June 21, 1938. M. J. GROSS ET AL 2,121,632

X-RAY TUBE

Filed May 11, 1936

Fig. 1.

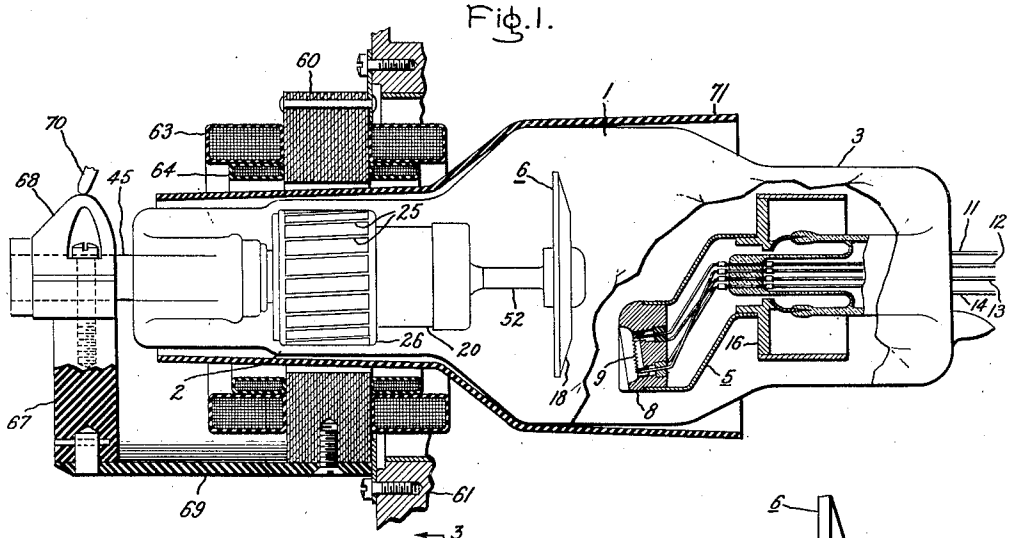


Fig. 2.

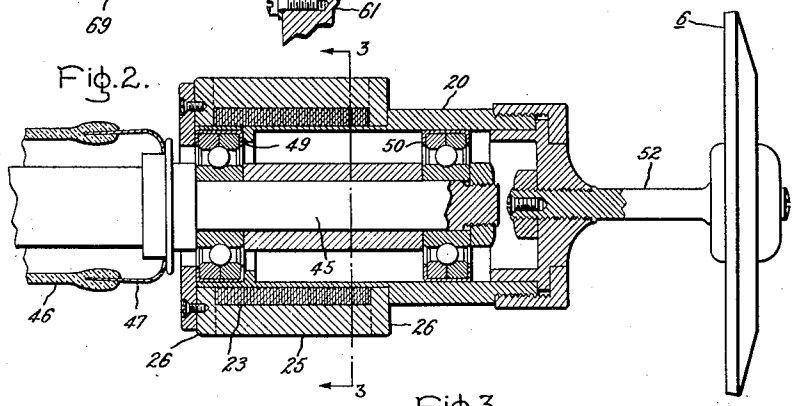


Fig. 3.

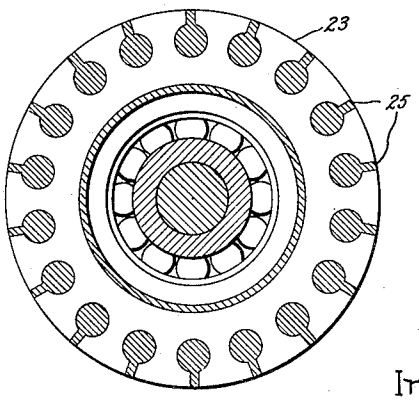
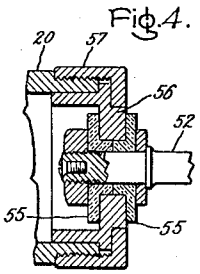


Fig. 4.



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X-RAY TUBE

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Application May 11, 1936, Serial No. 78,996

4 Claims. (Cl. 250—35)

The present invention relates to X-ray tubes, and more particularly to improvements in X-ray tubes in which one of the discharge electrodes is movable with respect to the other to provide relative motion between the electron beam and the surface of the anode or target.

In our copending application, Serial No. 78,994, filed May 11, 1936, and assigned to the same assignee as the present application, we have disclosed and claimed an apparatus assembly embodying an X-ray tube of the type above specified. The present invention is more especially concerned with the rotatable structure to be used in such a tube. Among the particular objects of the invention are included the provision of an electromagnetic rotor which is capable of developing high torque, is essentially free from occluded gases, and is generally adapted for operation in a highly evacuated discharge vessel.

The features of novelty which we desire to protect herein are pointed out with particularity in the appended claims. The invention itself, however, both as to its construction and its mode of operation, together with further objects and advantages thereof, will best be understood by reference to the drawing in which Fig. 1 shows in elevation an X-ray tube suitably embodying the invention; Fig. 2 is a cross-sectional view showing the details of the rotor structure; Fig. 3 is a further section taken on line 3—3 of Fig. 2; and Fig. 4 shows in section the details of a particular construction for joining the anode to the rotor structure.

Referring now particularly to Fig. 1 we have shown as illustrative of the use of our invention an X-ray tube comprising an enclosing envelope consisting of a main central cylinder 1 merging at the ends into smaller cylinders 2 and 3 respectively. This envelope is preferably exhausted to a high vacuum on the order of one micron, for example, in accordance with the procedure outlined in Coolidge Patent No. 1,203,495, and forms a sealed enclosure for discharge electrodes adapted to cooperate in X-ray generation. In the present case these electrodes consist of a cathode 5 and a target or anode 6 axially spaced therefrom and arranged within the central envelope cylinder 1. The envelope as a whole may be enclosed in a sealed casing filled with oil as described in our aforementioned application, Serial No. 78,994.

The cathode 5 comprises a focusing cup 8 having in the face thereof a pair of recesses adapted to accommodate alternatively usable electron-emissive filaments. In the view shown in Fig. 1 the focusing cup is broken away to show only the filament 9, which is supplied with heating current by means of lead-in conductors 11 and 12 respectively. A second filament, concealed in this view by the structure just described, is supplied with heating current through a separate pair of wires 13 and 14. The two cathode filaments are made of different size in order to increase the effective operating range of the tube. Near the base of the cathode we provide a metal shielding structure 16 which is effective to intercept random X-ray emanations and electrically charged particles proceeding toward the cathode during the radiographic use of the X-ray tube.

Electrons emitted from the cathode are projected onto the opposed target face 18 of the disk-shaped anode 6 and cause the generation of X-rays from its surface. The target face is inclined with respect to the main axis of the tube at an angle, for example 75 degrees, so that the generated X-rays may be projected laterally through the side walls of the tube onto a desired objective.

It is possible by continuously rotating the anode disk to increase very materially the permissible intensity of the electron beam which may be projected against the target surface. Since by the rotation the heating effect of the electron beam is distributed over a considerable area, serious burning of the target metal may be avoided under any but the most intensive bombardment. In the present case such rotation of the anode is accomplished by connecting it to a rotor structure such as is shown in detail in Fig. 2.

This rotor structure comprises a cylindrical sleeve 20 which at one end is joined to an electro-magnetic rotor similar to the so-called "squirrel cage" induction type. This consists in the present instance of a core of stacked laminations 23 made of highly magnetic material, such as silicon steel, and is provided with axially extending slots slightly skewed with respect to the rotor axis. These slots, the cross-sectional appearance of which is shown in Fig. 3, are filled with a metal, such as copper, which thus forms a series of peripherally displaced conducting bodies 25 extending longitudinally of the rotor core. These bodies are joined at their ends by integrally fused rings 26 (Fig. 1) of the same material.

Rotors of the type just described possess very high torque characteristics when compared with the structures heretofore employed in this field of use. On the other hand, the degassing of a rotor structure such as that described, if con-

structed in accordance with conventional methods, presents such a formidable task that it has not been previously accomplished. We have found, however, that if the conducting bodies **25** are cast into the rotor under vacuum conditions, then the rotor structure may be made gas-free to an extent sufficient to permit its use in a highly evacuated discharge device.

For the casting operation the rotor laminations may be assembled in the desired relationship and enclosed in a gas tight heating chamber along with an ingot of copper or other suitable material of high electrical conductivity. The chamber is then exhausted to a low vacuum, preferably on the order of one millimeter of mercury, and sufficient heat applied to melt the ingot into the rotor slots. In order to facilitate the latter operation the ingot may be suspended so that the fused metal drips down over the stack of laminations. The laminations themselves should be slightly oxidized to insulate them from the conductive material and are preferably dusted with borax which acts as a flux during the casting process. After the casting is completed, the cast material is allowed to cool under vacuum conditions, and the excess material is removed by machining the rotor to finished dimensions.

A rotor structure thus formed is strikingly different in gas-emitting characteristics from a structure cast in the usual manner. The copper is non-porous and is essentially free from occluded gases, while the laminations and slots do not retain trapped bubbles which can be released in the subsequent use of the structure. We have thus provided a cast laminated rotor of high torque characteristics which can be successfully incorporated in an X-ray tube adapted to operate for a life of many hundred hours at a vacuum not materially in excess of one micron of mercury pressure.

The completed rotor is supported on a stationary shaft **45** which is secured to the reentrant envelope stem by a metal flare **47** forming with the glass a hermetic seal. In order to decrease as much as possible the rotational resistance of the rotor, anti-friction means comprising spaced bearing units **49** and **50** are interposed between it and the shaft **45**. These comprise ball bearings of the so-called "full" type having inner and outer races but omitting retainer rings. It will be noted that the outer race of the bearing **50** is movable with respect to the cylinder **20** to permit relative expansion of the structural parts.

A major and heretofore insoluble problem in the construction of a satisfactory rotatable anode X-ray tube consists in the provision of suitable bearing surfaces adapted to stand up under the unusual conditions encountered in this particular use. For example, the bearings must be able to withstand heating to extremely high temperatures over a considerable period of time during the process of degassing and evacuating the envelope. Furthermore, because of the necessity of excluding from the tube all substances having an appreciable vapor pressure, the bearings are required to be operated without the assistance of any type of lubricating film.

These requirements are fulfilled in the present case by providing retainerless bearings which are constituted of a hard abrasion-resisting metal capable of retaining its properties under the normal conditions of manufacture and operation of the X-ray tube. Materials satisfactory for this use comprise precipitation hardened metals which are characterized by a Rockwell C hardness of at least 55 and preferably between 60 and 65 units and which are able to retain this hardness after vacuum firing at a temperature of at least 600° C. and are capable of high speed operation without substantial abrasion in the entire absence of a lubricating film. Bearings comprising such materials are the invention of George Hotaling and are fully described and claimed in his application Serial No. 123,222, filed January 30, 1937. A particular metal which has been used successfully consists of a precipitation hardened alloy having an analysis of approximately 0.77 per cent carbon; 18.5 per cent tungsten; 4.52 per cent chromium; 1.75 per cent vanadium; 1 per cent molybdenum; 9 per cent cobalt, and a complementary percentage of iron. It should be understood, however, that the above figures represent the analysis of a particular sample of the metal, and that the percentages given are not invariable or limiting. After hardening to a Rockwell C hardness of from 63 to 65 units this material will maintain a hardness in excess of 62 units after heating for prolonged periods at from 500° to 650° C. Furthermore, it will stand use in the bearing structure above described under normal operating conditions without the occurrence of substantial abrasion.

The procedure of degassing the bearings has the effect of roughening the metal surfaces and thereby decreasing the radial clearance between the balls and their races. In order to offset this effect, it is necessary to use a larger initial clearance than is customary. For example, whereas standard radial clearance may be 0.0004 inch, we have found it desirable to provide a clearance in the untreated bearings of from 0.002 to 0.005 inch.

Because of the necessity for operating the bearings without lubrication and because of the surface roughening mentioned above, they develop considerable friction in comparison with similar bearings lubricated with oil. The torque characteristics of the particular rotor structure which we have described in the foregoing are sufficiently great, however, to overcome this friction and to rotate the anode at a speed of at least 2500 revolutions per minute.

In order to minimize the transmission of heat from the anode **6** to the rotor and bearing structure and to avoid the need for special cooling means for the bearings, the two parts are separated by a shaft **52** of small diameter with relation to its length. If, however, it is desired to decrease still further the rate of heat transfer, the assembly shown in Fig. 4 may be utilized. In this figure the shaft **52** is coupled to the end of the cylinder **20** through the intermediation of washers **55** of an insulating material, for example, magnesium oxide. These washers are pressed against opposite sides of a flanged supporting member **56** which in turn is firmly retained against the end of the cylinder 20 by the threaded clamping plate **57**. We consider it desirable in joining the anode to the rotor structure to form the screw-threaded parts in such a way that all such parts tighten in a single direction. Accordingly, if the rotor is driven in that direction, there will be no tendency for the parts to become loosened.

In a rotating anode X-ray tube it is expedient to have a large diameter anode in order to make available as great a target area as possible. On the other hand, it is desirable to have a small

rotor structure in order to obtain minimum weight. It is also desirable to reduce the clearance between the rotor and its cooperating stator (to be later described) to a smaller value than the clearance required between the anode disk and the glass. Further it is desirable to get the rotor and the anode disk as close together as possible in order to obtain a short tube, a minimum weight of rotor structure and minimum vibration. To accomplish this purpose the shape of the tube envelope shown in Fig. 1 is most advantageous, viz:—a large cylindrical mid-section in which the anode 6 rotates converging abruptly into a smaller cylindrical end section in which the rotor is placed.

An additional factor which necessitates a large clearance between the rotating anode and the envelope is that some melting of the tungsten of the beveled target face 18 may be allowed because the melting is spread over a large area. Where this actually occurs a considerable surface of glass must be provided for condensation of the tungsten and this surface must be an appreciable distance from the interelectrode space so that it is out of the strong electric field.

Power may be transmitted to the rotor structure by means of an electromagnetic stator 60 mounted externally of the tube and surrounding the cylindrical portion 2. The stator 60 is held in place by clamping to a stationary body 61, which may comprise a portion of the casing in which the X-ray tube is enclosed, and consists of a series of stacked laminations of ferro-magnetic material. The construction of the stator corresponds to that of induction motors of known types and includes windings 63 and 64 respectively arranged in slots in the inner periphery of the stator core. These windings are adapted to be energized either from a source of polyphase current or through phase-splitting means from a single phase source in order to create a rotating electric field. By electromagnetic induction such a field is capable of generating circulating currents in the conducting bodies 25 arranged in the slots of the rotor structure and of producing a strong rotational torque upon the rotor as a whole.

In order to minimize stresses set up in the glass envelope at the instant of starting the rotor, the envelope itself is supported on the shaft 45, as previously explained, being free to vibrate with the shaft rather than resisting such vibration. Further, as a convenient means of mounting the shaft 45 to prevent relative motion between it and the stator 60, a rigid connection is provided between them. This comprises an insulating body 67 clamped at one end to the shaft by a two-part metal clamp 68 and to the stator itself by an insulating shell 69 securely bolted to the outer surface of the stator laminations.

The tube is operated by energizing the stator windings 63 and 64 to produce high speed rotation of the anode 6 and thereafter impressing on the anode and cathode a high potential from an external source (not shown). The anode is connected to the potential source through a conducting stud 70 (in part broken away) contacting the metal clamp 68, while the cathode receives heating current and is maintained at high potential with respect to the anode by means of the in-lead connections 11 to 14. To provide sufficient insulation between the stator 60 which it is desirable to have at ground potential and the parts of the X-ray tube which are at anode potential, we provide a continuous sleeve 71 of an insulating material, such as phenolic resin, disposed between the stator and the envelope cylinder 2.

It will be understood that the passage of an electronic discharge from the cathode to the anode results in the generation of X-rays from the beveled target face 18 and their projection onto a desired objective surface.

While we have shown a particular embodiment of our invention, it will be understood by those skilled in the art that modifications in the structure may be made without departing from our invention, and we aim in the appended claims to cover all such modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States, is,—

1. In an X-ray tube, a highly evacuated envelope containing a cathode and a rotatable anode, a stationary shaft projecting into said envelope, a rotor structure concentric with said shaft, means including anti-friction bearings supporting the rotor structure on said shaft, a mechanical connection between the rotor structure and said anode, and electromagnetic means arranged outside said envelope for transmitting driving force to the rotor structure, said rotor structure comprising a cylinder of laminated ferromagnetic material having a plurality of circumferentially spaced longitudinal slots therein, and a squirrel cage of vacuum-cast copper having longitudinally extending portions filling said slots and rings interconnecting said portions at the ends thereof.

2. In an X-ray tube, an evacuated envelope enclosing a cathode and a rotatable anode provided with a target face thereon, a rotor structure for driving said anode, means including anti-friction bearings for supporting said rotor structure within the envelope, a mechanical connection between said anode and rotor structure and means including a non-metallic insulating element interposed in said connection for decreasing the heat transmitted from said target face to said bearings.

3. In an X-ray tube, an evacuated envelope enclosing a cathode and a rotatable anode provided with a target face thereon, a rotor structure connecting with the anode for driving the same, means including anti-friction bearings supporting said rotor structure within the envelope, and means for limiting the heat transmitted from the anode to said bearings through the rotor structure, said means including a shaft of small diameter with relation to its length comprising substantially the sole connection between the anode and the rotor structure and a body of insulating material forming a part of said connection.

4. A discharge device comprising a highly evacuated envelope enclosing cooperating discharge electrodes, one of said electrodes being rotatable with respect to the other, a rotor structure mechanically connected to said rotatable electrode, means including anti-friction bearings for supporting the rotor structure, and electromagnetic means arranged outside the envelope for transmitting driving force to the rotor structure, said rotor structure comprising a cylinder of laminated ferromagnetic material having a plurality of circumferentially spaced longitudinal slots therein, bodies of vacuum-cast copper filling said slots and means conductively interconnecting said bodies at the ends thereof.

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