

Sept. 22, 1959

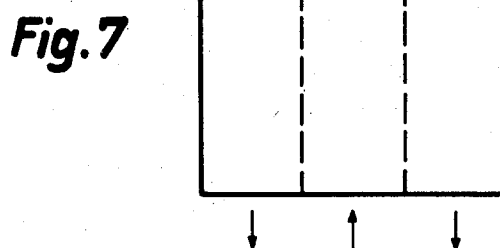
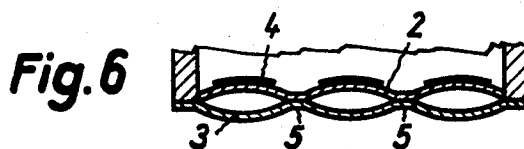
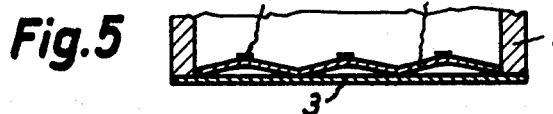
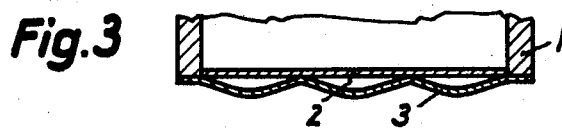
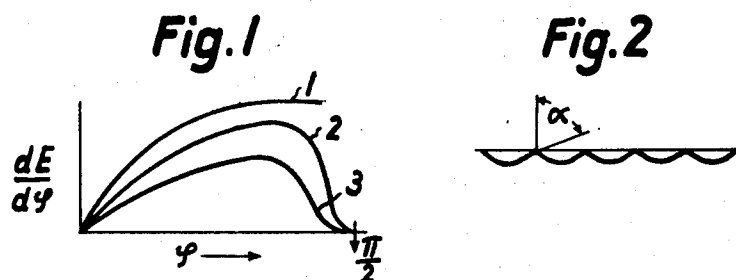
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HIGH POWER X-RAY TUBE WITH MEMBRANE ANODE

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3 Sheets-Sheet 1



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Fig.8

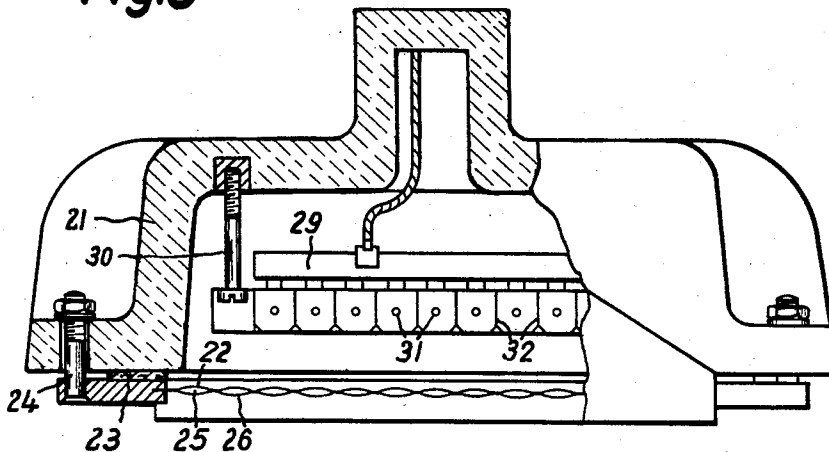
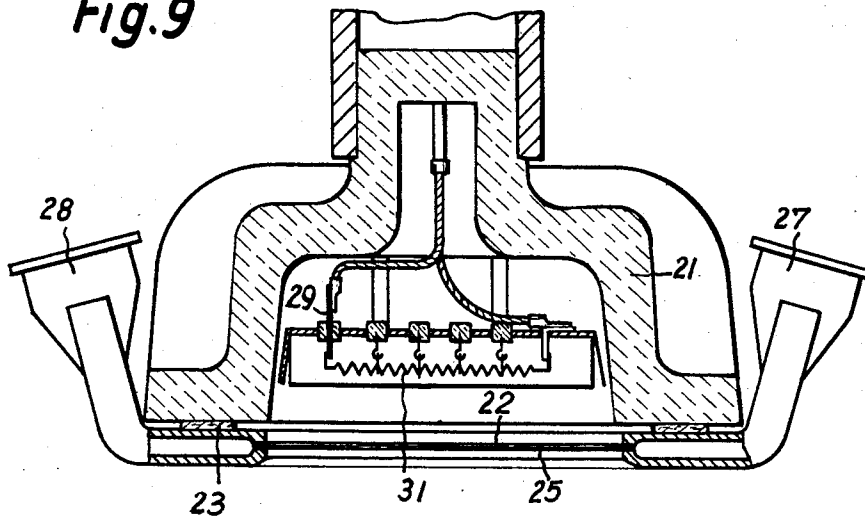


Fig.9



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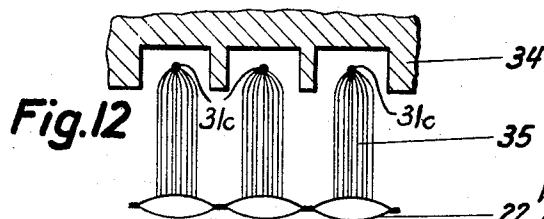
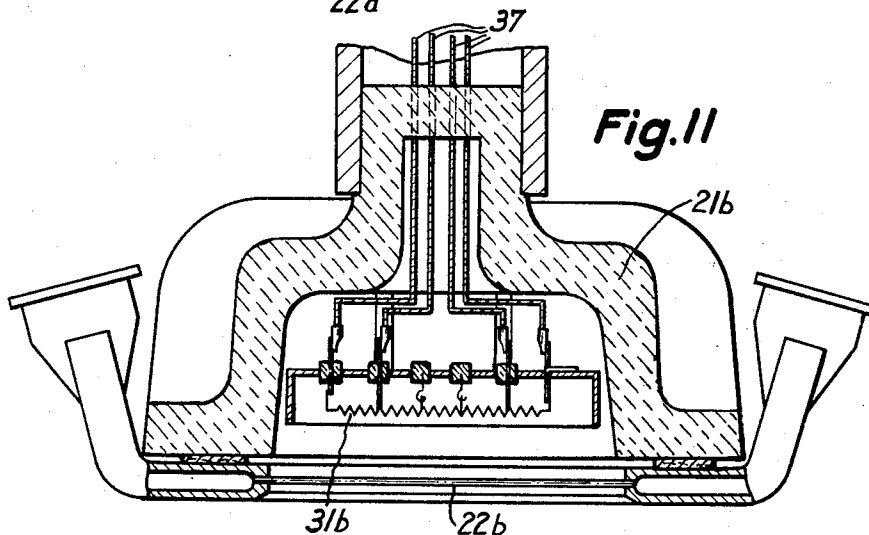
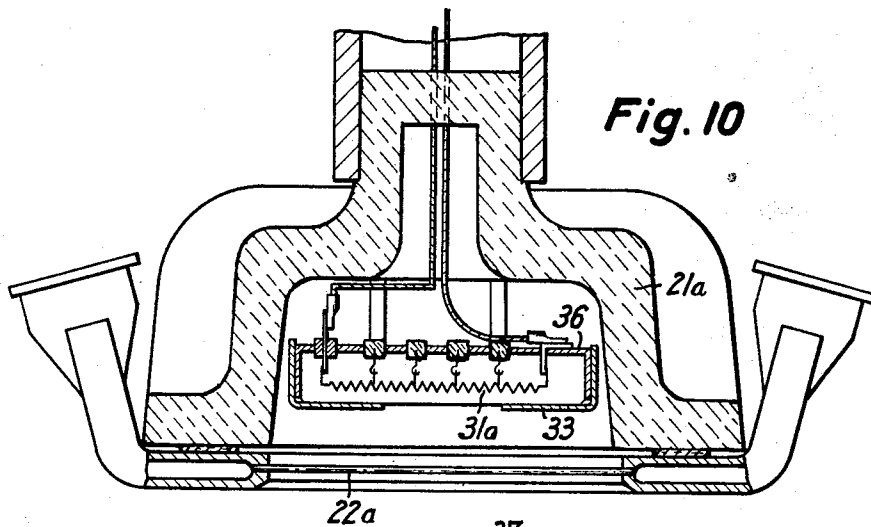
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3 Sheets-Sheet 3



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2,905,841

HIGH POWER X-RAY TUBE WITH MEMBRANE ANODE

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16 Claims. (Cl. 313—55)

The present invention relates to X-ray tubes. More in particular, the present invention relates to high-tension X-ray tubes with membrane anodes and more particularly still to the cooling means and the cathode and anode assemblies of such X-ray tubes.

It is known in the art that in X-ray tubes only a small fraction of the emitted electrons impinging upon the anode-target is converted into useful X-rays (1% at 120 kv. and W-anodes). It is known that a great amount of the X-rays is absorbed before reaching the object to be subjected to the radiation. For these reasons, every attempt must be made to reduce the loss of energy and to increase the amount of X-rays produced by a certain amount of energy, and to transmit as great a portion of the created X-rays to the object to be treated by radiation.

It is already known in the art to reduce the loss of energy by bringing the object as close as possible to the anode constituting the source of X-rays. This has been accomplished to some extent by employing the anode simultaneously as the X-ray-transmissive window of the tube. According to this construction the anode consists of a thin sheet of metal forming a part of the casing of the X-ray tube. This membrane anode must, however, be provided with highly efficient cooling means, since the greater part of the energy of the electrons impinging upon the anode target is converted into heat rather than X-rays. It has been proposed to effect the cooling of the membrane anode by erecting a waterproof wall consisting of a material having a light atomic weight in front of the anode and by circulating a cooling liquid in the intermediate space between the anode and the wall.

Such a cooling system is, however, accompanied by a number of serious disadvantages. The arrangement does not only result in a high absorption of the useful X-rays but it also does not lend itself to bring about a turbulent current of the cooling liquid which is required in order to prevent the formation of a cushion of vapor at the anode.

It is the general object of the present invention to provide for a high-tension X-ray tube having a membrane anode in which compared with known constructions a greatly reduced amount of energy is needed in order to produce the radiation needed for a particular purpose.

It is another general object of the present invention to provide for a high-tension X-ray tube having a membrane anode in which a greater amount of X-rays is transmitted to the object than by known constructions.

It is another object of the present invention to provide for a high-tension X-ray tube having a membrane anode in which the absorption of the useful radiation is greatly reduced.

It is a further object of the present invention to provide for a high-tension X-ray tube having a membrane anode which is equipped with greatly improved and more efficient cooling means.

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It is still a further object of the present invention to provide for a high-tension X-ray tube having a membrane anode which is equipped with cooling means in which the formation of a cushion of vapor at the anode is avoided.

It is another object of the present invention to provide for a high-tension X-ray tube having a membrane anode in which the load applied to the membrane anode can be adapted to the requirements of the object to be subjected to the radiation.

It is still another object of the present invention to provide for a high-tension X-ray tube having a membrane anode which can be operated without prolonged interruptions due to defects in the cathode or anode assemblies.

These objects as well as other objects and advantages which will become apparent as the description of the present invention proceeds are achieved by the improved high-tension X-ray tube with a membrane anode.

According to the present invention, the X-ray tube is equipped with a cooling system comprising several parallel cooling channels of which the membrane anode forms an integral part and through which the cooling liquid is conveyed, thus passing along and thereby cooling the anode.

A waste of energy is avoided by the X-ray tube of the invention by adapting the load applied to the anode to the particular requirements of the object to be treated with X-rays. This is accomplished by providing means for adapting and directing the stream of electrons within the X-ray tube to a surface of the cooled anode membrane corresponding to the desired field of radiation. Therefore only those areas of the large membrane are supplied with impinging electrons which are actually needed for producing the radiation required at any particular moment and for a specific purpose. Thus, objects of various sizes and dimensions can be subjected to the radiation of the X-ray tube of the invention without wasting energy by building up a large field of radiation which is actually not needed.

The invention will be better understood by the following description of the accompanying drawings, wherein Figure 1 is a diagram demonstrating the efficiency of the cooling system for the membrane anode of the X-ray tube of the invention;

Figure 2 is another diagram of one embodiment of the cooling channel of the invention and shows the advantages of the present invention;

Figure 3 is a cross-sectional view of the cooling channels for the X-ray tube of the invention;

Figure 4 is a cross-sectional view of another embodiment of the cooling channels for the X-ray tube of the invention;

Figure 5 is a cross-sectional view of still another embodiment of the cooling channels for the X-ray tube of the invention;

Figure 6 is a cross-sectional view of a preferred embodiment of the cooling channels for the X-ray tube of the invention;

Figure 7 is a diagram showing the direction of flow of the cooling liquid within the cooling channel shown in Figures 3 to 6;

Figure 8 is a cross-sectional view of one embodiment of the X-ray tube of the invention;

Figure 9 is a longitudinal sectional view of the embodiment of the X-ray tube of the invention shown in Figure 8;

Fig. 10 is a longitudinal sectional view similar to Fig. 9 but showing another embodiment of a cathode assembly;

Fig. 11 is a longitudinal sectional view similar to

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Figs. 9 and 10 but showing still another embodiment of a cathode assembly; and

Fig. 12 is a fragmentary cross-sectional view of yet another embodiment of a cathode assembly.

Referring now to the drawings somewhat more in detail and turning first to Figure 3, the ray-transmissive membrane anode 2 is fastened at the casing wall 1. A corrugated body 3 is mounted upon the membrane anode and thereby several tubular channels are formed. The cooling means flows through these tubular channels in a vertical direction relative to the plane of Figure 3.

It is also possible to employ a membrane anode 2 which is also corrugated as shown in Figure 4, or to have a corrugated membrane anode 2 and a planar body 3 (see Figure 5).

According to a preferred embodiment shown in Figure 6 of the drawings the tubular channels do not contact each other directly. They are connected to each other by solid bridges 5 which can, for example, be welded to the adjoining channel walls. In this case it is advantageous to choose bridges having a width which is greater than the combined width of the anode membrane at the wall of the body 3.

The lens shaped construction of the cooling channels has proved to be of great advantage. The channels are preferably constructed of a thin material absorbing only a small portion of the X-rays, as for example aluminum or plastics. The structure of the channels also results in a mechanical stabilization of the membrane anode. On their vacuum sides the channels can be thinly coated with a heavy metal e.g. gold.

The best results in regard to an even and effective cooling of all portions of the anode are obtained if the cooling liquid flows through the cooling system regularly and alternately in opposite direction (see diagram of Figure 7).

In order to protect the welding seam from thermal overloading it is advisable not to subject the entire anode to the impact of impinging electrons. As shown in Figures 4, 5, and 6 a focal spot having the form of a streak 4 (hereinafter called focal streak) can be created upon the anode portion of each cooling channel. The energy of the various focal streaks may vary, but the energy must be equally and evenly distributed across the entire focal streak, if a regular and even radiation is to be achieved. The object to be subjected to the radiation of the X-ray tube must of course be moved in a vertical direction to the focal streaks.

The adaptation of the stream of electrons to the desired field of radiation can be effected by providing a number of different cathode and/or anode assemblies which can be exchanged at will. Thereby the field of radiation can be varied and adapted to the requisite purpose. In addition, there is the advantage of eliminating interruptions in the operation of the X-ray tube, since cathode or anode assemblies which are worn out or which do not properly function can be easily replaced. Tubes of this kind are usually constantly evacuated during their operation by a system of vacuum pumps. Preferably they work at an operational voltage of from 100 to 250 kv.

According to another embodiment the X-ray tube of the invention is equipped with electro-optical means causing particular heating filaments or particular portions of the heating filaments not to emit electrons towards those parts of the membrane anode which are not needed for the particular purpose. For example, certain portions of the heating filaments can be electro-statically screened against the anode by screens having the cathode potential. As a result, no X-rays are created upon the corresponding portions of the membrane anode. The energy of the stream of electrons is thus used solely for creating X-rays upon that portion of the anode membrane which is needed for the radiation to be applied to the particular object.

According to another embodiment of the invention,

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the heating filaments can be subdivided and/or provided with supply wires or taps which are guided out of the X-ray tube separately and isolated from each other. In this case the size and the configuration of the field of radiation of the X-ray tube can be varied from the outside by switching in the corresponding portion of the heating filaments. It is self-evident that also several heating filaments can be connected in series or in parallel in groups. In that case one or several of the groups can be switched in at will. It is also possible to combine both switching arrangements just indicated.

Within the cathode elements there may be arranged one or several heating filaments.

Every cathode element used for creating a focal spot is screened against the other cathode elements and is electro-statically caused to create the desired focal streak upon the membrane anode. The heating filaments of the cathode elements can be connected in parallel or in series either singly or in groups. During its operation the X-ray tube is preferably constantly evacuated.

The invention will be even better appreciated upon the following description of an embodiment of the X-ray tube of the invention which is to be considered as an example not limiting the scope of the invention.

The anode is loaded with several focal streaks each produced by a cathode element. A separate cooling channel is provided for each focal streak. The membrane anode 22 is exchangeably fastened at the tube wall 21 by means of a screw 24, sealing means 23 being interposed. The membrane anode is of a corrugated shape. In front of the latter there are located the cooling channels 25, the walls 26 of which are also corrugated.

The cooling liquid is supplied through pipe section 27 and removed through pipe section 28. The casing wall 21 consists of a metal as, for instance, copper or a ceramic material. The cathode assembly 29, which may be isolated, is exchangeably fastened at the wall 21 of the casing by means of screw 30. The cathode assembly comprises a plurality of parallel positioned, heating filaments 31 which are separated from each other by screen 32. These screens are so arranged that the electrons emitted by any particular of the heating filaments 31 impinge only upon the crest of the corresponding corrugation of the membrane anode. In order to prevent the point of sealing 23 from being thermally overloaded there are provided two additional cooling pipes which have no corresponding cathode. The heating filament 31 of the cathode element consists of one single coiled wire. The cathode assembly can be exchanged for another cathode assembly after the anode assembly which includes the anode membrane has been removed, the removal of the anode and cathode assemblies being made possible by unscrewing the screws 24, 30. In the other cathode assembly substituted for the original cathode assembly the single cathode elements may have a greater number or shorter or differently connected heating wires (for example connected in series) which may be at will switched off singly or in groups, each group comprising several wires. Such an arrangement is shown in Fig. 11 wherein the tube wall is indicated at 21b, the membrane anode at 22b, and the filaments at 31b. As a matter of course the various supply wires 37 have to be separately guided out of the tube. It has also been found that a cathode assembly such as is shown in Fig. 10 may be substituted. In this embodiment the tube wall is indicated at 21a, the membrane anode at 22a, and the filaments 31a are screened by electrostatic screens 33 which can be welded or soldered to the cathode assembly 36 in any desired adjusted position. In this way, the screens will be at cathode potential. Alternatively, the cathode assembly may, as fragmentarily shown in Fig. 12, include an electro-optical lens 34 which so influences the stream of electrons 35 emitted from the filaments 31c that this stream is restricted to an area of the membrane anode 22c sufficient to produce a desired field of radiation of X-rays.

The anodes of the embodiments of the X-ray tube of

the invention just described can be subjected to a high specific load, so that in case of equilibrium the anode assumes a temperature of 300 degrees centigrade. The cooling can be effected in the way of the generally known vapor cooling. If this cooling method is employed it is imperative to remove the resulting steam bubbles from the anode as quickly as possible by a high water pressure and a turbulent current of the cooling liquid. (Reynolds' number in excess of 10,000). If this is done, an energy of at least

$$750 \frac{\text{watts sec.}}{\text{cm.}^2}$$

can be continuously deducted.

The advantages of the cooling system of the invention will also be clearly recognized from the following considerations explained with reference to Figures 1 and 2 of the accompanying drawings.

Curve 1 in Figure 1 represents the X-ray energy E emitted at an angle φ into space angle element $d\varphi$. If the absorption by a planar anode membrane is taken into account, the curve 2 is obtained. If, furthermore, the absorption by a cooling layer of even thickness is considered, the curve 3 is valid. The final curve for $dE/d\varphi$ is situated between the curves 2 and 3 (indicating the mean value).

As curve 2 demonstrates, the absorption by the anode membrane causes a movement of the value from

$$\frac{dE}{d\varphi} \longrightarrow \theta \text{ for } \varphi \longrightarrow \frac{\pi}{2}$$

If a marginal angle φ_G is defined in such a manner that the integral intensity between

$$\varphi = \varphi_G \text{ and } \varphi = \frac{\pi}{2}$$

is small compared with the total intensity, i.e.

$$\int_{\varphi=\varphi_G}^{\varphi=\frac{\pi}{2}} (\text{curve 2}) d\varphi \ll \int_{\varphi=0}^{\varphi=\frac{\pi}{2}} (\text{curve 2}) d\varphi$$

the radiation in this space angle range does not substantially contribute to the total radiation of the respective surface area element of the anode membrane.

According to the invention a cooling tube system can be used which is composed of assembled cylinder segments. By way of example, Figure 2 shows a cross-section of such a cooling system. If the angle (α) between the perpendicular upon the anode membrane and the tangent of the cooling system at the point of intersection between the anode membrane and the channel wall is selected, so that $\alpha = \varphi_G$, the following advantages are attained:

(1) All essential shares of space angles of the radiation (with $\alpha \leq \varphi_G$) can reach the work space after having pierced the outer wall only once.

(2) Those portions of the radiation which have been weakened by a transverse piercing of the wall are weakened to a smaller degree by the cooling system of the present invention than by an ordinary parallel cooling system.

It will be understood that this invention is susceptible to modification in order to adapt it to different usages and conditions, and, accordingly, it is desired to comprehend such modifications within this invention as may fall within the scope of the appended claims.

What we claim is:

1. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said membrane anode forming an integral part of said cooling channels.

2. A high power high-tension X-ray tube, comprising

a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said cooling channels being formed by said anode membrane and by an outer wall, said membrane anode being planar and said outer wall being corrugated, said outer wall and said membrane anode being joined to form said cooling channels.

3. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said cooling channels being formed by said anode membrane and by an outer wall, said membrane anode being corrugated and said outer wall being planar, said outer wall and said membrane anode being joined to form said cooling channels.

4. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said cooling channels being formed by said anode membrane and by an outer wall, said membrane anode and said outer wall being corrugated, said membrane anode and said outer wall being joined to form said cooling channels.

5. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said cooling channels being formed by said anode membrane, by said outer wall and by a plurality of bridges, said membrane anode and said outer wall being corrugated, said membrane anode and said outer wall being joined to form said channels and said bridges separating each of said channels from the adjoining channels.

6. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said cooling channels being formed by said anode membrane, by said outer wall and by a plurality of bridges, said bridges having a thickness which is greater than the combined thickness of said anode membrane and said outer wall, said membrane anode and said outer wall being corrugated, said membrane anode and said outer wall being joined to form said channels and said bridges separating each of said channels from the adjoining channels.

7. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said cooling channels being formed by said anode membrane and by an outer wall, said membrane anode and said outer wall being joined to form said cooling channels, said cooling channels being provided at their respective sides inside the vacuum of said X-ray tube with a thin layer of heavy metal.

8. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a

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cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said cooling channels being formed by said anode membrane and by an outer wall, said membrane anode and said outer wall being joined to form said cooling channels, said cooling channels being provided at their respective sides inside the vacuum of said X-ray tube with a thin layer of gold.

9. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said membrane anode forming an integral part of said cooling channels, and means for imparting an elevated speed to said cooling liquid within said cooling channels that a turbulent current is formed.

10. A high power high-tension X-ray tube, comprising a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade and a cooling system for cooling said anode, said cooling system comprising a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said membrane anode forming an integral part of said cooling channels, and means for creating a separate focal spot for each of said cooling channels.

11. An X-ray tube as described in claim 10, wherein said focal spots are formed as a streak, said streaks covering only a part of the anode portion of each of said cooling channels.

12. A high power high-tension X-ray tube comprising an anode assembly including a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade, a cooling system for cooling said membrane anode, said cooling system including a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said membrane anode forming an integral part of said cooling channels, a cathode assembly including a plurality of heating filaments emitting electrons when heated for creating separate focal spots on those areas of said membrane anode which are cooled by said plurality of cooling channels, respectively, and means for varying the stream of electrons emitted by said filaments

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of said cathode assembly with a view to supply an area of said membrane anode with a stream of impinging electrons which is sufficient to produce a desired field of radiation of X-rays.

13. An X-ray tube as described in claim 12, wherein at least one of said assemblies is removably arranged within said X-ray tube, said one assembly thus being replaceable by another assembly.

14. A high-power high-tension X-ray tube comprising an anode assembly including a ray-transmissive membrane anode which operates at a temperature of the order of 300 degrees centigrade, a cooling system for cooling said membrane anode, said cooling system including a plurality of cooling channels for circulation of cooling liquid therein, said cooling channels being arranged parallel to each other, said membrane anode forming an integral part of said cooling channels, a cathode assembly including a plurality of heating filaments emitting electrons when heated for creating separate focal spots on those areas of said membrane anode which are cooled by said plurality of cooling channels, respectively, and electro-optical means for restricting the stream of electrons emitted by said filaments to an area of said membrane anode sufficient to produce a desired field of radiation of X-rays, said electro-optical means including a plurality of adjustable screens at cathode potential for electrostatically screening various portions of said heating filaments against said membrane anode.

15. An X-ray tube as described in claim 12, wherein said heating filaments are subdivided and are provided with supply lines, said supply lines being separately and isolatedly guided out of the interior of the X-ray tube.

16. An X-ray tube as described in claim 12, wherein said cathode assembly comprises a plurality of cathode elements, said cathode elements being positioned parallel relative to each other, each of said cathode elements being provided with at least one of said heating filaments, each of said cathode elements influencing its corresponding wire so as to produce each one focal streak, and means for switching in from the outside any of said heating filaments singly or in combination.

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