said insulating member at a greater radius than that of the rim of said flange.

10. An X-ray tube according to claim 9, further defined by said filament being of sinewave configuration formed about a right cylindrical surface disposed coaxially outward from said anode and inwardly from said ground plane and heat shield, and said grid comprising a plurality of circumferentially spaced longitudinally extending wires secured in electrically conducting relation to said anode and having their free ends interconnected by a ring.

No references cited.

JAMES W. LAWRENCE, Primary Examiner

C. R. CAMPBELL, Assistant Examiner

U.S. Cl. X.R.

250—96, 99; 313—55, 59