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HIGH ENERGY FIELD EMISSION ELECTRON RADIATION
PULSE GENERATOR, X-RAY APPARATUS AND
SYSTEM EMPLOYING SAME
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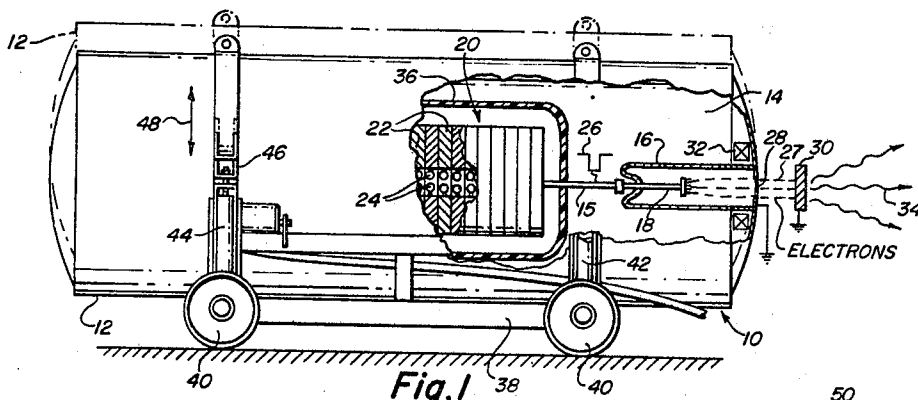


Fig. 1

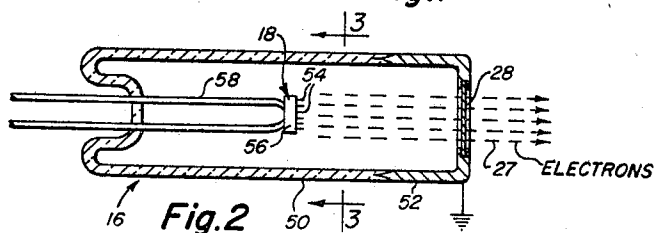


Fig. 2

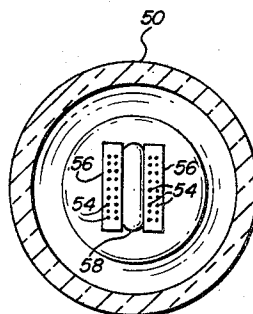


Fig. 3

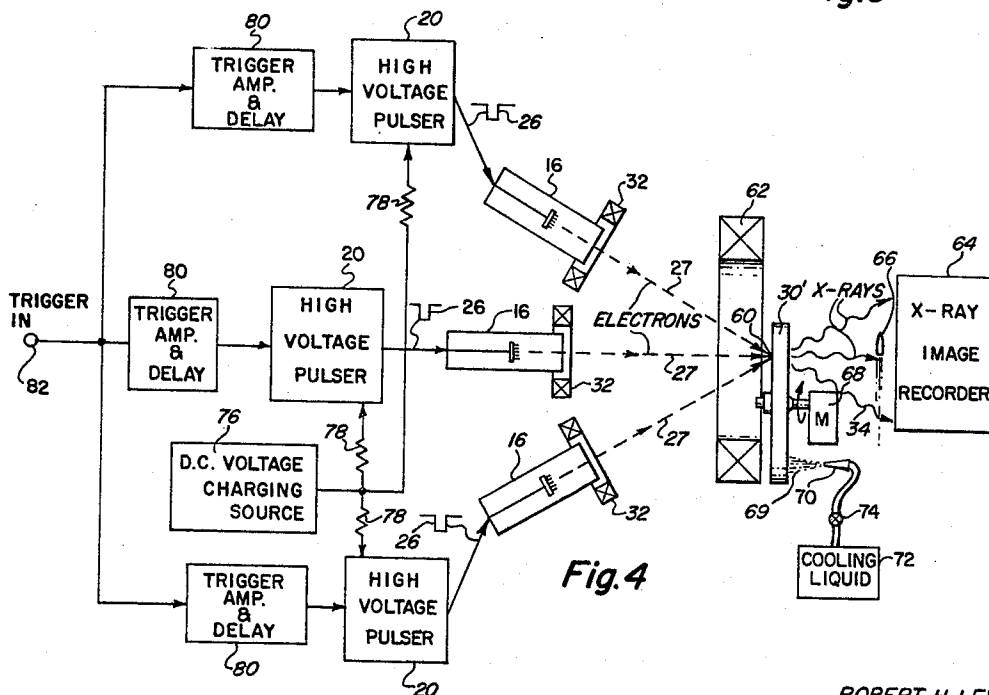


Fig. 4

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3,482,096

HIGH ENERGY FIELD EMISSION ELECTRON RADIATION PULSE GENERATOR, X-RAY APPARATUS AND SYSTEM EMPLOYING SAME

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17 Claims

ABSTRACT OF THE DISCLOSURE

A high energy field emission electron pulse generator and radiographic system is described in which an external target may be positioned in the atmosphere outside of the generator housing to convert the electron pulses to X-ray pulses. The housing is mounted on a wheeled carriage and contains an electron radiation tube having a field emission cathode and an electron transparent anode, as well as a pulser including a plurality of energy storage modules provided within a separate casing containing a gas different than the insulating gas within the remainder of the housing. Also described is a cineradiographic system employing a plurality of electron radiation tubes which bombard a common external target with electron pulses at different times to cause X-ray pulses to be emitted from a common focal spot thereon for recording the X-ray image of a moving object.

The subject matter of the present invention relates generally to the generation of narrow high energy electron radiation pulses by field emission, and more specifically to electron irradiation apparatus, an X-ray apparatus converting such electron pulses into X-ray pulses of high intensity, neutrons or other radiation, and to a cineradiographic system employing a plurality of electron pulse generators and a common external target which emits X-rays when bombarded by such electron pulses to record the X-ray image of a moving object.

Briefly, one embodiment of the electron pulse generator of the present invention includes a vacuum tube containing a field emission cathode structure including a plurality of spaced emitting elements, such as needles, knife edges, or microscopic points on a gross surface, and an anode window for transmitting electrons out of such tube, as well as a high voltage pulser including a plurality of energy storage modules connected together by spark gaps to enable such modules to be discharged in series through the electron tube. In order to provide an X-ray source, an external target is positioned outside the anode window of the electron tube and an electromagnetic coil is employed to focus the electrons emitted from such tube onto a small focal spot on such target to emit X-ray pulses therefrom. In addition, a plurality of such electron radiation tubes can be focused onto the same external target to provide a cineradiographic system which generates a plurality of short X-ray pulses from a common source at a high repetition rate by discharging their associated storage modules through the electron tubes at different times.

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The electron pulse generator of the present invention has several advantages over conventional electron radiation sources including the production of narrower pulses of higher current and voltage which may be, for example, 20 nanoseconds (10^{-9} seconds) wide with a current of 4000 amperes and a voltage of 2 million volts. This results in extremely high dose rates on the order of 3.5×10^{14} rads per second for such electron pulses. In addition, X-ray pulses emitted from an external target bombarded with electrons emitted by the electron radiation tube of the present invention, have a pulse width of about 17×10^{-9} seconds and a peak dose rate of 2×10^{11} rads per second, approximately.

These extremely high dose rates are made possible by employing a field emission cathode structure including a plurality of spaced emitting elements which may be needle-shaped and produce a vacuum arc operation in the manner described in our copending United States patent application Ser. No. 141,260 now Patent No. 3,259,773 filed Sept. 25, 1961 by W. P. Dyke and Frank J. Grundhauser of which the present application is a continuation in part. A portion of at least one of the cathode needles vaporizes when a high voltage electrical pulse is applied thereto, so that ions of cathode material are produced within the evacuated envelope of the tube. These positive ions neutralize the negative space charge ordinarily surrounding the field emission cathode elements and thereby enable much greater current to flow from such cathode to the anode for the brief period of time the tube is conducting. The present invention is an improvement over that shown in our earlier United States Patent No. 3,173,006 issued Mar. 9, 1965 to W. P. Dyke and F. J. Grundhauser.

The narrow electrical pulses of high voltage and high current applied to the electron radiation tube of the present invention are produced in a pulser unit connected to such tube by discharging a plurality of storage modules containing artificial transmission lines which are connected together by spark gaps in the manner shown in copending United States patent application Ser. No. 103,796 now Patent No. 3,248,574 filed Apr. 18, 1961 by W. P. Dyke, F. J. Grundhauser and N. W. Stunkard, as well as in copending United States patent application Ser. No. 245,182 now Patent No. 3,256,439 filed Dec. 17, 1962 by the same inventors.

There are several advantages which result from employing an external target with the present electron radiation tube to provide an X-ray source, since such target can be replaced as often as desired when it is damaged by the high energy electron pulse or when it is desired to use different target materials. In addition, since the X-ray emitting target is not included within the evacuated envelope of the tube, targets of different thickness and different atomic number materials can be interchanged to provide maximum X-ray conversion efficiency and to change the frequency spectrum of the emitted X-rays. Furthermore, since the electron beam is distributed over a large area on the anode window of the present tube such window absorbs little electron energy and is not heated to as high a temperature as an X-ray target so that there is little gas released from the window during bombardment. As a result less out-gassing of the tube is necessary to remove gas absorbed in the surface of such

anode window and other tube elements, which considerably reduces the cost of manufacturing such tube. Also since the electron beam is transmitted through the anode window over a rather large area and there is less heating, such anode window has a much longer useful lifetime on the order of ten times that of an internal X-ray emitting anode, which increases the tube lifetime accordingly.

Of course the apparatus of the present invention has the advantage that many different types of radiation can be produced by means of a single tube. For example, electrons, X-rays, neutrons, ions and even chemical radicals can all be produced by the same tube merely by changing target materials and by eliminating the target or adding additional targets. Another advantage of the X-ray source of the present invention is that the external target can be more easily cooled by rotating the target or applying cooling liquid thereto. Also the X-ray emitting target may be connected to the same ground potential as the anode window so there is no shock hazard from either such anode or such external target.

The cineradiographic system of the present invention has a high repetition rate which is on the order of megacycles per second and is not limited by the recharging time of the energy storage pulser units. Furthermore, short X-ray pulses about 17 nanoseconds width of high intensity and dose rate on the order of 2×10^{11} rads per second can be produced by the X-ray source employed in the present cineradiographic system because the common X-ray emitting target can be replaced if damaged by electron radiation pulses of higher voltage and current density than previously used. In addition, since the X-ray pulses produced by different electron tubes are emitted from a single focal spot of small size on the common target, the resulting X-ray images have better resolution than those produced by a system employing a plurality of X-ray tubes, each having a separate X-ray emitting target. The present cineradiographic system is also of relatively small size and much less expensive in cost and operation with respect to previous systems of similar capability. Furthermore the present X-ray apparatus and system is more versatile, has greater reliability and is more mobile than such previous apparatus of comparable performance, such as those employing linear accelerators. Another advantage of the present cineradiographic system as a result of employing a plurality of electron radiation tubes having field emission cathodes together with a common external target, is that such tubes are electrically isolated from one another and may produce X-ray pulses of the same or different intensity by applying electrical pulses of the same or different voltages to each of such tubes.

It should be noted that advantages similar to those of the cineradiographic system are present when the multiple tube system of the present invention is used for electron irradiation of an object without X-ray generation. In addition, the tubes may be spaced about the object to provide more uniform irradiation of the object.

It is therefore one object of the present invention to provide an improved electron radiation apparatus and system for producing short electron radiation pulses of high energy and high dose rate which is of relatively small size and inexpensive construction.

Another object of the present invention is to provide a source of high intensity X-ray pulses of narrow pulse width and high dosage rate which employs a field emission electron tube and an external target to generate such X-rays which enables the use of interchangeable targets of different thicknesses and materials and allows the replacement of the target when it is damaged to provide a more versatile apparatus of longer useful life time.

A further object of the present invention is to provide a high energy radiation generator which is capable of producing a variety of different types of radiation including electrons, X-rays and neutrons by means of the same field

emission electron tube merely by changing the material of an external target employed outside the anode window of such tube, removing such target or adding additional targets.

An additional object of the present invention is to provide a mobile source of short, high intensity X-ray pulses of high dosage rate which employs a plurality of storage modules containing transmission lines which are discharged in series at substantially the same time to apply a narrow rectangular electrical pulse of high voltage and current to an electron radiation tube having a field emission cathode structure with a plurality of spaced emitting elements at least a portion of which are vaporized for each pulse to produce a vacuum arc within such tube to greatly increase the current flow to an external X-ray emitting target and to provide such tube with a long life.

Still another object of the present invention is to provide an improved cineradiographic system which generates a plurality of short, high intensity X-ray pulses at a very high repetition rate from a small focal spot on a common external target by means of a plurality of separate electron radiation tubes having field emission cathodes emitting electron pulses which are focused on such focal spot to produce X-ray images of high resolution.

Other objects and advantages of the present invention will be apparent from the following detailed description of a preferred embodiment and from the attached drawings of which:

FIG. 1 is a plan view of one embodiment of the electron radiation apparatus of the present invention as it is used to produce X-ray pulses by means of an external target, with parts broken away for clarity;

FIG. 2 is an enlarged section view of one embodiment of the electron radiation tube employed in the apparatus of FIG. 1;

FIG. 3 is a vertical section view taken along the line 3—3 of FIG. 2 shown on an enlarged scale; and

FIG. 4 is a schematic view of a cineradiographic system employing a plurality of the electron radiation devices of FIG. 1 to bombard a common external X-ray target in accordance with the present invention.

As shown in FIG. 1, an electron radiation apparatus 10 made in accordance with the present invention includes a hollow cylindrical metal housing 12 which may be filled with a dielectric gas in cavity 14 to insulate the housing from the high voltage terminal 15 of an electron radiation tube 16 contained within such housing. The metal housing also acts as an R.F. shield to protect external equipment against high frequency electric fields produced within such housing. A field emission cathode 18 in electron tube 16 is connected to the output of a high voltage pulser 20 also contained within the housing, through terminal 15. The pulser 20 may be a Marx surge generator including a plurality of energy storage modules 22 which contain artificial transmission lines that are charged in parallel and discharge in series through spark gap electrodes 24. The storage modules are supported in stacked relationship so that the spark gap electrodes 24 attached to such modules are positioned to locate the spark gaps between each pair of electrodes in a common light path in the manner of copending United States patent application Ser. No. 245,182 referred to above. Each of the storage modules 22 contains a plurality of capacitors and inductors embedded in plastic and connected to form one or more lumped constant transmission lines of substantially the same uniform characteristic impedance. The transmission lines are charged in parallel from a common source of high D.C. voltage (not shown) of about 30 kilovolts and are discharged in series through the spark gaps provided by electrodes 24 connected to the outputs of such lines to apply a narrow negative rectangular pulse 26 of high voltage and high current to the cathode of tube 16. When this happens, electrons 27 are emitted from the field emission cathode structure 18, accelerated to a high ve-

locity and transmitted through an electron transparent anode window 28 provided as a portion of the envelope in one end of the tube. The anode window is grounded to the housing 12 to provide the necessary high electric field between the cathode and such window. The electrons are transmitted through the anode 28 and through an aperture in the housing aligned with such anode to the exterior of the tube and such housing with approximately 5% energy absorption. When X-rays are to be produced, the electrons are caused to bombard an external X-ray emitting target 30 of tungsten or other suitable metal positioned in the atmosphere outside the housing 12. While not essential, the electrons 27 may be focused onto a large area of the anode window 28 by means of an electromagnetic coil 32 positioned within the housing and connected to an external source of D.C. voltage. Also a second magnetic coil (not shown) may be employed to focus the electrons onto a small area of the X-ray target as in FIG. 4. The target 30 may be of the transmission type in the form of a flat plate of tungsten of about .05 millimeter thick supported perpendicular to the axis of the electron flow to enable X-rays 34 to be emitted from the opposite side of the target from that which is bombarded by the electrons 27. Of course the X-ray target may also be of the reflection type in which case it is supported at an acute angle with respect to the electron beam axis, to emit X-rays from the bombarded side of the target.

A gas tight casing 36 of epoxy resin plastic or other insulating material is provided about the storage modules 22 within housing 12 and filled with nitrogen gas different from the dielectric gas within such housing. The casing 36 enables the pressure of the gas in the spark gaps between electrodes 24 to be varied to change the breakdown voltage of such spark gaps. In addition, it has been found that when one of the spark gaps breaks down ultraviolet light is emitted from the ionized gas of such spark gap during the discharge. This ultraviolet light is transmitted to all of the remaining spark gaps, since they are positioned in a common light path, and greatly reduces the time required for all of such spark gaps to break down. This connects the storage modules together, thereby producing the output pulse 26 on output terminal 15. It should be noted that an external source of X-rays or other ionizing light can be used to cause the spark gaps to break down. In addition, a separate spark gap which is not connected to any of the storage modules 22 of the pulser 20, may be provided within casing 36 or outside the housing 12 in order to supply the initial ultraviolet light. While the ultraviolet light itself may be employed to cause the spark gaps to break down in the manner described in copending United States applications Ser. No. 245,182 referred to above, this light may also be of lower intensity in order to "prime" the spark gaps by partially ionizing the gas therein before such spark gaps are caused to break down by overvoltage, which greatly reduces the breakdown voltage and decreases the breakdown time jitter. However in either case the time required to break down all of the spark gaps is materially reduced.

The housing 12 may be mounted on a frame 38 having four wheels 40 attached to axles on such frame in order to provide a mobile electron radiation apparatus. In addition, two pairs of fluid cylinders 42 and 44 may be provided adjacent the front wheels and the rear wheels, respectively, on opposite sides of the frame. The pistons within such cylinders are attached to brackets 46, secured to housing 12, while the cylinders 44 are secured to the frame 38 in order to enable the housing to be moved upward into the position shown in phantom lines as indicated by arrow 48 when all of such cylinders are actuated equally. It is also possible to tilt the housing 12 by actuating either the front cylinders 42 or the rear cylinders 44 independently.

The electron radiation tube 16 shown in greater detail in FIGS. 2 and 3 has an evacuated envelope including a glass portion 50 and a metal portion 52 secured to such glass portion in a conventional manner. The anode window 28 is a thin metal plate attached over an opening

through the metal envelope portion 52 by welding or the like to form a vacuum tight envelope. The anode window 28 may be circular, flat metal disc of titanium, beryllium, aluminum or other metal which absorbs very little energy of the electrons 27 transmitted from the field emission cathode structure 18 through such window. For example, a titanium anode window of about .003 inch thick absorbs only about 5% of the electron energy for 2 megavolt pulses. In addition, the focusing coil 32 may be used so that its magnetic field reduces divergence of the electron beam within the tube and causes the electrons 27 to be substantially uniformly distributed over a large area of the anode window 28. As a result of this uniform distribution and the low electron absorption, there is very little anode heating. Lower heating means that less gas is emitted from the anode and other parts within the tube during its operation, than if an X-ray target were employed inside the tube envelope, since such target is heated to a much higher temperature. This means that a somewhat lower vacuum can be employed and less outgassing of the tube is necessary during its manufacture, which cuts down its cost of production considerably so that it is much less expensive than a conventional tube having an internal X-ray target.

The field emission cathode structure 18 employed in the electron radiation tube 16 is similar to that shown in copending United States patent application Ser. No. 141,260 referred to above. The cathode structure employs a plurality of needle-shaped emitting elements of tungsten 54 which are supported in two rows in spaced relationship in blocks 56 of copper. Two of the needle blocks 56 are secured to the opposite side of a U-shaped support wire 58 by welding or the like. The cathode support wire 58 extends through a re-entrant end of the glass envelope portion 50 and is sealed thereto in a conventional manner so that the cathode needles 54 are directed toward the anode window 28 and substantially uniformly spaced therefrom. When a high energy electrical pulse is applied to the field emission cathode 18 by discharging the storage modules through output terminal 15, a portion of at least one of the cathode needles is vaporized to generate ions of cathode metal within the evacuated envelope. These ions of cathode metal produce a vacuum arc between the anode and the field emission cathode structure, which greatly increases the current flow. As a result a peak current of about 4000 amperes is transmitted in the electron pulse 27 emitted through the anode window 28 of tube 16 for the short time such tube is conducting, which is on the order of 20×10^{-9} seconds. Apparently one reason for this great increase in current is that the positive ions of cathode metal neutralize the negative space charge ordinarily surrounding the cathode needles. The vacuum arc operation is described in greater detail in copending application Ser. No. 141,260.

FIG. 4 shows a cineradiographic system employing three of the electron irradiation apparatuses 10 of FIG. 1 positioned so that the electron pulses emitted from the tubes 16 of such apparatuses are directed onto a common focal spot 60 on the surface of one side of an annular, external, rotating X-ray target 30'. The anodes 28 of the three electron tubes 16 are uniformly spaced from the focal spot 60 but are spaced from one another so that their longitudinal axes are inclined at different angles with respect to the bombarded surface of the target. A common electromagnetic focusing coil 62 is positioned about the axes of all of the tubes between such tubes and such target to focus the electron pulses of each tube onto focal spot 60. Each electron pulse bombarding the left side of target 30' emits a corresponding X-ray pulse from the opposite side of such target. The X-ray pulses are transmitted to an X-ray image recorder 64 through a moving object 66 when such object is positioned between the recorder and the X-ray target in order to record the X-ray image of such object. The X-ray image recorder 64 may be a radiological film, a fluorescent screen whose

visible light image is recorded by a conventional camera, an X-ray sensitive television pickup tube, or any other conventional recording apparatus.

While the X-ray target 30' may be a stationary target, it may be desirable when a large number of pulses are applied to the target by repeated charging and discharging of the pulsers 20, to cool such target in some manner such as by rotating it with an electric motor 68 in order to move the focal spot 60 in a circular path along the surface of the target about its axis of rotation. In addition, a cooling liquid 69, such as water, may be applied to the X-ray target by spraying the opposite side of the target from that which is bombarded, through a nozzle 70 from a pressurized source 72 of cooling liquid. A valve 74 may be provided in the line connecting the nozzle to the source of cooling liquid in order to regulate the flow through such nozzle. It should be noted that because the X-ray target 30' is external and not positioned within an evacuated envelope, it can be rotated much more easily using conventional lubricating materials and can be further cooled by spraying cooling liquid directly onto the target rather than passing it through such target. In addition, the target can easily be replaced at low cost if it is damaged by overheating.

As stated above, the high voltage pulsers 20 of all of the electron radiation tubes 16 are charged from a common source of D.C. voltage 76 through isolation resistors 78. Each of the high voltage pulser units 20 is connected to a trigger amplifier and delay circuit 80 which amplifies a trigger pulse applied to a common input terminal 82 connected to such circuits and applies such trigger pulse to such pulser unit. In addition, each of the three trigger amplifier and delay circuits 80 is provided with a different time delay, so that the trigger pulses transmitted from such circuits are applied at different times to each of the three different high voltage pulsers 20. As a result, the pulsers 20 produce their negative rectangular output pulses 26 at different times and render the electron tubes 16 successively conducting. The time delay difference between the output pulses 26 of the high voltage pulsers determines the repetition rate of the electron radiation pulses emitted by tubes 16 and applied to the X-ray target and therefore also the repetition rate of the corresponding X-ray pulses emitted by such target. Thus an extremely high repetition rate can be provided which is not limited by the charging time of the pulsers.

It should be noted that if a second target of beryllium is positioned in the path of the X-rays 34 emitted by the X-ray target 30 of the apparatus of FIG. 1, such second target will emit neutrons when struck by the X-ray pulses. Thus the radiation apparatus of the present invention may also be employed as a neutron source. Of course the electrons emitted by the tube 16 can also be employed to bombard gas or other material outside of the tube to produce ions or chemical radicals. Furthermore, since the electron and X-ray pulses are short compared with the half-life of such chemical radicals, it is possible to shock-excite a chemical substance by the present apparatus and study the radiation effects in the absence of the radiation producing such effects.

Another possible use of the high energy electron radiation apparatus of the present invention is electron photography, since the high velocity electrons will pass through some objects to produce an electron image on a photographic film in a similar manner to an X-ray image due to the absorption of electrons by such objects. Thus an electron photograph produced by the apparatus of the present invention can be obtained of much thinner objects than can be radiographed by X-rays, with better image resolution. The field emission electron radiation apparatus of the present invention has the advantage of producing large electron radiographs in a short time because of its short high current pulses.

It will be obvious to those having ordinary skill in the art that many changes may be made in the details of

the above described preferred embodiment of the present invention without departing from the spirit of the invention. For example, the electromagnetic focusing coil 32 can be eliminated or replaced with an electrostatic focusing ring. Also, as previously discussed above, the system of FIG. 4 can be used for other than cineradiographic purposes, such as to irradiate an object with electrons from many sides by positioning the tubes 16 about such object. In addition, the cineradiographic system of FIG. 4 can employ a single electron tube 16 and pulser 20 by repeated charging and discharging of such single pulser to produce a plurality of X-ray pulses having a repetition rate up to about 1000 pulses per second. Therefore the scope of the present invention should only be determined by the following claims.

We claim:

1. An electron radiation pulse generator comprising:
 - a tubular housing containing an insulating gas;
 - an electron radiation tube mounted within said housing, said tube having an evacuated envelope, a field emission cathode structure mounted within such envelope, and a thin electron transparent anode forming a portion of such envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube and through an aperture in said housing to the exterior thereof;
 - a gas filled casing supported within said housing and containing a gas different than said insulating gas;
 - a plurality of storage modules mounted within said casing and containing transmission lines of substantially the same uniform characteristic impedance, said modules having spark gap electrodes attached thereto to form a plurality of spark gaps between the outputs of the transmission lines which connect said lines together to apply a narrow electrical pulse of high voltage and current to said electron tube when said spark gaps break down; and
 - means supporting said storage modules to position said spark gaps in a common light path to enable the light emitted from the ionized gas in one spark gap to be transmitted to the remaining spark gaps to reduce the time required for all of said spark gaps to break down.
2. An electron radiation pulse generator comprising:
 - an electron radiation tube having an evacuated envelope, a field emission cathode structure mounted within such envelope, and a thin electron transparent anode forming a portion of such envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube;
 - said cathode structure including a plurality of spaced emitting elements directed toward said anode and substantially uniformly spaced from said anode;
 - a gas filled casing;
 - a plurality of storage modules mounted within said casing and containing transmission lines of substantially the same uniform characteristic impedance, said modules having spark gap electrodes attached thereto to form a plurality to spark gaps between the outputs of the transmission lines which connect said lines in series to apply a narrow electrical pulse of high voltage and current to said electron tube when said spark gaps break down;
 - means supporting said storage modules to position said spark gaps in a common light path; and
 - a housing mounted on a wheeled carriage and containing said tube, said casing and said storage module sealed within said housing and having an aperture in alignment with the anode of said tube for transmitting the electrons to be transmitted out of said housing.
3. An electron radiation pulse generator comprising:
 - a tubular metal housing containing an insulating gas;

an electron radiation tube mounted within said housing, said tube having an evacuated envelope, a field emission cathode structure mounted within such envelope, and a thin electron transparent anode forming a portion of such envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube and through an aperture in said housing to the exterior thereof;

said cathode structure including a plurality of spaced needle shaped emitting elements directed toward said anode and substantially uniformly spaced from said anode;

a gas filled casing supported within said housing and containing an ultraviolet emitting gas different than said insulating gas;

a plurality of storage modules mounted within said casing and containing transmission lines of substantially the same uniform characteristic impedance, said modules having spark gap electrodes attached thereto to form a plurality of spark gaps between the outputs of the transmission lines which connect said lines in series to apply a narrow electrical pulse of high voltage and current to said electron tube when said spark gaps break down; and

means supporting said storage modules to position said spark gaps in a common light path to enable the light emitted from the ionized gas in one spark gap to be transmitted to the remaining spark gaps to reduce the time required for all of said spark gaps to break down;

said electrical pulse being of sufficiently high voltage and current to vaporize a portion of at least one cathode needle element to generate ions of cathode material within said envelope which cause a vacuum arc to be produced between the cathode structure and said anode to greatly increase the current flow in said tube.

4. An X-ray pulse generator comprising:

an electron radiation tube having an evacuated envelope, a field emission cathode structure mounted within such envelope, and a thin electron transparent anode forming a portion of such envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube;

an external target of metal supported in the atmosphere outside of said electron tube in position to be bombarded by said electrons to emit X-rays from said target;

a gas filled casing;

a plurality of storage modules mounted within said casing and containing transmission lines of substantially the same uniform characteristic impedance, said modules having spark gap electrodes attached thereto to form a plurality of spark gaps between the outputs of the transmission lines which connect said lines in series to apply a narrow electrical pulse of high voltage and current to said electron tube when said spark gaps break down; and

means supporting said storage modules to position said spark gaps in a common light path.

5. An X-ray pulse generator comprising:

a tubular metal housing;

an electron radiation tube mounted within said housing, said tube having an evacuated envelope, a field emission cathode structure mounted within such envelope, and a thin electron transparent anode forming a portion of such envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube and through an aperture in said housing to the exterior thereof;

said cathode structure including a plurality of spaced needle-shaped emitting elements directed toward said anode and substantially uniformly spaced from said anode;

an external target of metal supported outside of said housing and said electron tube in position to be bombarded by said electrons to emit X-rays from said target;

a gas filled casing supported within said housing;

a plurality of storage modules mounted within said casing and containing transmission lines of substantially the same uniform characteristic impedance, said modules having spark gap electrodes attached thereto to form a plurality of spark gaps between the outputs of the transmission lines which connect said lines in series to apply a narrow electrical pulse of high voltage and current to said electron tube when said spark gaps break down; and

means supporting said storage modules to position said spark gaps in a common light path to enable the light emitted from the ionized gas in one spark gap to be transmitted to the remaining spark gaps to reduce the time required for all of said spark gaps to break down;

said electrical pulse being of sufficiently high voltage and current to vaporize a portion of at least one cathode needle element to generate ions of cathode material within said envelope which cause a vacuum arc to be produced between the cathode structure and said anode to greatly increase the current flow in said tube.

6. An X-ray pulse generator comprising:

a cylindrical metal housing containing an insulating gas;

an electron radiation tube mounted within said housing, said tube having an evacuated envelope, a field emission cathode structure mounted within such envelope, and a thin electron transparent anode forming a portion of such envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube and through an aperture in one end of said housing to the exterior thereof;

said cathode structure including a plurality of spaced needle-shaped emitting elements directed toward said anode and substantially uniformly spaced from said anode;

an external target of metal supported in the atmosphere outside of said housing and said electron tube in position to be bombarded by said electrons to emit X-rays from said target;

electromagnetic focusing means for causing the electrons to be distributed over a large area of said anode to reduce the heat produced in said anode, and for focusing said electrons onto a small area of said target to provide an X-ray source of small size;

a casing of insulating material supported within said housing containing a gas different than said insulating gas;

carriage means having wheels for moving said housing and said carriage means, and having a plurality of fluid cylinders for moving said housing with respect to such housing;

a plurality of storage modules mounted within said casing and containing transmission lines of substantially the same uniform characteristic impedance, said modules having spark gap electrodes attached thereto to form a plurality of spark gaps between the outputs of the transmission lines which connect said lines in series to apply a narrow electrical pulse of high voltage and current to said electron tube when said spark gaps break down; and

means supporting said storage modules to position said spark gaps in a common light path to enable the light emitted from the ionized gas in one spark gap to be transmitted to the remaining spark gaps to reduce the time required for all of said spark gaps to break down;

said electrical pulse being of sufficiently high voltage and current to vaporize a portion of at least one cathode needle element to generate ions of cathode material within said envelope which cause a vacuum arc to be produced between the cathode structure and said anode to greatly increase the current flow in said tube.

7. A cineradiographic system comprising:
 at least one electron radiation tube having an evacuated envelope, a field emission cathode structure within said envelope and a thin electron transparent anode forming a portion of said envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube;
 an external target of metal supported in the atmosphere outside said electron tube in position to be bombarded by the electrons emitted from said tube to emit X-rays from said target;
 pulser means including charge storage means connected to said tube, for applying pulses of high voltage and high current between the cathode and anode of said tube when said storage means is triggered; and
 recording means positioned adjacent said target for recording the X-ray image of any object placed between said recording means and said target.

8. A cineradiographic system comprising:
 a plurality of electron radiation tubes each having an evacuated envelope, a field emission cathode structure within said envelope and a thin electron transparent anode forming a portion of said envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube;
 a common external target supported outside said electron tubes in position to be bombarded by the electrons emitted from each tube to emit X-rays from said target;
 focusing means for focusing the electrons emitted from each electron tube onto substantially the same small focal spot on said target;
 X-ray sensitive means positioned adjacent said target for recording the X-ray image of any object placed between said X-ray sensitive means and said target; and
 a plurality of energy storage means connected to different ones of said tubes, for applying a plurality of narrow electrical pulses of high voltage and current to said electron tubes successively so that a plurality of pulses of electrons are emitted from said tubes and caused to bombard said target at different times to produce a plurality of X-ray pulses.

9. A cineradiographic system comprising:
 a plurality of electron radiation tubes each having an evacuated envelope, a field emission cathode structure within said envelope and a thin electron transparent anode forming a portion of said envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube, said cathode structure including a plurality of spaced needle-shaped emitting elements;
 a common external target supported outside said electron tubes in position to be bombarded by the electrons emitted from each tube to emit X-rays from said target;
 focusing means for focusing the electrons emitted from each electron tube onto substantially the same small focal spot on said target;
 means for rotating said target;
 X-ray sensitive means positioned adjacent said target for recording the X-ray image of any object placed between said X-ray sensitive means and said target; and
 a plurality of energy storage means connected to different ones of said tubes, for applying a plurality of narrow electrical pulses of high voltage and current to said electron tubes successively so that a plurality

of pulses of electrons are emitted from said tubes and caused to bombard said target at different times to produce a plurality of X-ray pulses,
 said electrical pulses being of sufficient intensity to vaporize a portion of at least one of the cathode emitting elements in each tube to produce a vacuum arc between the cathode and anode of the tube and increase the current flow through such tube.

10. An electron radiation pulse generator comprising:
 a tubular housing;
 an electron radiation tube having an evacuated envelope, a field emission cathode structure mounted within such envelope, and a thin electron transparent anode forming a portion of such envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube;
 means for mounting said tube within said housing with said anode in alignment with an aperture in said housing so that said electrons are transmitted to the exterior of said housing; and
 energy storage means mounted within said housing inside a gas tight chamber separate from that containing said tube, said energy storage means including at least one transmission line of substantially uniform characteristic impedance and spark gap electrodes attached thereto to form at least one spark gap between the output of the transmission line and said electron tube to apply a narrow electrical pulse of high voltage and current to said electron tube when said spark gap breaks down.

11. An electron pulse generator in accordance with claim 10 in which the energy storage means includes a plurality of storage modules each containing at least one artificial transmission line and having spark gap electrodes attached thereto to form spark gaps connecting said transmission lines together, said storage modules being provided within a gas filled casing forming said chamber inside said housing and said tube being positioned outside said casing in another portion of the housing containing a different gas of greater insulation properties.

12. An electron pulse generator in accordance with claim 11 including carriage means having wheels for supporting said housing for mobility.

13. An X-ray pulse generator comprising:
 an electron radiation tube having an evacuated envelope, a field emission cathode structure mounted within such envelope, and a thin electron transparent anode forming a portion of such envelope to enable electrons emitted by said cathode structure to be transmitted through said anode out of said tube;
 an external target supported in the atmosphere outside of said electron tube in position to be bombarded by said electrons to emit X-rays from said target; and
 energy storage means including at least one transmission line of substantially uniform characteristic impedance and having spark gap electrodes attached thereto to form at least one spark gap between the output of the transmission line and said electron tube to apply a narrow electrical pulse of high voltage and current to said electron tube when said spark gap breaks down.

14. An X-ray pulse generator in accordance with claim 13 in which the energy storage means applies electrical pulses to the electron radiation tube of sufficient intensity to cause a portion of the field emission cathode to vaporize and produce a vacuum arc which greatly increases the current flow between the cathode and anode.

15. An X-ray pulse generator in accordance with claim 14 in which the energy storage means includes a plurality of storage modules each containing at least one artificial transmission line with the transmission lines connected together at their output by spark gaps formed between spark gap electrodes attached to said modules.

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16. An X-ray pulse generator in accordance with claim 15 in which the storage modules are supported so that the spark gaps are positioned in a common light path.

17. An X-ray pulse generator in accordance with claim 16 which also includes means for transmitting ionizing electromagnetic radiation along said common light path to cause said spark gaps to break down substantially simultaneously.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,482,096 Dated December 2, 1969
Inventor(s) ROBERT H. LEWIS, JOHN P. BARBOUR,
WALTER P. DYKE and FRANK J. GRUNDHAUSER

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 35, delete "high" (second occurrence);
column 5, line 50, "applications" should be --application--;
column 6, line 3, after "be" insert --a--; column 8, line 60,
"to" (second occurrence) should be --of--; column 12, line 51,
after "target" insert --of metal--.

SIGNED AND
SEALED
JUN 2 1970

(SEAL)

Attest:

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