June 21, 1938. M. J. GROSS ET AL 2,121,630

X-RAY APPARATUS

Filed May 11, 1936 2 Sheets-Sheet 1

Fig. 1.

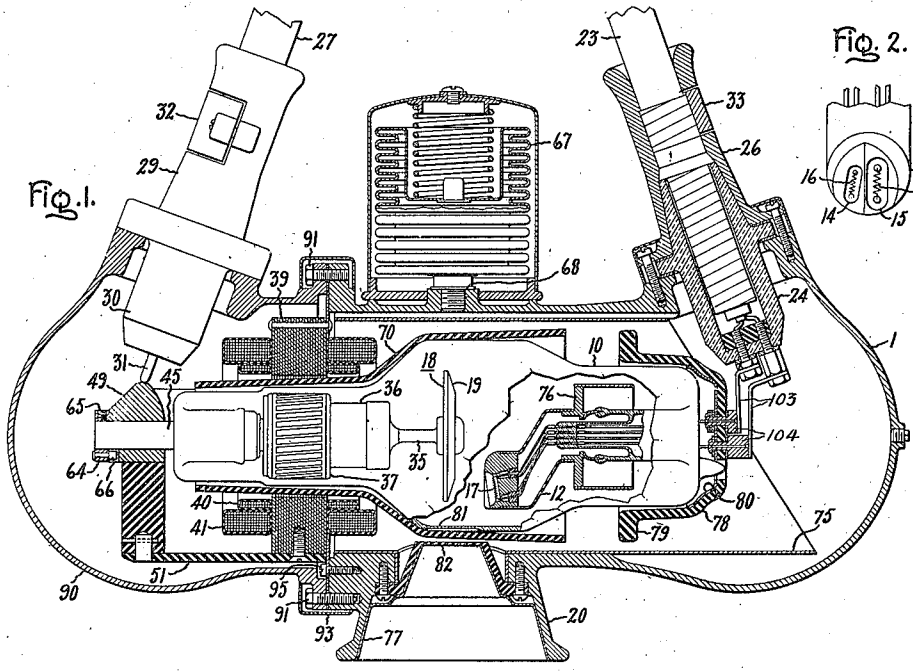


Fig. 2.

Fig. 6.

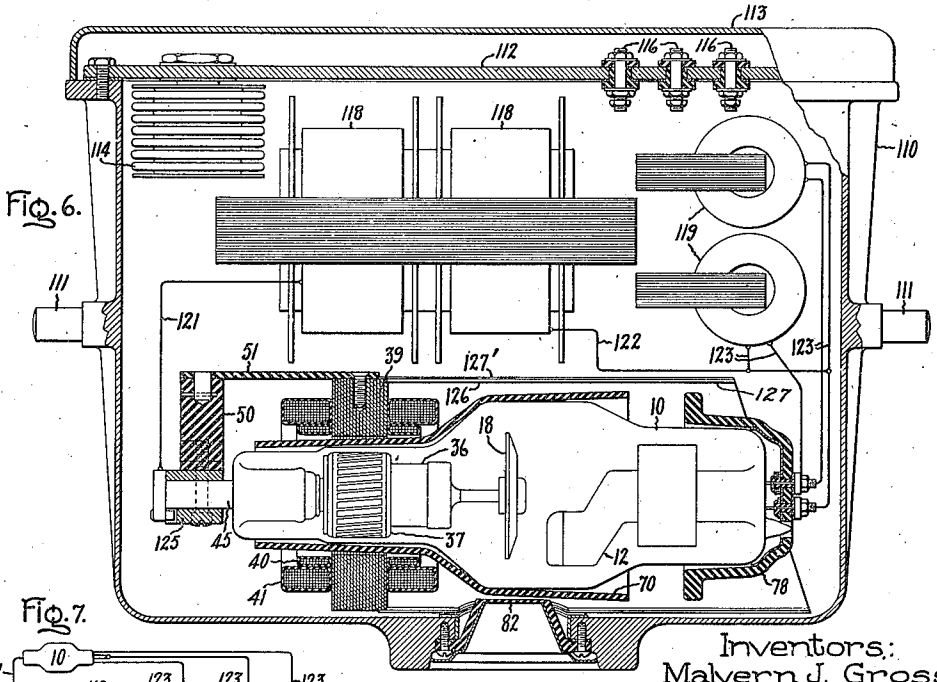
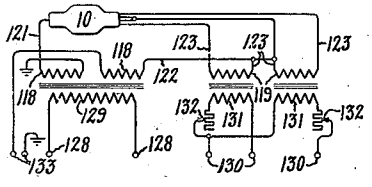


Fig. 7.



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Fig. 3.

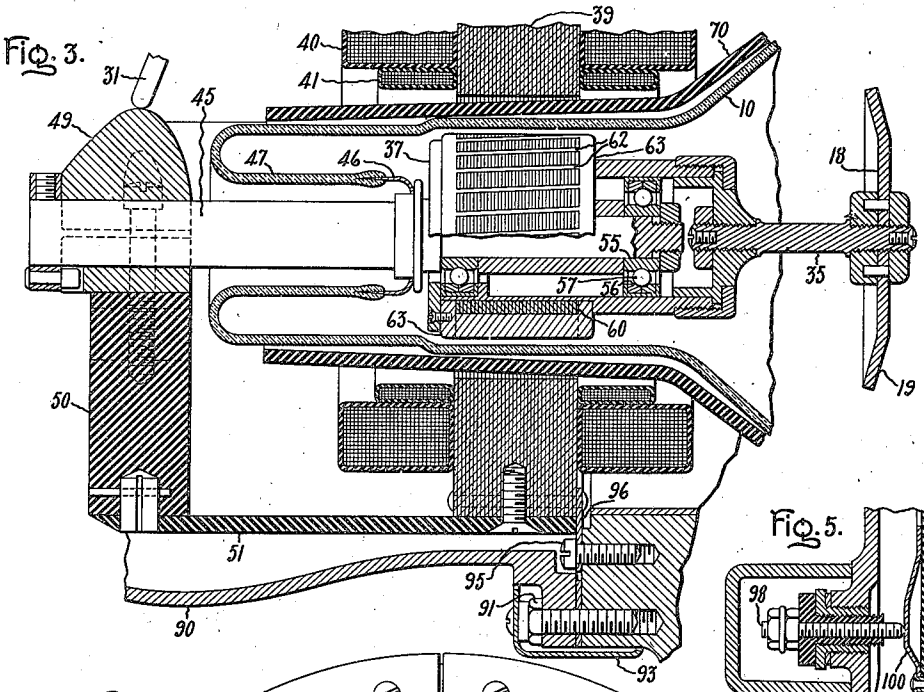


Fig. 5.

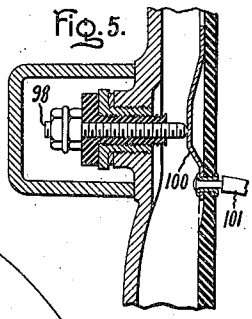
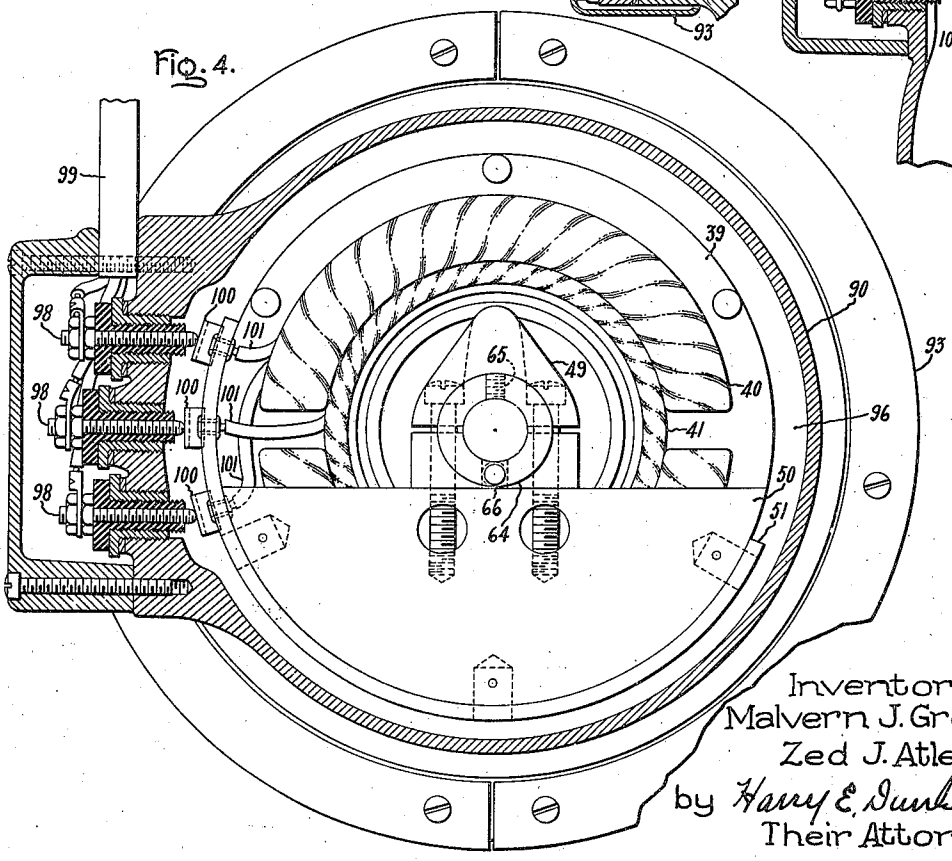


Fig. 4.



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UNITED STATES PATENT OFFICE

2,121,630

X-RAY APPARATUS

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Application May 11, 1936, Serial No. 78,994

9 Claims. (Cl. 250—34)

The present invention relates to X-ray apparatus, and more particularly to improvements in apparatus embodying an X-ray tube 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.

Our invention has for an object the provision of conveniently usable X-ray apparatus especially adapted for heavy duty use, and for long commercial life under such use. To this end we have combined an improved form of rotatable anode X-ray tube with a distinctive apparatus assembly which besides being rugged and well protected against mechanical vibration is exceptionally light and compact and is easily demountable to facilitate inspection and replacement of parts. The construction is also made unusually safe from the standpoint of operator and patient by novel shielding means rendering the whole apparatus electrically shockproof and essentially impervious to random X-ray emanations.

The features of our invention which we desire to protect herein will be pointed out with particularity in the appended claims. The invention itself, however, both as to its construction and mode of operation, together with additional objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the drawings, in which Fig. 1 is a longitudinal sectional view of a portable X-ray apparatus embodying the invention; Fig. 2 is a detail view showing the frontal appearance of the cathode structure; Fig. 3 is an enlarged fragmentary view in section showing the details of the anode construction and mounting; Fig. 4 is an end-view of the embodiment of Fig. 1, in which the casing has been cut along the line 4—4 and removed to reveal the tube supporting structure; Fig. 5 is another fragmentary section disclosing the appearance from below of the contact mechanism illustrated at the extreme left of Fig. 4; Fig. 6 is a longitudinal sectional view showing the application of the invention in a modified form wherein the alternating current transformer units as well as the X-ray tube are enclosed in a single container; and Fig. 7 shows diagrammatically the circuit connections pertaining to the construction of Fig. 6.

Referring now more particularly to Fig. 1, we have illustrated our invention as applied to a portable X-ray apparatus which combines high allowable X-ray output with small bulk and weight to an extent not previously attainable in devices of this class.

Externally viewed this apparatus comprises a metal casing 1 which terminates at each end in a rounded bulbous portion and consists centrally of a substantially cylindrical section of somewhat reduced diameter.

Arranged axially within the casing 1 and supported therefrom in a manner to be specified more fully hereinafter is provided a novel X-ray tube of our invention. This comprises a glass envelope 10 evacuated in accordance with the procedure outline, for example, in Coolidge Patent No. 1,203,495. At one end of the envelope is arranged a cathode structure 12 offset from the center of the tube. As shown in greater detail in Fig. 2 this cathode structure comprises a focusing cup 13 having in the face thereof a pair of recesses 14 and 15 each containing a substantially linear filamentary cathode. These filaments, numbered 16 and 17, respectively, are of different size and are electrically separate so that they may be used alternatively to permit a greater range of operation of the X-ray tube. The respective outer faces of the focusing cup associated with each of the filaments 16 and 17 as well as the filaments themselves are angularly disposed so that their projections on the face of the target or anode 18 will produce substantially parallel focusing spots. The details of construction of the cathode are disclosed and claimed in our copending application Serial No. 78,995 filed May 11, 1936, and assigned to the same assignee as the present invention.

The anode 18 may comprise a disk of refractory metal such as tungsten, preferably roughened to increase its heat dissipating qualities. Adjacent its outer periphery the anode is provided with a smooth beveled face 19 angularly inclined to the major plane of the anode by a relatively small angle in the neighborhood of 15°. This beveled face is adapted to receive electrons projected from the cathode and to generate X-rays which may pass through the wall of the X-ray tube and of the casing 1 into the cone 20, which may also constitute a supporting base for the entire apparatus. Since the target as a whole is rotated during tube operation, as will be more fully explained in the following, more intense bombardment and greater X-radiation can be permitted than is allowable with stationary anode devices. Heating current is supplied to the filament of the cathode 12 through a cable 23 which also serves to connect the cathode to an external source of high potential. This cable

is heavily insulated as shown and is enclosed for a portion of its length in an insulating bushing 24, for example, of porcelain, which projects toward the interior of the casing 1. Mechanical bracing and protection are afforded to the cable by an outwardly projecting metal sleeve 26 comprising a separately affixed extension of the main casing. A high potential connection to the anode is made at the other end of the casing by a similar insulated cable 27 brought in through corresponding sleeve and bushing parts 29 and 30 and having a projecting stud 31 adapted to make friction contact with the terminal structure of the anode. In connection with each of the sleeves 26 and 29 clamping portions 32 and 33 are provided having adjustable tightening means for causing them to grip the surface of the cable and to hold it firmly in place.

In accordance with our invention the anode 18 is coupled through a shaft 35 with a rotor structure comprising a bearing housing 36 and an induction rotor 37. To this latter element, the construction of which will be more fully described in the following, driving force is transmitted from a cooperating stator 39 mounted outside the tube envelope. As is best shown in Fig. 1, this stator comprises a core of stacked laminations of magnetic material having exciting windings 40 and 41 arranged in slots provided for that purpose in the inner periphery of the stator core. The construction of the stator corresponds to that employed in induction motors of known types and need not be described in detail. It is sufficient for present purposes to state that when a rotating field is established in the field space within the magnetic core by energization of the stator windings, the rotor 37 will be subjected to a powerful rotational torque due to circulating currents induced in its conductive parts.

The spacing and creepage distances required between the exposed electrode connections to prevent electrical break-down are considerably lessened by the provision in the casing 1 of a suitable liquid dielectric as, for example, a suitable oil. Furthermore, the clearance between the X-ray tube and the wall of the casing is made much less than would be permissible with an air filling. The combination of these factors results in an impressive reduction of the bulk of the whole unit.

An even more significant economy of space and weight is realized, however, through the particular disposition of the stator which we have provided. In the first place, the superior cooling properties of the oil, in which it is immersed, permit the use of much smaller dimensions in the core and windings than would be allowable in open air. In addition, by electrically grounding the stator core to the casing rather than maintaining it at the potential of the anode we avoid the use of a massive insulating transformer for insulating the stator supply connections. It may be noted that the presence of the oil makes such grounding feasible in spite of the relatively short creepage distance to the anode lead-in connection. We further prevent direct break-down to the rotor through the wall of the envelope by the interposition of a shield 70, which comprises a continuous shell of insulating material, for example, phenolic resin. This shield includes a portion projecting into the gap between the rotor and stator, and a further portion surrounding the enlarged central cylinder of the envelope. By the provision of such a unitary shield, having no joints or regions of low dielectric strength, we have found that a high degree of protection is afforded.

Referring now to Fig. 3, we have shown in greater detail the particular features of construction of the anode and rotor structure and of the means employed for supporting the various parts. It will be seen that the rotor structure is supported on a rigid shaft 45 of conducting material, for example, copper, which projects through the envelope wall. The shaft is affixed to the envelope by means of a hermetically tight glass-to-metal joint comprising a tapered metal flange 46 fused into a reentrant glass stem 47. Externally it is rigidly fixed as by the connection to the stator frame shown in the drawings.

We have found that if the envelope 10 is supported within the casing by a rigid or unyielding clamping connection to the outside of the envelope, torque impulses occurring during the starting period of the motor are transmitted from the rotor 37 to the shaft 45 and must be absorbed by the frangible glass-to-metal connection between the shaft and the glass envelope. In order to prevent this possibility and to avoid the danger of breakage resulting therefrom, we support the envelope as well as the rotor 37 from the shaft 45. Apart from this connection the envelope is substantially free to move within the casing, further support being made unnecessary by the presence of the oil bath which more or less floats the envelope in a condition of equilibrium. Whereas this type of mounting might be impractical in air or other gaseous atmospheres because of blurring or apparent enlargement of the focal spot due to vibrations generated by the high speed rotation of the anode 18, in the present arrangement such vibrations are largely damped by the presence of the oil. Further, the magnitude of the vibrations is substantially lessened by the shortened envelope permitted by the corona-preventing properties of the oil.

In order to provide a simple and compact support for the shaft 45 and to prevent as far as possible the transmission of shaft vibrations to the wall of the casing, we provide a substantially rigid connection between the stator frame and the shaft 45 which effectively suppresses any tendency for relative motion to occur between these parts. This connection includes the conducting terminal 49, which is rigidly clamped to the shaft 45 as best shown in Fig. 4, a segmental block 50 of phenolic resin or other insulating material and a supporting element shown as a semi-cylindrical shell 51 securely bolted to the peripheries of both the segmental block and the stator 37.

Proper orientation of the X-ray tube and more particularly of the focal spot with respect to the cone 20 is secured by an adjustable aligning means comprising the circular ring 64, the set screw 65, and the key 66. Prior to the assembly of the apparatus, the proper position of the ring 64 on the shaft 45 may be determined by setting the tube in an aligning jig provided for that purpose. After such alignment is once made the tube may be installed in its casing in the manner shown with assurance that its parts will be properly disposed with respect to the X-ray window.

A major problem in the construction of a satisfactory rotatable anode X-ray tube consists in the provision of suitable bearings 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, due to the extremely high vacuum which must be maintained at all times during operation, the bearings must be qualified to run at high speed without any form of lubrication whatever. In order to meet these qualifications we provide anti-friction bearings of the form illustrated in Fig. 3. These comprise ball bearings of the so-called "full" type having inner and outer races 55 and 56 respectively but preferably omitting the retainer rings, which we have found particularly susceptible to abrasion during tube operation. The balls 57 as well as the cooperating race members should be made 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 maintain this hardening 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 found adequately to fulfill these requirements 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. 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 heat treatment required satisfactorily to degas the bearings inevitably produces pitting and roughening of their working surfaces. Since these surfaces are required to run without lubrication, considerable friction will be present and a rotor structure capable of developing high torque is desirable to overcome this friction. However, in view of the extreme difficulty of effectively degassing rotor structures, the tendency has been to use simple low-torque constructions and to avoid bearing difficulties by failing to heat the parts to a true degassing temperature. We have succeeded in incorporating into a thoroughly degassed X-ray tube a laminated rotor construction having high torque characteristics by casting the windings into slots in the periphery of the stacked laminations under vacuum conditions.

Referring again to Fig. 3 the details of construction of our improved rotor will be evident. It is shown as consisting of a stack of annular laminations 60 provided with longitudinally extending slots slightly skewed with respect to the rotor axis. These slots are filled with vacuum cast material 62, preferably copper, and the windings thus formed are interconnected at their ends by peripherally extending rings 63 of the same material. Due to the fact that the windings and laminations are degassed during the casting process, little difficulty is experienced in sufficiently degassing the assembled rotor structure after installation in the tube in spite of the relatively great mass of material comprised in the laminated core. This rotor construction is claimed in our copending application, Serial No. 78,996, filed May 11, 1936 and assigned to the same assignee as the present invention.

During operation, heat flow to the bearings and rotor structure from the anode 18 is minimized by the fact that the thermal circuit between them consists only of the relatively small shaft 35 which is inherently of limited heat conductivity. Heat flow may be still further reduced by forming a part of the shaft 35 or of its coupling with the anode 18 of a refractory insulating material such as magnesium oxide. For accomplishing sufficient heat dissipation from the anode surface we are able to rely on the radiation of heat to the walls of the envelope adjacent the anode and its subsequent absorption by the oil bath. This effectual separation of the anode and bearings obviates the necessity of providing special cooling means in connection with the latter to avoid their deterioration by the heat transmitted to them. Expansion and contraction of the oil due to changes in temperature is permitted by the provision of a sylphon bellows 67 in communication with the casing through a central duct 68.

In a rotating anode X-ray tube it is desirable 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 and stator structure in order to obtain minimum weight. It is also desirable to reduce the clearance between the stator and rotor 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 rotating structure and minimum vibration. To accomplish these purposes the shape of the tube envelope shown in Fig. 1 is most advantageous, viz: a large cylindrical section in which the anode 18 rotates, converging abruptly into a smaller cylindrical section about which the stator 37 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 face 19 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 electrical field.

The apparatus is made substantially impervious to X-rays emanating in directions other than through the cone 20 by the provision of a cylindrical lead sheath 75 surrounding a major proportion of the envelope 10, including particularly the interelectrode space. This sheath is grounded to the casing by direct connection thereto and is adequately insulated from the high potential electrode parts by the extended enlarged portion of the sleeve 70.

Additional protection against radiations coming from the target as well as against secondary radiations from the other parts of the tube is afforded by the metal masses of the cathode structure, by lead cap 77 partially lining the cone 20, and by the cathode base 78. This latter may be constituted of an insulating material, for example, phenolic resin impregnated with an oxide of a metal of high atomic number, and may

comprise a flaring collar 79 attached to the main portion of the base. It may also have a lining 80 of lead or a similar X-ray impervious metal.

In order to minimize absorption of X-rays emitted in the desired direction, viz: outwardly through the cone 20, the glass wall of the envelope comprises a portion 81 of reduced thickness adjacent the cone opening. The X-ray window formed by aligned apertures in the lead sheath 75 and the casing 1 is closed by a reentrant cone 82, suitably of phenolic resin. Since the face of this cone closely approaches the outer surface of the sleeve 70, it decreases substantially the amount of intervening oil required to be traversed by the X-rays.

It is further desirable to make the apparatus demountable to permit occasional inspection and replacement of parts. To this end the casing 1 is divided in the region adjacent the stator 39. Here the bulbous cap portion 90 is joined to the main body of the casing by removable means such as screws 91. During the use of the apparatus this joint may be concealed by a cover plate or ring 93.

The X-ray tube is so arranged that the section comprising the rotor mounting projects from the main body portion of the casing 10. The stator core 39 is removably supported against the end of the casing by means of an annular mounting ring 96 rigidly affixed to the stator core as by riveting thereto. With this arrangement the removal of the casing end-portion 90 renders accessible whatever retaining means, corresponding to the screw 95 shown in Figs. 1 and 3, is employed to hold the mounting ring in place.

To further facilitate the removal of the stator without requiring the severance or manual disconnection of its current leads, we provide the special contact arrangement best seen in Figs. 5 and 6. This comprises a series of conducting screws 98 projecting into the casing 1 but being externally connected to a low potential supply source through a cable 99. Within the casing the ends of these screws are in contact with a series of flat resilient leaf springs 100 which in turn are connected to wires 101 leading directly to the stator windings. The resilience of the springs 100 is sufficient to permit the tips of the screws 98 to slide past without substantial interference so that disengagement of the contacts is an incident of the removal of the cap-portion.

Once the cap portion is taken off the removal of the stator and envelope structure is a relatively simple matter. The cathode connections comprise simply spring conductors 103 frictionally engaging terminals stud 104, and the envelope is otherwise unsecured within the casing.

In Fig. 6 we have shown a modified use of our invention as applied to a self-rectifying type of apparatus in which the high potential alternating current transformers as well as the X-ray tube and motor structure are immersed in a liquid dielectric medium. In this embodiment the transformers are shown schematically rather than in detail, and other elements corresponding to those already described in connection with the preceding figures are identically numbered. The supporting means for the transformers and X-ray tube are not shown but may conveniently consist of insulating braces depending from the top of the casing.

In the construction illustrated the casing comprises an oil-filled metal tank 110 suitably of cast aluminum provided at each end thereof with stub shaft projections 111 adapted for mounting the apparatus in trunnion supports. The tank is sealed at the top by a closure plate 112, tightly bolted thereto, and is furnished with a removable cover 113 surmounting the closure plate. Here again, a sylphon bellows 114 is provided in the upper left-hand corner of the tank for permitting expansion of the oil.

Low voltage electrical connections are brought to the inside of the tank by means of a plurality of insulated conductors 116. The connections between these and the various transformers have been omitted in Fig. 6 in order to avoid confusion of the drawing, but will correspond to the connections indicated in Fig. 7. The high potential circuit connected to the high voltage side of the transformers 118 comprises the conductors shown in Fig. 6 in full outline. These include the anode connection 121, the corresponding cathode connection 122, and the heating circuit connections 123 leading from the secondaries of the filament transformers 119.

The other portions of the apparatus are substantially similar to those already described although it will be noted that in this case the supporting member 51 and the attached segmental insulator 50 are connected to the top rather than the bottom of the stator 39. The conducting clamp 125 is also of somewhat different form than the corresponding element described in connection with Fig. 1 because of the possibility of making a permanent rather than removable connection to the source of anode supply voltage. Also in this case the lead sheath 127 is given additional mechanical support by means of an enclosing sheath 127', suitably of brass or steel, fitted on to the periphery of the stator core 39.

In Fig. 7 we have illustrated diagrammatically the complete circuit connections pertaining to the apparatus assembly described in connection with Fig. 6. It will be seen that the low potential connections, which are accessible externally of the casing 110, include terminals 128 for connecting the transformer primary 129 to a suitable source of external potential (not shown) and similar terminals 130 for the filament transformer primaries 131. Also connected in series with these latter transformer windings may be included variable impedance means 132 for regulating the heating of the respective filaments. Additional connections which it is desirable to have externally available include terminals such as those indicated at 133 for the inclusion in the transformer secondary 118 of means for measuring the intensity of the discharge current.

With the arrangement just described, the apparatus is intended to operate as a self-rectifying unit, a mode of operation for which it is particularly well adapted. In self-rectifying tubes of prior construction a relatively low upper limit of permissible discharge current has been imposed by the condition that the target surface must not be permitted to become so hot as to be electron emissive. With a moving target surface, a temperature of emissivity is attained only under very much heavier bombardment, and a considerable gain in energy rating of the apparatus for self-rectifying use may be realized.

While we have described particular embodiments of our invention it will be understood by those skilled in the art that modifications may be made without departing from the invention, and we aim by 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 X-ray apparatus, a casing comprising a main body portion open at one end thereof, an X-ray tube envelope arranged within said main body portion but having a section projecting from said open end, cooperating discharge electrodes within said envelope, a rotor structure within said projecting section of said envelope for rotating one of said electrodes, means for transmitting driving force to said rotor structure, said means comprising an electromagnetic stator surrounding said section of said envelope, means readily accessible at the open end of said casing for removably supporting said stator, and a cap portion removably closing said open end of said casing and enclosing the projecting section of said envelope and said stator.

2. In X-ray apparatus, a casing comprising a main body portion open at one end thereof, an X-ray tube envelope arranged within said main body portion but having a section extending toward said open end, cooperating discharge electrodes within said envelope, a rotor structure within said section of said envelope for rotating one of said electrodes, means for transmitting driving force to said rotor structure comprising an electromagnetic stator surrounding said section of said envelope, contact terminals on said stator for conducting electrical current thereto, a cap-portion removably closing said open end of said casing and including means frictionally contacting said terminals for conducting current thereto.

3. In X-ray apparatus, a casing comprising a body portion open at one end thereof, an X-ray tube envelope arranged within said body portion but having a section projecting from said open end, cooperating discharge electrodes within said envelope, a rotor structure within said projecting section of said envelope for rotating one of said electrodes, means comprising an electromagnetic stator surrounding said section of said envelope for transmitting driving force to said rotor structure, contact terminals associated with said stator for conducting current thereto, means readily accessible at the open end of said casing for removably supporting said stator, a second portion of said casing removably closing the open end thereof and enclosing the projecting section of said envelope and said stator, one of said casing portions including contacts engaging said terminals for conducting current thereto, disengagement of said contacts being an incident of the removal of said second casing portion.

4. In X-ray apparatus, a casing comprising a main body portion open at one end thereof, an electrode containing envelope arranged within said main body portion but having a section including an electrode terminal projecting from said open end, a rotor structure within said projecting section of said envelope for rotating said one of said electrodes, means for transmitting driving force to said rotor structure, said means comprising an electromagnetic stator surrounding said section of said envelope, contact terminals mounted on said stator for conducting electrical current thereto and a cap portion removably closing said open end of said casing and enclosing the projecting section of said envelope and said stator, said cap portion comprising means frictionally contacting all of said terminals for conducting electrical current thereto.

5. In X-ray apparatus, a casing comprising a portion open at one end thereof, an X-ray tube envelope within said portion but having a section thereof accessible from said open end, cooperating discharge electrode within said envelope, a rotor structure within said section of said envelope for rotating one of said electrodes, means for transmitting driving force to said rotor structure including an electromagnetic stator surrounding said section of said envelope, means readily accessible at the open end of said casing for removably supporting said stator, and a second portion of said casing removably closing the open end thereof.

6. In X-ray apparatus, a casing substantially completely filled with a liquid dielectric medium, an envelope consisting at least partly of glass immersed in said medium, cooperating discharge electrodes within the envelope including a rotatable anode, means for producing rotation of said anode, means including a member which is substantially immovable with respect to the casing for rotatably supporting said anode from said casing, and means supporting said envelope on said member, said envelope being otherwise substantially unsupported within the casing.

7. An X-ray apparatus comprising a casing, an X-ray tube within the casing including an envelope enclosing a cathode, a rotatable anode and an electromagnetic rotor structure for driving the anode, a shaft having a portion projecting externally of the envelope at one end thereof and a portion projecting internally of the envelope for supporting said rotor structure, an electromagnetic stator structure for supplying driving force to the rotor structure, means independent of the envelope and connecting with the externally projecting portion of said shaft for substantially immovably supporting the shaft within said casing, a connection including a hermetic seal between the shaft and said envelope providing substantially the sole support for said envelope, and a liquid dielectric medium surrounding the envelope and effective to dampen relative vibratory motion between the shaft and the envelope occasioned by rotation of said rotor structure.

8. An X-ray apparatus comprising a casing, an X-ray tube within the casing including an envelope enclosing a cathode, a rotatable anode and an electromagnetic rotor structure for driving the anode, an electromagnetic stator structure outside the envelope for supplying driving force to the rotor structure, means supporting the stator structure within the casing, a shaft comprising a portion projecting externally of the envelope at one end thereof and a portion projecting internally of the envelope for supporting said rotor structure, means independent of the envelope and connecting with the externally projecting portion of the shaft for supporting the shaft substantially immovably within the casing, said last named means including a mechanical connection effective to prevent relative movement between the stator structure and said shaft, a connection including a glass-to-metal seal between the shaft and the envelope providing the principal means of support for said envelope and a liquid dielectric medium surrounding the envelope and effective to dampen vibrations thereof caused by rotation of said rotor structure.

9. An X-ray apparatus comprising a casing, an X-ray tube within the casing including an envelope which encloses a cathode and a rotatable anode, means including a rotor structure within the envelope for driving the anode, a

shaft extending within the envelope for rotatably supporting the anode and rotor structure, a glass-to-metal seal rigidly connecting said shaft to the envelope, means outside the envelope for immovably supporting the shaft from the casing independently of the glass-to-metal seal so as to protect the seal from torsional forces exerted on the shaft by the rotor structure, and a filling of liquid dielectric medium within the casing serving in cooperation with the shaft-supporting means to support the envelope and to prevent vibratory motion thereof.

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