July 21, 1942. J. W. M. DU MOND 2,290,226

X-RAY GENERATING DEVICE

Filed Dec. 19, 1940 2 Sheets-Sheet 1

Fig. I

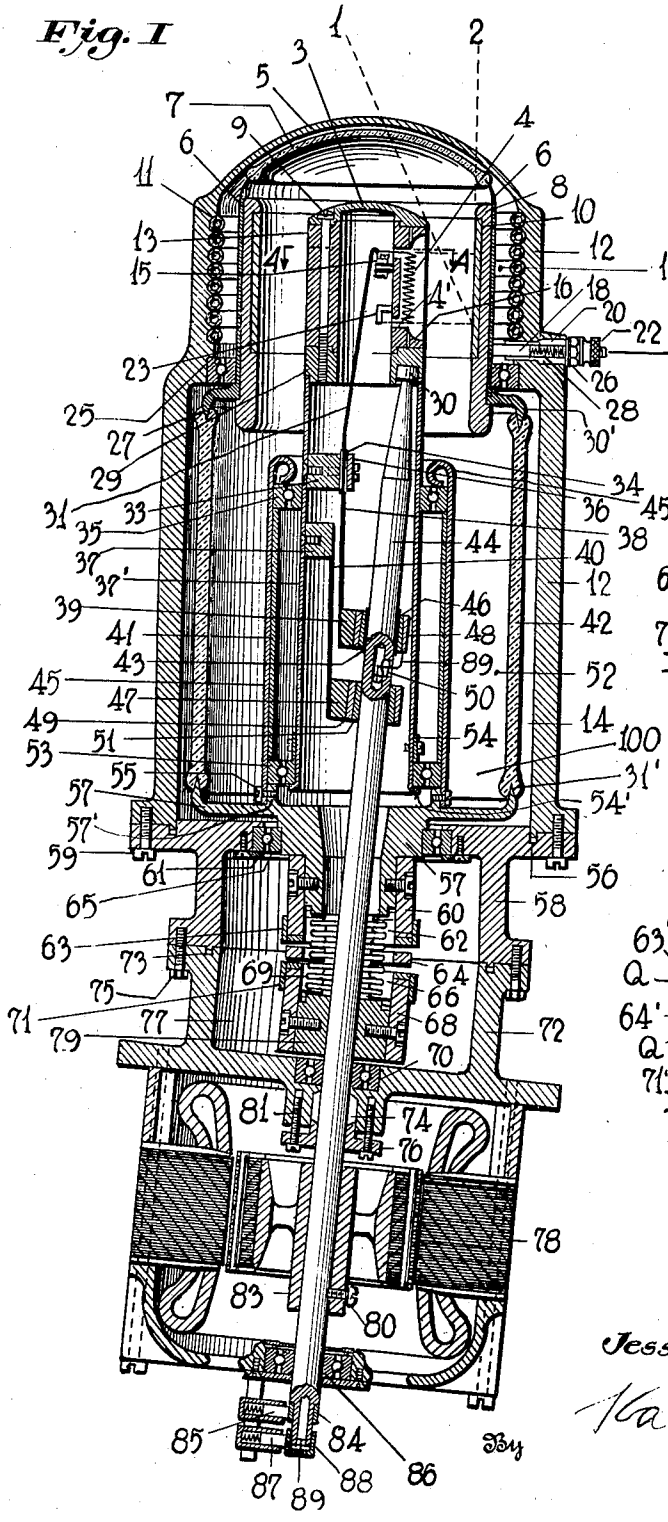


Fig. II

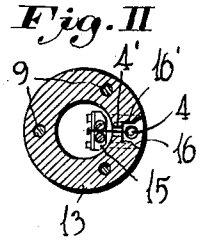


Fig. III

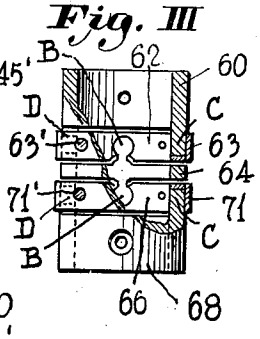
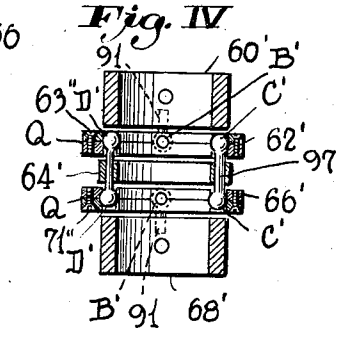


Fig. IV



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Fig. V.

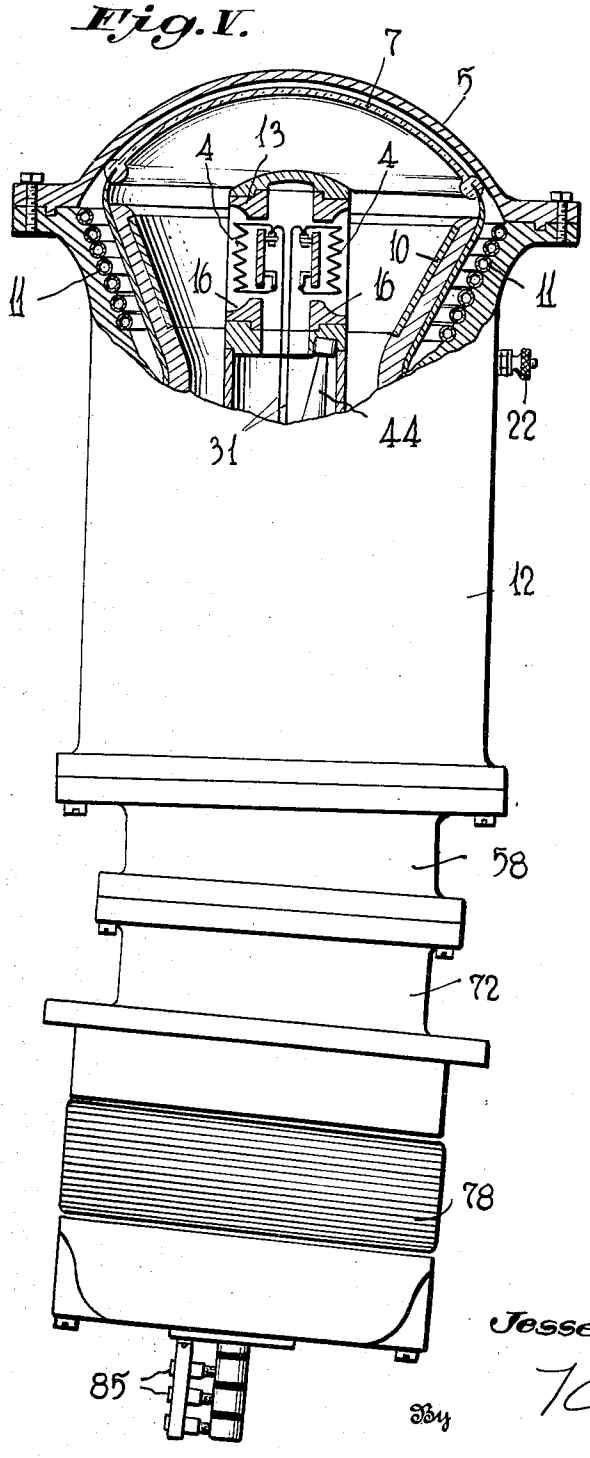
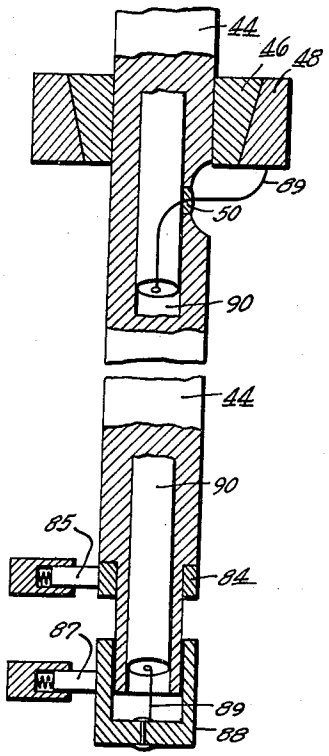


Fig. VI.



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2,290,226

X-RAY GENERATING DEVICE

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15 Claims. (Cl. 250—148)

This invention relates to X-ray tube constructions and pertains more particularly to X-ray tube constructions in which continuous relative movement is obtained between the target surface or anode and the focal spot of the electron beam from the cathode.

An object of the invention is to provide an X-ray tube adapted for operation under very high average power input conditions over indefinitely extended periods of time without detriment.

Another object of the invention is to provide an X-ray tube adapted to operation under very high momentary power input per unit area of the focal spot where the electron beam impinging upon the target surface excites the X-radiation. For many applications in radiography (X-ray photography) of the human body it is desirable to have a short exposure time coupled with a large total quantity of X-rays emitted in that time coming from a focal spot of the smallest possible dimensions. Apparatus made in accordance with the present invention accomplishes this result.

The invention is adapted to provide an X-ray tube structure in which the emission of X-rays from the target is obtainable in a direction so related to the direction of the cathode rays exciting the X-rays as to yield a maximum quantity of X-rays utilizable for radiography.

The invention provides a movable anode X-ray tube which may be completely shielded internally against the escape of unwanted X-rays.

Another object of the invention is to provide an X-ray tube permitting of relative motion between anode (or target) and cathode structure the cathode preferably being maintained stationary in space to the highest degree by positive mechanical means rather than by magnetic fields or gravitational forces. This may insure that the focal spot or source of X-rays shall be perfectly stationary during the exposure in radiography. The arrangement may tend to prevent the tube from becoming inoperable due to any tendency for bearings, especially those in the evacuated region of the X-ray tube, to stick or exhibit increased friction.

The invention provides an X-ray tube permitting of the highest degree of thermal conductivity from the focal spot where heat is generated to efficient external cooling media such as fluids capable of being continuously cooled. This aids in permitting a high average power input over indefinitely long periods of time.

The rotatable anode X-ray tube construction is capable of shock-proof design.

The invention contemplates a rotatable anode X-ray tube construction mounted within an enclosed housing on bearing means disposed outside the evacuated structure such enclosed housing being adapted to contain a body of fluid of high dielectric strength which may serve as an insulating medium, as a cooling medium and as a lubricating agent for the bearing means.

Another object of the invention is to provide a rotatable X-ray tube construction permitting relative motion between anode and cathode members in which all parts revolve upon their axes of symmetry so as to achieve complete freedom from vibration due to the inertial forces from the motion of unbalanced masses.

Another object of the invention is to provide a rotatable X-ray tube construction permitting relative motion between anode and cathode members and permitting the use as a source of electrons of an elongated or "line focus" cathode and cathode focusing cup adapted to generate an intense electron beam impinging on the target surface in a substantially rectangular elongated focal spot of small size in its narrow dimension, the direction of motion of the target surface being along the narrow dimension of the focal spot so that portions of the target surface are subjected to heating for the shortest possible time.

Another object of the invention is to provide a rotatable X-ray tube construction in which the X-rays can emerge through a window situated about the axis of rotation and at one end of the tube so that the window can be made thin and hence transparent to the emerging X-rays without seriously weakening the mechanical strength of the rotating envelope.

Another object of the invention is to provide a rotatable anode X-ray tube construction with a stationary internal cathode structure capable of providing in one tube a plurality of electronic emitters and focusing cups which may if desired furnish focal spots of different sizes and shapes adapted to different applications or uses.

Another object of the invention is to provide in such a tube means whereby without displacing the tube as a whole the position in space of the focal spot on the rotating target surface can be changed as is desirable for instance in stereoscopic radiography.

The tube which forms the subject of the present invention avoids difficulties heretofore experienced by providing immobility of the internal cathode structure through positive mechanical means and by so disposing target and X-ray window that the latter need not be an important element in the structural strength of the tube.

A new technique recently developed in radiography consists in projecting the X-ray image on a fluorescent screen, the fluorescent light from this screen being then photographed by a camera provided with a very luminous large-aperture lens on a small negative. The advantages of this new technique result from the possbility of utilizing an inexpensive small sized negative easy to file compactly in large numbers. This method recommends itself especially for military or navel applications in which large numbers of radiographs must be made in rapid succession and in civilian applications under war conditions. This new technique requires four or more times as much power input in an exposure of given duration as is required in radiography made directly on a full sized negative. The objects of the present invention are especially directed to the requirements of this new technique and more especially under the severe conditions of long continued use of the tube for many hours during which exposures are made in rapid succession without interruption, as in photographing soldiers. The present invention may also find usefulness in other adaptations of X-rays where high intensity may be desirable such as in examining metals, castings, etc.

An object of the present invention is therefore to provide an X-ray tube having all the advantages of rotary tubes heretofore designed and in addition permitting the use of an internal stationary elongated cathode emitter and focusing cup facilitating intense emission directed toward a small spot on the target capable of giving sharply defined focal spots as needed for fluorescent screen technique. Two other advantages are obtained from this new design namely: (1) the stationary cathode structure permits of the provision of a multiplicity of emitters and focusing cups capable of giving in one tube structure focal spots of different sizes and shapes adapted to different applications and (2) two cathodes diametrically opposed on the cathode member may be arranged to give two focal spots in different locations in space on the rotating target surface so that without displacing or adjusting the tube as a whole the requisite motion of the focal spot required in stereoradiography may readily be obtained in closely sequential exposures.

Advantageous features needed in radiography and more especially desirable with the fluorescent screen technique present in the present invention include:

(*a*) Provision of a narrow elongated focal spot on the target with the utilized X-rays emitted obliquely to its long dimension to insure sharp definition of the radiographs coupled with larger spot area.

(*b*) Provision of a stationary elongated cathode emitter and elongated focusing cup to generate the line focal spot and permit intense emission.

(*c*) Provision of a moving anode or target structure with motion in the direction of the short dimension of the focal spot which will allow the target to move its surface over a distance many times the short dimension of the focal spot during the time of one exposure.

(*d*) Positive mechanical means for holding the cathode and hence the focal spot stationary in space or relative to objects being radiographed especially as regards motions that would blur the radiographic image.

(*e*) Provision of high thermally conducting paths from the point of heat generation at the focal spot on the target to external fluid cooling means outside the vacuum envelope whereby sustained high input power may be permitted in all day uninterrupted service without damage to the tube.

(*f*) Disposition of target and X-ray window so that the direction of the X-rays utilized will be that in which emission is most intense.

(*g*) Disposition of target and X-ray window so that the window is not an essential element of the structural strength of the tube thus permitting the use of a thin window very transparent to X-rays.

(*h*) Provision of an X-ray tube capable of being completely shielded internally against the escape of unwanted X-rays.

(*i*) Provision of an X-ray tube capable of adaptation to shock-proof design.

(*j*) Provision of an X-ray tube design permitting oil or other fluid immersion, including gas immersion, which may provide cooling, lubrication of external bearings in the case of oil immersion, and improved insulation of the high voltage with consequent increased compactness of design.

(*k*) Provision of a design in which all moving parts execute only circular motion of rotation about axes of symmetry to give maximum freedom from vibration.

(*l*) Provision in one tube of a plurality of focal spot sizes and shapes adapted to different techniques.

(*m*) Provision in one tube of focal spots generated at two different positions in space to adapt the tube to stereoradiography without displacement of the tube as a whole.

These desiderata may be obtained according to the present invention by provision of a rotating anode structure carrying a target face of extended area preferably forming a part of the inner surface of the vacuum envelope and formed as a surface of revolution removed from the axis of rotation of said anode and adapted to be moved in an annular path, together with a cathode structure which may be of cylindrical or conical form whose axis of symmetry is concentric with the axis of rotation of the anode and at one or more positions around the circumference of which may be provided one or more axially elongated thermally emitting cathodes embedded in elongated focusing cups in the cathode structure each capable of directing cathode ray beams at the surface of the anode. The cathode structure is supported inside the rotating X-ray tube on bearing means such as ball-bearings coaxial with the axis of rotation of the tube and anode permitting the cathode structure to be held stationary in space or with respect to objects to be radiographed while the tube and anode rotate. The cathode structure may be held stationary by means of a shaft rotating on its own axis of symmetry which axis is obliquely directed to the axis of rotation of the tube and this shaft may be connected to the tube structure by a flexible metal bellows whose flexure permits the angle of obliquity between the two axes of rotation. The plane of this angle of obliquity determines the azimuth of orientation of the cathode. The shaft engages the cathode structure in a small bearing removed from the axis of the cathode. The tube may be provided with an X-ray window at one end of the hollow cylindrical or conical anode disposed near the axis of rotation thereof so as not to form an im-

portant part of the structural strength of the rotating tube body which window can therefore be made thin and transparent to X-rays. The tube as a whole, whose walls may be partly of glass and partly of metal, is submersible in an oil or other fluid bath contained in a jacket partly of moulded electrically insulating plastic material and partly of metal and rotates on bearing means outside the vacuum envelope which may be in a lubricating bath. The outer jacket is provided with a thin wall transparent to X-rays where they must emerge.

Other features and objects of the invention will be brought out in the ensuing description of certain preferred embodiments, or will be apparent therefrom.

Referring to the accompanying drawings Figure I is a longitudinal vertical section of one form of embodiment of the invention. Fig. II is a transverse section of the circular cylindrical cathode structure only taken along the line A—A in Fig. I and viewed in the direction of the arrows to show the thermally emitting filament, filament support and focusing cup. Fig. III is a side elevational view broken away in part of the universal joint surrounding the bellows in Fig. I. Fig. IV is a longitudinal cross-section showing another form of universal joint which may be substituted for that shown in Fig. III. Fig. V is a side elevation, parts being broken away, of another embodiment of the invention. Fig. VI is an enlarged fragmentary detail of a portion of Fig. I.

The dotted lines 1 and 2 indicate the extreme right and left hand limits of a cone of X-rays emerging from the tube of Fig. I through the walls 5 and 7 which may be referred to as the window. The radiation is generated on the metal surface or lining 10 of the rotatable anode by the bombardment of that surface with electrons emitted from the stationary thermal cathode 4 by thermionic emission and accelerated from that cathode to the anode by the agency of a high potential gradient maintained between these two elements.

There is a housing 12 preferably of some suitable moulded electrically insulating plastic compound provided at one end with a thin walled X-ray window portion 5 transparent to the X-rays. The opposite end of the housing 12 is closed with metal housings of die cast or otherwise fabricated pieces 58 and 72 preferably of metal. To insure fluid tightness suitable gaskets 56 and 73 are provided. These parts are secured together in any suitable way, screws 59 and 75 being shown. A rotatable shaft 44 enters the housing through a fluid-tight packing gland which may be provided with packing 74 compressed by a flanged sleeve 76. Within this fluid-tight housing assembly an X-ray generating tube indicated generally by 100 is rotatably supported on bearing means such as the ball bearings 25 and 65 the latter held in place by means of a ring 61 which may be held in place by any suitable means such as the screws shown. The X-ray tube rotates inside the housing with but a small clearance space 14 which may be filled with a fluid such as oil which seeps through the bearings 25 and 65 affording communication or circulation from end to end of the clearance space.

The X-ray tube 100 consists of an evacuated enclosure 52 bounded by the following parts: A thin window 7, the anode structure 8 which is enclosed in the sleeve 6 the latter being sealed to the window 7, the glass envelope 42 sealed to the sleeve 6 at 27, the end piece 57 sealed to the glass envelope 42 at 31', the flexible metal bellows or "sylphon" 69 attached as by welding to the metal end piece 57, the metal plug 79 attached as by welding to the "sylphon" bellows 69 through which passes the oblique shaft 44 which may be hermetically welded or made integral with the metal piece 79. The thin window 7 may be of some such material as glass and should be transparent to the desired X-radiations and impervious to the entry of gases which could spoil the vacuum. It may be formed of metals or other materials transparent to the X-radiation utilized. If of glass it may be coated internally with a vaporized metal coating transparent to X-rays capable of conducting away electrical charges built up by secondary electron or ion bombardment or a shield of metal transparent to the utilized X-rays may be placed just inside the window. The thin window 7 may be joined or sealed to the sleeve 6 which should be of a suitable material for this purpose such as alloy Kovar or other material having the proper temperature and expansion coefficient. The sleeve 6 may form a part of the true vacuum-tight enclosing envelope and the anode structure 8 may then be, for example, of copper cast in a hydrogen atmosphere a material difficult to render vacuum tight. A sleeve 10 of some suitable refractory metal such as tungsten or tantalum to form the target surface upon which the cathode rays impinge to excite the X-rays may be cast into or otherwise suitably inserted in the anode structure 8 as shown. The other end of the sleeve 6 may be provided with a flanged enlargement 30' so as to seal at 27 on to 42 the glass envelope of the tube. The sleeve 6 may be turned or otherwise made thin to insure good heat conductivity as metal alloys suitable for sealing to glass frequently are rather poor conductors of heat. Either the glass envelope 42 or the glass window 7 may be provided at some point with a teat (not shown) through which the vacuum space 52 of the tube can be pumped out with suitable pumps during manufacture. This teat may then be sealed off leaving only a small projecting button of glass not shown in Fig. I. It will be noted that the vacuum space 52 extends from the window 7 to the plug 79. Or the tube may be evacuated through the hollow shaft 44 in which case a hole in said shaft may communicate freely with the space 52 to be evacuated and a glass or other seal-off at the outer end of the shaft 44 may be provided and subsequently covered with a metal protecting cap. In the latter case the cathode connecting wire 89 to be described below may be brought out through this seal-off.

The cathode structure consists of a thick walled metal cylindrical portion 13 which may have relatively thick metal walls in the external cylindrical surface of which is provided one or more (two being shown in Fig. V) elongated oval bathtub shaped cavities 16 with a somewhat smaller and deeper cavity 16' at the bottom of each. These act as focusing cups for the cathodes. In each of these lower cavities 16' stands a thermally emitting filament 4 shown as helical, which can be heated by the passage through it of an electrical current of sufficient intensity to raise and maintain its temperature at a sufficient value to cause it to emit electrons at a sufficient rate to furnish the requisite cathode ray emission currents. This helical filament is terminated in straight ends directed radially to

the axis of the helix and passing with adequate clearance for insulation through holes 4' in the cylinder 13. One straight end of the filament 4 is welded to a metal support 23 which in its turn is welded to the cylinder 13. The other straight end of the filament is connected to the wire 31 through an insulated connecting member 15 mounted in the cylinder 13. Current may be supplied to the thermally emitting filament in a variety of ways to be described hereinafter.

The arrangement produces a line focus or elongated focal spot with the short dimension along the direction of motion of the target. This causes an enlarged focal spot area without loss of sharp definition since the emergent beam of X-rays is in the general direction of the longer dimension of the focal spot. Since the focusing cup and cathode emitter are elongated the beam of electrons can have a cross section of the same elongated shape as the focal spot on the target. There is thus produced an intense emission from the elongated spot bombarded. Since the elongation is at right angles to the direction of movement of the rotary target the bombardment area need have but a very narrow dimension in the circumferential direction of the target, being that direction in which the target moves when rotated. Thus the actual area of the target on which bombardment takes place changes rapidly with the rotation of the target and the tendency for overheating is materially diminished since the heating incident to continuous production of the X-rays is distributed over successive areas of the target.

The cathode structure 13 further includes a metal cap 3 and a hollow thick-walled cylindrical portion 29 welded or otherwise attached to a thinner walled tube 37'. Parts 3, 13 and 29 are suitably held together as by one or more long longitudinal screws 9. Centering of the parts 3, 13 and 29 may be insured by shoulders shown at the joints between them. The entire structure 3, 13, 29 and 37' is rotatably supported on ball bearings 35 and 53 between it and the anode structure so that it is free to rotate on its axis of symmetry and independently of the anode structure 8. The ball bearings 35 and 53 are themselves supported in a cylindrical sleeve 45 which may be provided at the end toward the window with preferably a smooth polished rolled lip or bead 45' as shown to afford a surface of sufficient radius of curvature to avoid cold field emission in vacuum. The sleeve 45 fits over an annular shoulder 57' provided for this purpose centrally on the end piece 57, screws such as 55 being used to secure it in place. The ball bearings 35 and 53 and the sleeve 37' are insured against displacement by the cooperation of the above mentioned rolled bead 45', an internal sleeve 41 spacing the bearings apart, and the above mentioned annular shoulder 57'.

In operation the anode and outer envelope of the tube including the parts 6, 7, 8, 10, 42, 45, 57, 69, 79, 44, etc., rotate, while the cathode structure including the parts 3, 13, 29, 37' etc., are held stationary, so as to assure a stationary focal spot, although it be supported through ball bearings 35 and 53 on the rotating sleeve 45. The anode structure and the shaft 44 each may be rotated in any suitable way by separate means or by the same means as by the motor 78 shown for rotating the shaft 44 which as shown transmits rotary motion to the shell 12. The immobility of the cathode structure 13 may be obtained by direct mechanical means as follows: The oblique shaft 44 is connected to the rotating envelope of the X-ray tube through the flexible metal bellows 69 so as to form a complete vacuum tight enclosure. The oblique shaft 44 is aligned in ball bearings 70 and 86 which so determine the axis of rotation of 44 that the axis intersects the axis of rotation of the tube envelope 42, etc., at a point at or near the center, preferably both longitudinally and radially, of the flexible bellows 69. Since bellows 69 can support no appreciable torsion, but only bending, both the tube envelope 42, etc., and the oblique shaft 44 rotate in unison though they do not rotate on exactly the same axis but on axes slightly inclined relatively to each other. Since ball bearings 35 and 53 establish a fixed axis of rotation in space on the tube housing 37' etc., and ball bearings 70 and 86 establish another fixed axis in space for the oblique shaft 44 the plane of the angle formed by these two axes in space is fixed and invariable. The upper end of the oblique shaft 44 is engaged in the inner race of a small ball bearing 30 whose outer race is seen only in full view, not in cross section, in Fig. I. The outer race of the bearing 30 is located in a recess or cavity of appropriate size and orientation located in the wall of the cylinder 29 at a position radially removed from the axis of the entire cathode assembly, 3, 13, 29 etc., as shown in Fig. I. Because of the invariable position in space of the plane of the angle formed by the two above mentioned axes of rotation it is evident that this arrangement holds the cathode structure stationary while the anode structure rotates so that the cathode rays are projected from cathode to anode in an invariable direction, or at an invariable angle to the face of the anode plate or target 10.

The members 58 and 72 are not of uniform length throughout their circumferences both being illustrated as longer on the sides shown at the right of Fig. I thus the bearings 70, 86 for the shaft 44 are not parallel with but at an angle to the bearings 25, 65 and 35, 53 of the anode structure and cathode structure respectively.

Provision may be made for supplying the cathode filament with heating current in a number of ways which would occur to anyone skilled in the art. One of these illustrated in Fig. I is as follows: Two ordinary insulated spring pressed brushes 85 and 87 bear respectively on the grounded slip ring 84 and the insulated slip ring 88 electrically connected respectively to the oblique shaft 44 and to an insulated wire 89 passing through an axial hole in the oblique shaft 44 which hole extends up to a point where a radial hole 50 leads from the axial hole to the outside of the shaft. The axial hole may be terminated shortly beyond this point. Wire 89 should be insulated from touching the walls of the axial hole with any suitable insulating substance 90, (see Fig. VI), such as glass beads threaded over the wire, capable of withstanding the temperature to which it and the rest of the tube structure may be subjected during the outgassing process which should accompany evacuation. The wire 89 is brought out through the radial hole 50 and a glass seal filling the annular space between the walls of hole 50 and wire 89 may be provided so as to seal the hole 50 hermetically and prevent a vacuum leak in which case it would be desirable to construct the shaft 44 of some suitable material such as Kovar adapted for sealing to glass. An alternative solution is to place the glass seal at the lower end of the shaft 44 just inside the cap

88 which thus may serve as a slip ring and also as a protecting cap for the seal. It is, of course, unnecessary to make the entire shaft 44 of Kovar since Kovar is readily welded and otherwise joined to other metals and a small sleeve of Kovar or the like may appropriately be introduced locally at the point where the seal is required. A small grounded slip ring 49, 51 and a small insulated slip ring 46, 48 insulated from the oblique shaft 44 with a mica sleeve 43 may be provided as shown. A convenient method of assembly of such slip rings consists in making the adjacent surfaces of 46 and 48 (and similarly 49 and 51) conically tapered, the inner ring being split longitudinally so that when the outer ring is pressed over it the inner ring or sleeve hugs down tightly around the oblique shaft 44 or around the mica insulation 43 on that shaft as the case may be and the assembly is thereby tightly secured to the shaft 44 by friction. The wire 89 may be connected as by solder or welding to the insulated slip ring 46, 48. Brushes 39 and 47 are held in good electrical sliding contact with slip-rings 48 and 49 respectively by means of metallic leaf springs 38 and 40. Spring 40 is welded to a metal block 37 which is secured to the tube 37'. A contact block 33 mounted on tube 37' has a clamping bar 35 provided with mica insulation 34 on both sides of the spring 38 to insulate it from the block 33 and the cathode assembly. Blocks 33 and 37 may be secured to the sleeve 37' in any suitable way such as by the screw shown. A wire 31 welded to the upper end of the leaf spring 38 leads to the connecting member 15 to which one end of the filament 4 is attached. The wire 31 may be suitably attached to 15 as by welding. The electrical current for heating filament 4 may thus enter from any suitable external supply source at brush 85 through grounded slip ring 84 thence through the oblique shaft 44 and through the slip ring assembly 51 and 49 to brush 47 thence to the leaf spring 40 and through the block 37 and through 37', 29 and 13 to the support 23 and through the filament itself, thence into part 15, through wire 31, leaf spring 38, brush 39, slip ring assembly 46, 48, wire 89 to slip ring 88 and brush 87 from which latter point the current returns to the other pole of the supply source. Both heating current for the cathode and connections of the latter with one of the poles of the high voltage supply source are afforded by the circuits just described connected to brushes 85 and 87 each of which may be suitably connected to one pole of the high voltage source.

It is clear that heating current may be supplied to the filament in many other ways that will be obvious to those skilled in the art. For example the slip rings may be placed on the outside or at the lower end of the sleeve 37' and a brush or brushes may then lead the current to wires passing through insulating hermetical seals in the wall of the rotating X-ray tube and thence to other slip rings and brushes situated outside the vacuum envelope. Or the heating energy may be given to a coil inside the vacuum by the inductive action of an alternating magnetic field of moderately high frequency which may be supplied externally operating through the insulating walls of the tube without the necessity of any sliding contacts at all.

Connection of the anode or target member 10, 8, 6 to the other pole of the high voltage source is afforded through the brush 18 bearing on the smooth, true, rotating surface of sleeve 6 with pressure supplied by a helical spring 28. The brush 18 and spring 28 work in the metal sleeve 20 solidly embedded in a boss in the wall of the insulating housing 12 which may be of moulded plastic material. A removable threaded fitting with hexagonal enlargement 26 plugs the hole in 20. Gaskets may be used to insure that the fluid in space 14 may not leak out. This removable threaded fitting permits removal and renewal of the brush 18. The hexagonal enlargement 26 is provided with a threaded stem extension 24 integral with 26 to which a knurled thumb nut 22 can be screwed so as to secure a connecting wire leading to one pole of the high voltage source.

It is evident that the entire assembly may be made shock proof by enclosing it in a metallic housing (not shown). This housing may be at anode potential and arranged to enclose the entire sheath 12 and parts 58, 72 and 78 with safe voltage clearance. An insulating fluid such as oil inside this metal sheath may be used and if desired this fluid may communicate with and be part of the same fluid in the cavity 14 inside the sheath 12. Provision may then preferably be made such as by appropriate covers and packing glands to keep this insulating fluid from the brushes and rings 85, 87, 84, 88 and from the motor 78 to be described hereinafter. High tension leads coming into the outer metal sheath through shielded high tension cable and fluid-tight insulating bushings may then be used to conduct the high tension current, the filament heating current, and the current for running the driving motor 78, into the interior of the outer metal sheath. This outer metal sheath could be provided with a thin window portion such as thin aluminum transparent to the utilized X-radiation in the region of emergence of the X-ray beam and in this case the thin window portion 5 of the insulating case 12 would be unnecessary and could be omitted allowing the metal window just mentioned to stand in close proximity to the window 7 of the tube proper. In such a construction the role of the case 12 becomes merely that of a mechanical support and is not a fluid container.

It will further be evident to those skilled in the art that expansion chambers consisting of metal bellows or otherwise designed devices may be provided to maintain the fluid in space 14 under pressure and provide for its thermal expansion and it will further be similarly evident that this fluid may be circulated in that space either by external pumping means or by appropriately designed fins or contours of the surfaces of the rotating and stationary elements in contact with that fluid.

The rotation of the tube envelope and anode structure may be accomplished as shown in Fig. I through the agency of a motor 78 driving the oblique shaft 44. It will be obvious to those skilled in the art that this rotation may also be accomplished by a motor whose rotor is either directly connected or geared to the anode structure. But in the construction illustrated in Fig. I where the driving torque of the motor is applied to the oblique shaft 44 it is desirable to protect the flexible metal bellows 69 from the necessity of transmitting this torque to the rotating X-ray tube proper. It is further desirable to prevent this flexible metal bellows from collapsing longitudinally under the external pressure either of the atmosphere or of the fluid in the space 77 within the housings 58 and 72. For these purposes surrounding the bellows a univer-

sal joint may be provided consisting of parts 60, 62, 63, etc., as shown in Fig. I and more completely in the partial section of Fig. III. The function of this joint in preventing longitudinal collapse of the bellows 69 under atmospheric pressure is especially desirable during the manufacture of the X-ray tube while it is being outgassed in an oven and pumped out with vacuum pumps. During these stages of the manufacturing process the tube need not be held in its eventual supporting framework 12, 58, 72 etc., but may be supported in a manufacturing jig in the oven arranged so that the tube is held stationary to permit it to be hermetically sealed to the vacuum pumping means and so arranged that by gyrating the oblique shaft 44 the cathode can be rotated inside the stationary tube so as to permit bombarding preferably with cathode rays under high voltage and thereby outgassing all parts of the target surface at temperatures somewhat higher than they will ever subsequently be subject to in the most severe service. After the evacuation and sealing off processes the tube asembly must be removed from the jig in the oven and placed in its final suporting framework 12, 58, 72, etc. During this transfer it is desirable to provide support for the metal bellows 69 which is furnished by the universal joint construction 60, 62, 63, etc.

It is further desirable that this universal joint shall transmit rotation uniformly from element 68 to element 60 so that a uniform angular velocity impressed upon 68 in its rotation about its axis by rotation of the shaft 44 on which 68 is mounted shall result in the same uniform angular velocity of element 60 about its axis and in order to avoid subjecting the intervening bellows 69 to undue strain. It is well known and easy to prove by geometrical reasoning concerning a single universal joint of the well known fork and cross type, which consists of two shafts each terminated in a fork hinged to a single cross piece in such a way that the axes of the two hinges are at right angles to their corresponding shafts and also at right angles to each other that such a joint will not transmit the uniform, angular velocity of one shaft to result as a uniform angular velocity of the other shaft if the axes of rotation of these shafts are not parallel. It is however further well known and easy to prove by geometrical reasoning that two such universal joints one connecting a drive shaft to an intermediate shaft, the other connecting the intermediate shaft to a driven shaft will transmit uniform rotation of the drive shaft to result in uniform rotation of the driven shaft even though they are not parallel to each other provided (*a*) that the axis of rotation of the intermediate shaft makes equal angles with the axis of rotation of the drive shaft and the axis of rotation of the driven shaft, and (*b*) that the axes of the hinges of the two forks on the intermediate shaft are parallel.

The universal joint depicted in Figs. I and III is such a double universal joint, designed in tubular form so as to enclose the flexible metal bellows within it. Sleeves 60 and 68 fit accurately over cylindrical surfaces or parts 57 and 79 shown in Fig. I and parts 60 and 68 are preferably to be secured to 57 and 79 with both screws and dowel pins to insure a perfectly firm relationship free of all looseness. Parts 60, 64 and 68 are provided with projections having a partially cylindrical profile. In Fig. III these projections are seen in full profile view on the part 64 at B, B. They are seen in section on edge on the parts 60 and 68 at C, C on one side and at D, D they are indicated on the other side with dotted lines. Parts 60 and 68 each have two such projections C, D on diametrically opposite sides while part 64 has four such projections B consisting of two pairs the members of each pair being diametrically opposite one another and the axes of all four cylindrical surfaces lying in one and the same plane, a plane which passes through the axis of the ring 64. Parts 60, 64 and 68 are coupled together by means of rings 62 and 66.

Cylindrical holes pierce radially through the walls of these rings at four equally spaced positions around their circumferences and the material of the ring is cut away on one side of each of these holes as shown to admit the stems of the cylindrical projections B, C or D on parts 60, 64 and 68, with sufficient clearance to allow for a little hinge action by the turning of the cylindrical projection in the cylindrical hole in which it fits. The parts are assembled by sliding the cylinders B, C or D successively laterally into the holes. To prevent them from sliding out of these positions rings 63 and 71 are slid on over the parts 62 and 66 and secured to these parts with screws as 63' and 71'. This universal joint may be assembled and secured to parts 57 and 79 after the bellows 69 have been welded to 57 and 79 to insure locating the sleeves 60 and 68 of the joint in such a relationship to the parts 57 and 79 as to subject the bellows to no torque or strain. The use of a double rather than a single universal joint at this place has the further advantage that it permits both the cathode structure 3, 13, 29, 37' etc., and the oblique shaft 44 to be aligned independently each with its pair of ball bearings. A minute error in such alignment or a minute failure of the axis of cathode structure and oblique shaft to intersect will then be taken up without strain by the freedom afforded by the double universal joint. Such errors can readily be made small enough to introduce entirely negligible departures from uniform kinematic transmission of angular velocity by the double universal joint.

An alternative type of double universal joint is shown in Fig. IV. Parts of this figure analogous to parts in Fig. III are indicated with the same numerals to which a prime has been added. In this form the cylindrical projections B, C, D, in Fig. III are replaced by spheres mounted on cylindrical stems 91, 97, as shown the stems being firmly secured in parts 60', 64' and 68'. The part 60' is adapted to be attached to 57 and 68' to 79. The parts 60', 64' and 68' are mechanically coupled by means of the split rings 62' and 66' which are split along the planes indicated at Q into two separate parts joined with screws as 63'' and 71''. The spheres as B', B', C', C', and D', D', fit in sockets which may be in the shape of spherical zones or conical frustra in the split rings 62' and 66' and these socket cavities open out on at least one side through the walls of the rings 62' and 66' in holes of sufficient size to provide clearance for the stems supporting the spheres so as to permit adequate hinge action for the functioning of the universal joint.

While the rotation of the envelope is effected by the shaft 44 in the structure shown they might be separately driven in any suitable manner without departing from the invention in some of its aspects.

The fluid in the space 14 may serve several purposes including (1) to conduct heat from the anode structure 8 of the X-ray tube to cooling means such as the water cooling pipes 11 em-

bedded close at hand in the insulating housing 12. (2) To conduct heat from other portions of the outer surface of the X-ray tube such for example as the window 5 or the glass walls 42. (3) To lubricate the bearing means 25 and 65 and the working surfaces of the elements of the universal joint 60, 62, 63, 64, 66 and 68. (4) To insulate the high potential difference which must exist between the anode structure 8 and the parts connected to the cathode such as 57 which might otherwise cause electrical creepage over the glass surface 42 with resulting destructive electrical breakdown.

The driving motor shown diagrammatically at 78 may be of any conventional type such as an induction motor or a repulsion induction motor. No attempt has been made to depict this motor in detail as its construction is well known. Openings have been provided as shown in the frame of this motor and in its rotor to permit of ready access with a screw driver to the screws 81 by which the packing gland 74, 76 can be tightened or adjusted. To facilitate assembly and disassembly of the entire mechanism the rotor 83 of this motor is designed so that by loosening a screw 89 it can be slid off the shaft 44 the slip rings 84 and 88 being small or set in enough to permit this.

It is clear that my invention is not limited to the exact forms depicted. For example the shape of the target surface may be modified from that of an internal cylinder shown at 10 to that of a right circular cone flaring either outward toward the window or in the opposite direction (see Fig. V). Furthermore, the shape of the outer surface of the cathode structure in which the cathode focussing cup is located need not be cylindrical but may also be conical. It is clear that these surfaces may be so modified, shaped and positioned as to permit of utilizing the X-radiation which is emitted from the target in the general direction of most intense emission, a direction which is known to vary somewhat with the voltage for which the tube is designed to be operated, inclining more and more in the direction of the exciting cathode rays as the voltage increases. It is further clear that the words conical surface as here applied to the surfaces of the anode and cathode structures may include such special cases of the right circular cone when the half angle at the vertex of the cone is 90° and the surface becomes a plane.

It will be further clear that my invention admits of the provision of a multiplicity of thermal cathodes like that shown at 4 and of focusing cups like that shown at 16 positioned at various places about the circumference of the cathode structure which may be provided with separate connections to separate external circuits and designed to give, at the choice of the operator, focal spots of various sizes and shapes adapted to various technical applications in one and the same tube. It will be further clear that my invention admits of the provision of focal spots at two positions in space on the rotating target surface to adapt the tube to the making of stereoradiographs without displacing the tube structure as a whole as specifically illustrated in Fig. V.

In Fig. V is shown a target 10 inclined outwardly toward the window. The cathode structure 13 contains two filaments 4 each having an energizing wire 31 which may be connected through the rod 44 with a separate brush 85 at the end of the rod. The outer window 5 may be removable from the casing 12. The coils 4 may be separately energized at suitable times and the cups 16 may be each suitably shaped or positioned for whatever result may be desired. Thus successive pictures of the same object may be taken of the image cast by the differently produced X-rays to produce a pair of pictures which may give an impression of three dimensions.

It is further clear that my invention is not solely restricted to a design in which the X-rays emerge through a window in the end of the tube as shown though for many purposes this is a convenient and desirable design. The target and cathode may be so shaped, positioned and designed that the rays to be utilized emerge through the side walls in the more conventional way. The target structure can then completely close the end of the tube and fluid cooling can then be directly carried to the target structure proper, or to cavities in that structure, by means of rotating joints and fluid tight packing glands of reasonably small diameter located on the axis of rotation of the X-ray tube outside the target end.

It will be further clear that the invention admits of internal shielding of the tube from the escape of X-rays in undesired directions. This may be accomplished for instance in the design shown in Fig. I by making parts 8, 10, 45, 57, 79, etc., and also parts of the universal joint out of materials appropriately absorbent to X-rays or by providing shields or coatings of such materials to cover the parts named. Shielding may of course also be introduced in the various housing structures as 12, 58, 72 etc., or the shock proof shield above mentioned but not shown in the figures.

The invention is not confined to the specific apparatus shown.

I claim as my invention:

1. In an X-ray producing device, a rotating anode supporting member having on its inner surface an annular target, a stationary cathode supporting member, and a plurality of electron emitting filaments carried by the cathode member and adapted to bombard the target at different points producing distinct focal spots.

2. In an X-ray producing device, a rotating anode supporting member having on its inner surface an annular target, a stationary cathode supporting member, and two electron emitting filaments carried at diametrically opposite points on the cathode member and adapted to bombard the target at different points producing distinct focal spots.

3. In an X-ray producing device, a rotating anode supporting member having on its inner surface an annular target, a stationary cathode supporting member, and two electron emitting filaments carried by the cathode member and adapted to bombard the target at diametrically opposite points producing distinct focal spots.

4. In an X-ray producing device, a rotating anode supporting member having on its inner surface an annular target, a stationary cathode supporting member, and a plurality of electron emitting filaments carried by the cathode member each adapted to bombard the target in a different region producing distinct focal spots said regions being elongated and having their narrow dimensions in the direction of rotation of the target.

5. In an X-ray generating device an evacuated rotating envelope carrying an anode; a rod

entering the envelope and rotating on an axis at an angle with the axis of rotation of the envelope; a cathode member within the envelope; means for holding the cathode stationary; a bellows connecting the envelope and the rod at about the point where their axes cross; and a universal joint connecting the rod and envelope and surrounding the bellows and relieving the stresses therein.

6. In an X-ray generating device an evacuated rotating envelope carrying an anode; a rod for rotating the envelope but itself rotating on an axis at an angle with the axis of rotation of the envelope; a cathode member within the envelope held from rotation by the rod; a plurality of electron emitting devices on the cathode member; a bellows connecting the envelope and the rod at about the point where their axes cross; and a universal joint connecting the rod and envelope and surrounding the bellows and relieving the stresses therein.

7. In an X-ray generating device an evacuated rotating envelope carrying an anode; a rod for rotating the envelope but itself rotating on an axis at an angle with the axis of rotation of the envelope; a cathode member within the envelope held from rotation by mechanical means; a bellows connecting the envelope and the rod at about the point where their axes cross; and a universal joint connecting the rod and envelope and surrounding the bellows and relieving the stresses therein.

8. In an X-ray generating device an evacuated rotating envelope carrying an anode; a rod rotating on an axis at an angle with the axis of rotation of the envelope; a cathode member within the envelope held from rotation by the rod; a bellows connecting the envelope and the rod at about the point where their axes cross; and a universal joint connecting the rod and envelope and surrounding the bellows and relieving the stresses therein.

9. In an X-ray generating device comprising an evacuated rotating envelope anode member; a rod rotating on an axis at an angle with the axis of rotation of the envelope; a cathode member within the envelope held from rotation by the rod; a bellows connecting the envelope and the rod at about the point where their axes cross; and a universal joint connecting the rod and envelope and surrounding the bellows and relieving the stresses therein.

10. In an X-ray generating device comprising an evacuated rotating envelope anode member; a rod rotating on an axis at an angle with the axis of rotation of the envelope; a cathode member within the envelope held from rotation by the rod; and a bellows connecting the envelope and the rod at about the point where their axes cross.

11. In an X-ray generating device a housing member; an elongated evacuated envelope mounted for rotation within the housing member about a line extending along the length of the envelope, and provided with an X-ray permeable window extending transversely across one end thereof and X-ray producing means disposed interiorly thereof to cause generation of X-rays directed through the window; electron emitting means within the envelope; bearing means for the envelope mounted within the housing exteriorly of the envelope; bearing means within the envelope connecting the envelope and the electron emitting means; and a rod extending through the envelope and rotating on an axis at an angle to and crossing the axis of rotation of the envelope and engaging the electron emitting means eccentrically of its axis and holding it from rotation.

12. In an X-ray generating device a housing member; an elongated evacuated envelope mounted for rotation within the housing member about a line extending along the length of the envelope, and provided with an X-ray permeable window extending transversely across one end thereof and X-ray producing means disposed interiorly thereof to cause generation of X-rays directed through the window; a plurality of electron emitting means within the envelope; means for holding the electron emitting means stationary; bearing means for the envelope mounted within the housing exteriorly of the envelope; bearing means within the envelope rotatably supporting the electron emitting means from the envelope; and a rod extending through the envelope and rotating on an axis at an angle to and crossing the axis of rotation of the envelope and the electron emitting means.

13. An X-ray generating device which comprises a housing member; an elongated evacuated envelope mounted for rotation within the housing member about a line extending along the length of the envelope, and provided with an X-ray permeable window extending transversely across one end thereof and X-ray producing means disposed interiorly thereof to cause generation of X-rays directed through the window; electron emitting means within the envelope; bearing means for the envelope mounted within the housing exteriorly of the envelope; bearing means within the envelope connecting the envelope and the electron emitting means; a rod extending through the envelope and rotating on an axis at an angle to and crossing the axis of rotation of the envelope; and mechanical means for holding the electron emitting means from rotation.

14. In an X-ray generating device, a rod, means for rotating the rod about its central longitudinal axis, an evacuated envelope carried by the rod and rotated by the rod but on an axis at an angle to the axis of rotation of the rod, the axes crossing within the envelope, an anode carried by the envelope, a cathode structure within the envelope and engaged by the rod so as to hold it stationary in space, a bellows connecting the rod and envelope, and a hollow universal joint connecting the rod and envelope and surrounding the bellows.

15. In an X-ray generating device, a rod, means for rotating the rod about its central longitudinal axis, an evacuated envelope carried by the rod and rotated on an axis at an angle to the axis of rotation of the rod, the axes crossing within the envelope, an anode carried by the envelope, a cathode structure within the envelope, mechanical means to hold the cathode stationary in space, a bellows connecting the rod and envelope, and a hollow universal joint connecting the rod and envelope and surrounding the bellows.

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