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3,267,315

X-RAY SOURCE COMPRISING PLURAL REMOVABLE MODULAR UNITS

EACH HAVING AN ANODE TARGET AND CATHODE

Filed June 4, 1963

4 Sheets-Sheet 1

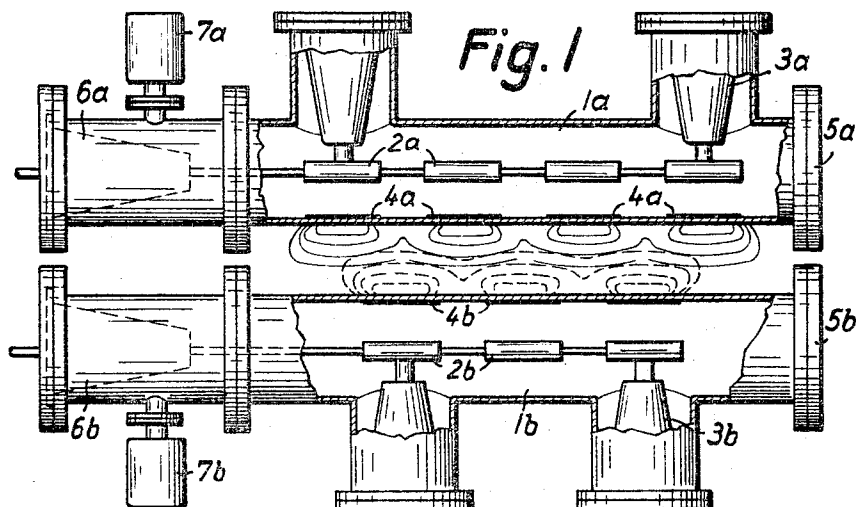


Fig. 2

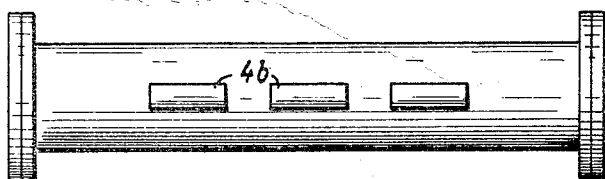


Fig. 3

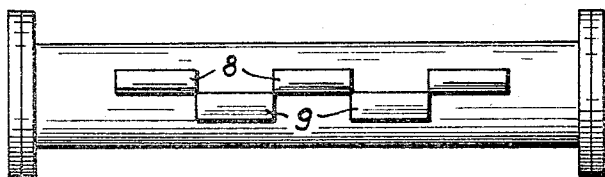


Fig. 4

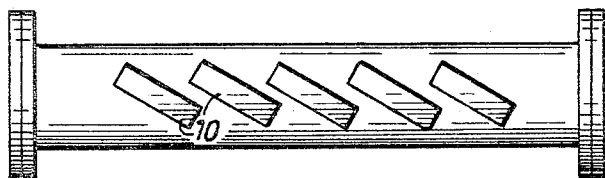
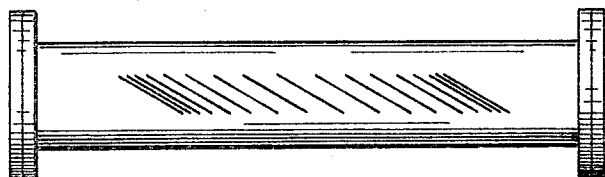


Fig. 5



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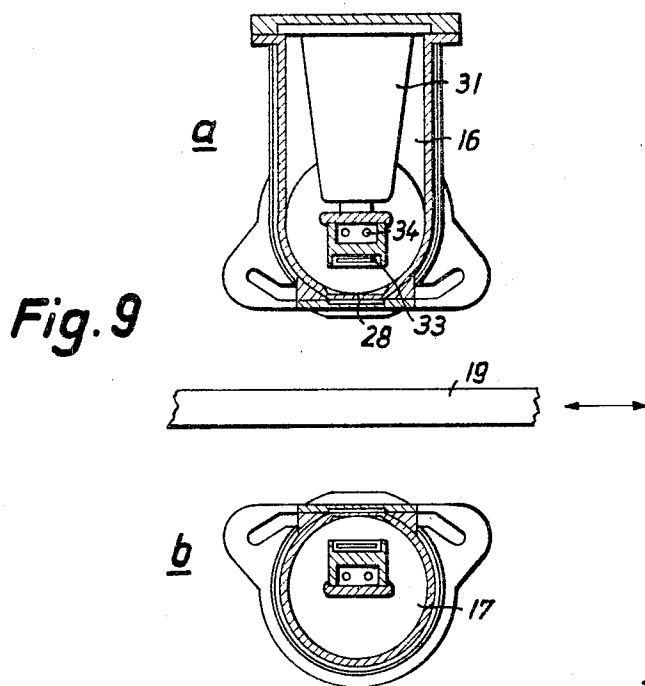
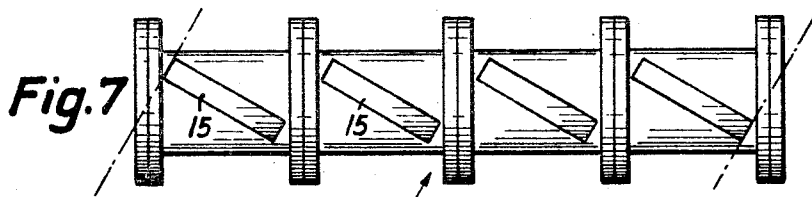
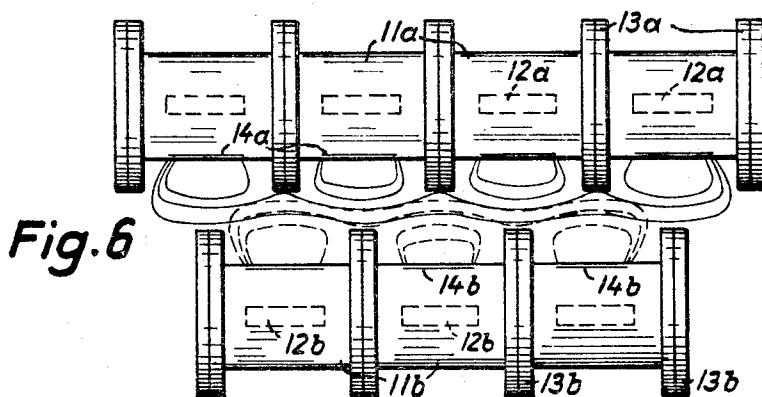
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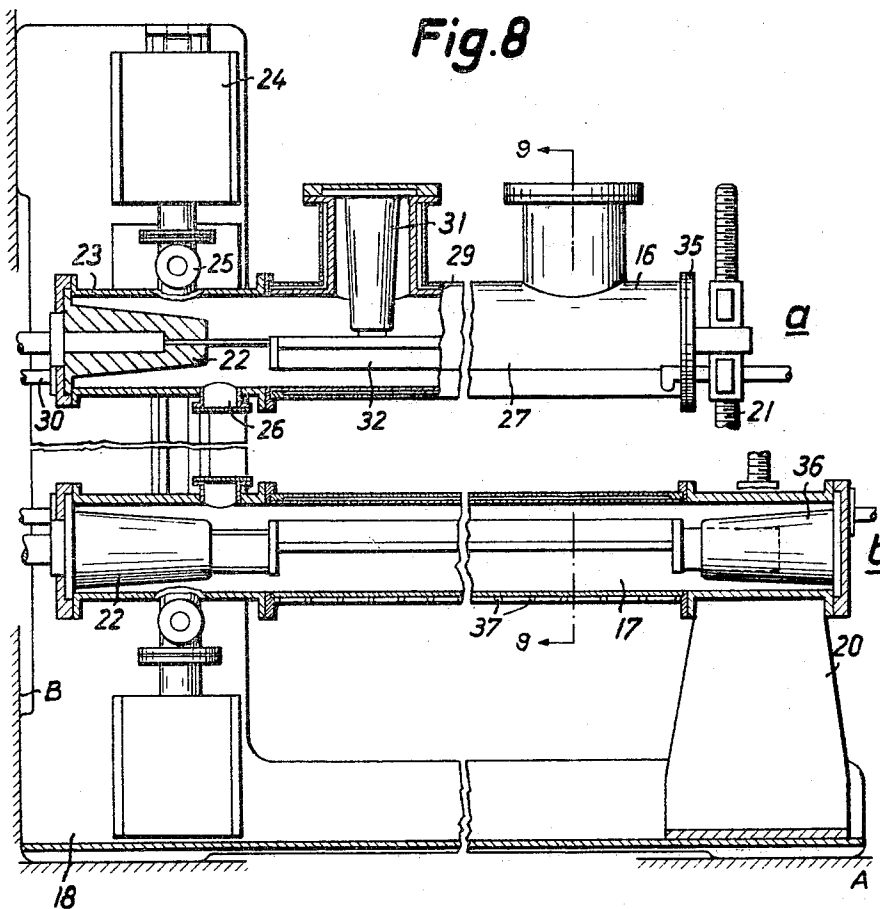
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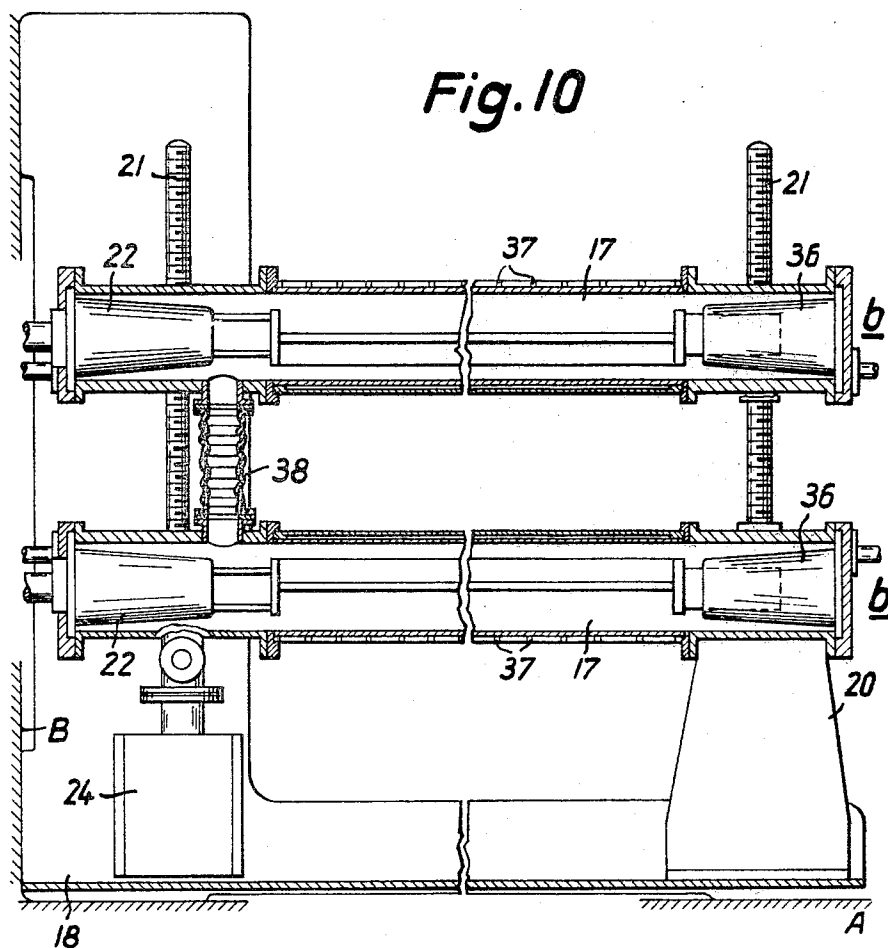
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X-RAY SOURCE COMPRISING PLURAL REMOVABLE MODULAR UNITS EACH HAVING AN ANODE TARGET AND CATHODE

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The present invention relates generally to X-ray tubes and, more particularly, to such tubes having a homogeneous radiation zone.

In conventional high or maximum power X-ray tubes, it is sought to use a complete tube unit having a focal point for electrons emitted by the tube cathode which is as large as possible. For example, rectangular focal points are used which have a size of 100 x 170 mm. With such focal points, the ratio of the sides is between 1:1 and 1:2. The fact that the focal point is of fixed size, however, is very disadvantageous for industrial applications since it only permits the use of such tubes when the size of the focal point is suited for the particular purpose. A proportional enlargement of the focal point generally requires a corresponding increase in the size of the whole tube and, insofar as the anode is concerned, this raises a number of structural and technological difficulties. At the same time, what has been sought to be obtained is a specific surface loading which is as uniform as possible. The radiation field which is obtained is generally bulb-shaped and is not parallel to the surface of the anode. The maximum intensity in planes parallel to the anode is, in any case, obtained on the axis of the radiation field. This produces a very uneven dosage distribution in the material to be irradiated.

In existing installations having but one tube, the dosage power decreases very rapidly with the distance from the anode, so that the material can be expected to be homogeneously irradiated only if it is repeatedly passed through the radiation field.

The radiation dosage which is applied to each portion of the material to be irradiated while the same passes through the radiation field depends on the path interval of the dosage in the direction of travel of the material. In order to obtain in the entire material a dosage distribution which is as suitable as possible, the path interval for each element of the material should, as it passes through the radiation field, be as even as possible. The absolute magnitude of the radiation dosage will then depend only on the speed with which the material passes through the field, i.e., the speed of the conveyor belt.

With these defects of the prior art in mind, the main object of the present invention is to provide a maximum power X-ray tube installation for irradiating substances thereby to change the physical, chemical, or biological characteristics of the substances, for example, for polymerizing or cross-linking (to obtain a lattice-like polymerization) plastics or for sterilizing, the material being passed through the radiation field and which is free of the above enumerated problems.

Another object of the present invention is to provide an installation which includes one or more tubes having an outer anode on which there is produced, by one or more cathode heating filaments or cathode heating filament groups, a band-shaped focal point.

A further object is to provide a device of the character described wherein the focal point is composed of individual focal point portions or sections so arranged or fashioned that the radiation energy of the tube or tubes, when the material runs through the radiation field, is distributed evenly on the material to be irradiated.

These objects and others ancillary thereto are accomplished according to preferred embodiments of the present invention wherein if the tubes are to be used only for industrial purposes, it is assumed that the material will be carried on or in a transport arrangement. It is not necessary to make the focal point planar because a narrow, for example, a 5 cm. wide focal point can be used whose longitudinal axis is preferably at right angles to the transport direction, or which forms a large angle with this transport direction, the length of which focal point is adapted to the transport width. In any event, the width of the focal point should not be small as compared to its effective length. For example, the length can be up to 100 cm. or more. From a structural and technological point of view, such an arrangement of the anode is very advantageous inasmuch as it can be made far more simply and far more stably than a membrane anode having a large surface, such as the rectangular focal points whose sides are the same length as the zone of the focal point, or focal points having a circular configuration. The size of the focal point and of the radiation field can, in the arrangement according to the present invention be very simply adapted to the needs of the situation in that the focal point together with the tube is lengthened or shortened in but one direction, namely, the longitudinal direction.

However, in order to obtain a radiation field which is approximately parallel to the surface of the anode, it is advantageous to subject the outer focal point regions to a greater average load than the inner ones or, if all of the focal points are subjected to equal specific surface loadings, to make the focal points at the outside wider.

It has therefore been proven advantageous to place two approximately similar tubes opposite each other. In this way, the radiation energy is distributed evenly onto the material to be irradiated from two sides. The arrangement preferably provides two similarly constructed tubes whose anodes are arranged opposite each other in such a manner that the conveyor belt can pass between the two tubes so that the material is irradiated evenly from both sides.

The tube structure is preferably such that it can be mounted in any position whatsoever, i.e., the tube axis can point in any one of three mutually perpendicular directions.

In order to allow the installation to irradiate the materials and to adapt the dosage field optimally to the particular absorption and thickness conditions, it is a further feature of the invention to mount the tubes in such a manner that the spacing between them can be adjusted. This can be achieved, for example, by mounting one tube fixedly and by allowing the position of the other tube to be adjusted with respect to the first tube. Alternatively, the arrangement can be such that the two tubes are adjustable independently of each other. Such an independent adjustment of the tubes is necessary, for instance, if one of the tubes is to be brought next to a conveyor belt and if the other tube is to be adjusted so as to allow for the different thickness and other characteristics of the goods to be irradiated. If the conveyor belt arrangement is adapted to the height of the tube arrangement, it is possible to make one tube stationary and to mount only the other tube to be movable. In order to adapt the tubes to the particular dimensions, particularly the width, of the material to be irradiated or the transport system with which the tubes are to be used, the tubes are, in accordance with the present invention, made up of modular units. The units are, for example, the following:

- (a) A unit for the cable connection and high voltage.
- (b) A unit for the vacuum systems, such as the pump, for example, an ion getter pump, measuring apparatus, and connections for pre-evacuating the tube.

(c) The tube units which, under certain circumstances, can be subdivided as follows:

(1) The tube units having a greater power output, which units are intended to be positioned at the end of the finished tube.

(2) Tube units of normal power output which are to be used, in any desired number, between the two tube units of greater power output.

(d) Closure flange units for mounting the tubes.

The arrangement can be modified. For example, the tube units can be broken up into the tube body and anode, the cathode, and, under certain circumstances, special supporting insulator elements for the cathode. As cathodes, linear heating filaments which are mounted in the cathode system and are resiliently mounted on at least one side can be used. Preferably, one or more cathode heating filaments or heating filament groups, are combined to form cathode portions so that each cathode portion produces a focal point portion having a band-shaped configuration on the outer anode of each individual tube. The linear heating filaments are preferably parallel to the longitudinal side of each band-shaped focal point portion. The focal point portions then act as a single band-shaped focal point. The present invention is not limited to the use of two tubes in that it is possible to use many individual tubes. Furthermore, the installation may be such that all of the individual tubes have a common vacuum chamber and thus constitute a single tube, the individual tube sections being connected to each other by flexible elements, as, for example, bellows.

Additional objects and advantages of the present invention will become apparent upon consideration of the following description when taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a diagrammatic side elevational view partly in section showing an installation according to the present invention having two opposite X-ray tubes.

FIGURES 2 through 5 are diagrammatic side views showing the arrangement of the cathodes or the focal points produced thereby.

FIGURE 6 is a diagrammatic side elevational view showing an X-ray tube installation including a plurality of modular units.

FIGURE 7 is a diagrammatic side view showing another way of arranging the focal points.

FIGURES 8 are diagrammatic side views, partly in section, of apparatus using the X-ray tube of the present invention, with (a) indicating one form of X-ray tube and (b) showing another form of X-ray tube.

FIGURES 9 are sectional views taken on line 9-9 of FIGURES 8 with (a) and (b) corresponding to FIGURES 8.

FIGURE 10 is a diagrammatic side view, partly in section, of apparatus using the X-ray tube of the present invention with two tube sections (b) connected to have a common vacuum space.

With more particular reference to the drawings, FIGURE 1 shows an X-ray tube arrangement according to the present invention which comprises two X-ray tubes 1a and 1b having cathodes 2a and 2b, respectively, the latter being connected to support insulators 3a and 3b, respectively. As is shown in FIGURE 1, the individual cathode filaments of the two X-ray tubes are arranged opposite each other in staggered relationship, so that, due to the superposition of the fields of radiation produced by the individual focal points 4a and 4b, the over-all radiation field is an essentially homogeneous one. The right side of each tube, as viewed in FIGURE 1, is sealed by a flange 5a, 5b, while the left side of each tube is connected to lead-in flanges 6a and 6b through which the high voltage and heating power is introduced into the interior of the respective tubes. FIGURE 1 also shows high vacuum pumps 7a and 7b connected to the X-ray tubes 1a and 1b, respectively, so as to maintain the necessary vacuum therein.

Each of the tubes itself incorporates conventional elements that are customarily used in X-ray tubes having focal points of large area. These elements include, among others, mercury diffusion or ion getter pumps, cable connectors which are insulated against high voltage and which serve to lead the high voltage and the heating current into the tube, and membrane-type anodes having lenticular cooling channels. These anodes may preferably be made of nickel, or of light metal through which the radiation passes, as, for example, aluminum or aluminum alloys, all of which are provided with a coating of heavy metal, such as gold, in order to increase the yield of X-rays. If aluminum anodes are used, however, the focal point does not have to be as sharply defined, so that it is possible to make do with a cathode construction which is simpler than that heretofore used.

The cathodes are connected with the tube, preferably by means of a rigid connection, such as a two point mounting, which secures the cathodes to the insulators, so that the cathodes form a rigid structural unit together with the X-ray tube. Alternatively, the cathode and the tube are not fixedly connected with the anode; but instead, the cathode may be mounted axially with respect to the tube body which, in this case, is tubular, by means of separate supporting insulator elements. In order to avoid the uncontrollable transfer resistance, it is expedient to connect the cathode heating filaments of all of the individual cathodes in series with each other, thereby making certain that the emission will remain the same from filament to filament.

It is expedient to make the X-ray tube body actually tubular and to let the longitudinal side of the focal point extend on the wall of the tube parallel to the axis of the tube wall. The tube body itself is preferably made of stainless steel, aluminum, or aluminum alloys. If stainless steel is used, the anodes must be flanged onto the steel, or be specially welded or soldered thereto. If, however, the tube wall is made of aluminum or aluminum alloy, the tube wall itself can serve as the anode, possibly after special treatment. If the tube wall itself serves as the anode, an aluminum tube can be used which has a diameter of between 300 and 400 mm., and a wall thickness of 10 mm., which wall, at the side thereof constituting the anode, is worked so as to be flat both inside and outside, so that there is obtained a flat anode surface having a wall thickness of approximately 3 mm. and a width of between 50 and 100 mm. Alternatively, a thin tube may be used which is not worked in any manner at all, in view of the operating conditions, the relatively small curvature of the focal point in the region of the anode is found to play no significant role. The end faces of the tubular body are provided with suitable flanges so that the tube may be connected with the other components. The tube may be sealed with suitable metallic seals so that the finished and evacuated tube can, if necessary, be annealed or otherwise heat-treated.

In order to avoid excessive heating of the tubular wall during operation, the same must be cooled in a suitable manner. For example, water can be continually passed through a cooling coil on the outside of the tubular body in good heat exchange contact therewith or, if the tubular body is a double wall element, the water can be made to flow through the interspace between the tube walls. Furthermore, the tube is suitably shielded with lead, so that the X-rays will be emitted only in the region of the focal point. The anode can be cooled by circulating water which is made turbulent in the region of the upper surface.

The length of the tube will depend on the application to which it is to be put so that, if a transport or conveyor belt is to be passed through the space between the two tubes, the length of the radiation field will correspond approximately to the width of the transport arrangement. However, inasmuch as, due to thermal

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expansion resulting from the heat, the cathode heating filaments can not always be made as long as desired, it is sometimes necessary to split up the cathode and therefore the focal point. In practice, if linear heating filaments are used, the effective emission length can not be much greater than 100 to 200 mm. In order to produce a focal point having a width of 5 cm., there will generally have to be a plurality, such as 2 to 5, heating filaments arranged parallel to each other. These heating filaments then produce a focal point section having a width of 5 cm. and a length of 10 to 20 cm., i.e., a surface area of 50 to 100 cm.². If the tube is to operate with a specific surface, i.e., power per unit area of anode, of approximately 500 watts per cm.², the anode power of such a tube element is, depending upon the length, about 25 to 50 kilowatts.

Any number of the above-described tube elements or modular units can be arranged in series so that a focal point of any desired length can be obtained. However, the suspension arrangement of the filaments and the cooling of its ends make it impossible, in the case of a linear alignment, to produce a continuous or coherent focal point. Consequently, interspaces will be formed between the focal points so that the dosage field of such a tube, will, at the places where the focal point is interrupted, have points at which the field intensity is a minimum, while the middle of the focal points will be intensity maxima. According to the present invention, therefore, the two tubes are placed opposite each other in such a manner that a point of minimal intensity as produced by one tube will be opposite a point of maximal intensity of the other tube. Here it is expedient to provide one of these tubes with one element less than the other, as shown in FIGURE 1. In this way, the field between the two tubes will be an approximately homogeneous one. A homogeneous field is obtained at the ends of the tubes either by increasing the specific surface load in the middle of the focal points resulting from the end-most elements, or, if the specific surface load is kept constant, by increasing the width of the focal point.

FIGURE 2 shows the focal points produced by the tube 1b of FIGURE 1. In order to avoid intensity minima between the partial focal points, it is possible, as shown in FIGURE 3, to arrange the successive focal point sections 8 and 9 in such a manner that they are laterally displaced so that their overall effect will be as if there were one long coherent or continuous focal point. It is true that such an arrangement requires a somewhat wider anode than in the first case, but it has the far more substantial advantage that, with the same tube length, a substantially higher total power is obtained. In this arrangement, it is possible to position two similar tubes opposite each other. As above, the dosage field is made homogeneous at the tube ends by increasing the average specific surface load or by enlarging the width of the focal point of the tube elements at the end.

As shown in FIGURE 4, the focal point sections 10 and the cathode sections can be arranged so as to be turned with respect to the axis, so that their projection onto a wall surface portion which is parallel to the tube axis will form a continuous or coherent focal point. The advantages and disadvantages are the same as described above; the same applies insofar as obtaining a homogeneous radiation field is concerned.

With the FIGURE 4 arrangement as a base, it is possible to use something other than cathode sections and to connect one heating filament after the other in a series in the manner as was done above with the cathode sections so that a coherent focal point, as shown in FIGURE 5, can be formed by means of a cathode which, according to need, can be made shorter or longer. In this case, it is particularly simple to render the radiation field homogeneous at the ends of the tube. This can be done as follows.

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If similar cathode filaments are used, the distances between the cathode filaments and the respective individual focal bands can, toward both ends of the tube, be made successively smaller thereby increasing, on the average, the specific surface loading toward the ends of the focal point.

In contradistinction to the above-described embodiments, the tube structures, can, as shown in FIGURE 6, be further subdivided, for example, into tube modular units 11a and 11b, some of which are at the end and some of which are in the middle. Each unit which is at the end is designed for a higher anode power than the corresponding intermediate units. One tube can then be built up by flanging together a desired number of units, and each of these modular units has a cathode 12a, 12b, as shown. The intermediate flanges 13a, 13b, do, however, make it difficult to form a coherent focal point. If the focal points 14a and 14b of each tube section are parallel to the axis, the voltage distribution is, in the region of each of the flanges, a minimum. In order to compensate for these minima, one of the tubes is made up of one unit fewer than the other, in the manner discussed above in connection with FIGURE 1. The two tubes are then so arranged that each flange 13 of one tube is opposite the middle of the focal point 14 of the other tube. In this manner, there will be a minimum which is opposite a maximum, and the result will be a relatively homogeneous dosage distribution which is parallel to the focal points.

Alternatively, the focal point sections 15 of each tube unit need not be parallel to the axis, but, as shown in FIGURE 7, may be turned with respect to the axis in such a manner that when the material which is to be irradiated passes at right angles to the longitudinal side of the focal point section, i.e., at an angle to the tube axis, there is obtained the effect of a coherent focal point. Such an arrangement has the advantage over that which has been described above in that two similar tubes can be used and the arrangement as a whole has a higher integral penetrability.

FIGURES 8 and 9 show two tubes 16 and 17 which are mounted on a support 18. FIGURE 8 shows the arrangement as being supported on a surface A. In order to show two modifications of the present invention, two embodiments of the tube are shown in FIGURES 8a and 8b, respectively, although in actual practice both tubes would be built in accordance with the same structural principles. In the arrangement the material to be irradiated with X-rays is carried on a conveyor belt 19, shown in FIGURE 9, which runs in the direction shown by the double arrow parallel to the plane A between the two tubes. The lower tube 17, is supported by the support 18 and the counter bearing 20. In this case, then, the X-ray radiation penetrates upwardly. The upper tube 16, however, is movably mounted and is displaceable, for example, by means of a suitable spindle drive. Here, the tube is so constructed that the X-ray radiation penetrates downwardly. The right-hand end of the upper tube can be supported by a further displaceable spindle 21 of the counter bearing 20.

The upper tube 16, shown in FIGURE 8a, includes the following structural elements:

(1) Unit 22 which supplies the cable lead-in for the high voltage and heating.

(2) Unit 23 which serves for attaching the vacuum pumps. This unit carries the vacuum pump 24, in this case an ion getter pump, and has an attachment flange 25 which is provided with a valve so as to allow pre-evacuation of the tube. The unit also has a closable mounting opening 26.

(3) The tube unit 27. The tube body here comprises a thick aluminum tube which, on its underside is both internally and externally machined to have a thickness of approximately 3 mm. This flat machined surface constitutes the anode 28 (FIGURE 9a) which, on the vacuum side, is provided with a layer of heavy metal, preferably

gold. The actual tube wall is encompassed by a further jacket 29 for receiving the coolant, such as water. Externally of this jacket, there is a lead coating so that the radiation will pass out only through the actual anode. A coolant water connection 30 is provided for cooling the anode, which connection 30 is flanged to the underside of the tube. In practice, the coolant is recirculated, in a closed circuit, via a heat exchanger. The anode is cooled with strongly turbulent flow acting as a surface boiling coolant. Two tubular studs with flanges are attached to the upper side of the housing and in each of these studs there is a supporting insulator 31. The cathode 32 is fixedly connected with the tube unit via the supporting insulators 31. The connection for the high voltage and the heating is effected via the cable lead-in 22. The heating filaments 33 (FIGURE 9a) are arranged in the cathode at an angle to the longitudinal side of the cathode in such a manner that a coherent or continuous focal point is formed on the anode 28 (FIGURE 9a). The arrangement corresponds, in principle, to that shown in FIGURE 5. In order to render the radiation field homogeneous at the ends of the tube, the heating filaments are arranged with successively decreasing spacing toward the cathode ends. This produces a focal point which, toward the end, has an increasing average specific surface loading so that there is obtained an isodosage field which is approximately parallel to the plane of the anode. The heating filaments are preferably connected in series. The current lead-ins 34 (FIGURE 9a) are, in the focussing body, arranged parallel to the longitudinal axis of the tube.

(4) Closure flange 35 constituting a structural unit for closing off the tube. The individual elements are connected to each other by means of flanges and seals. The seals are preferably metal seals so that the tube elements, after being evacuated can, if necessary be annealed or otherwise heat-treated.

In contradistinction to the arrangement of the upper tube 16, special supporting insulators for mounting the cathode to the tube housing are dispensed with in the case of the lower tube 17, as shown in FIGURES 8b and 9b. Here, the cathode is mounted as a separate element between the lead-in insulator of the cable lead-in 22 and a separate supporting insulator of the end element 36. The tube jacket is cooled, in contradistinction to the above-mentioned upper tube, with a cooling coil 37 through which water flows, and this coil 37 is in good heat exchange contact with the tube housing. Otherwise, the structure is in accordance with the above-described principles.

Beside the arrangement of the tubes as shown in the drawing, in which the tubes are on plane A, the tube may be mounted on plane B or on a plane which is parallel to the plane of the drawing. In the latter case, the material to be irradiated can, for example, pass in a vertical channel through the radiation field of both tubes. This is of advantage particularly in the case of loose material. On the other hand, in such an arrangement the material to be irradiated can be moved on a conveyor belt in the direction of the axes of the two tubes. This type of arrangement is particularly suitable in the case of smaller items to be irradiated, such as bottles, ampoules, cans, etc., which then do not traverse a radiation field which is particularly wide but one which is very long, as a result of which a very large throughput is obtained. In this case, however, it is expedient if the focal point is made at least 10 cm. wide.

The entire arrangement may be made such that the two individual tubes of the installation are so arranged on the support that they encompass, in a fork-like manner, the space or zone in which the irradiation is to occur, and in which all of the lead-ins for high voltage, vacuum, and cooling water are arranged only at the side. This would make it possible to place the two tubes with respect to an existing conveyor belt without it being necessary to disassemble anything.

If the effective length of a coherent partial focal point is 1 m., each tube can be operated optimally with 250-300 kilowatts, the entire installation thus operating at between 250-600 kilowatts. The operating voltages will generally be 120-200 kilovolts, but even higher voltages are conceivable.

As mentioned above, the outer anodes can, for increasing the X-ray field, be provided with a coating of heavy metal, as, for example, gold. Due to the alternating effect of the X-ray generation and the absorption, the thickness of the heavy metal coating will, in the case of external anodes, be preferably 60 to 100% of the maximal penetration depth of the electron at the particular acceleration voltage in the particular heavy metal layer.

Another arrangement corresponding to FIGURES 8 and 9 of the X-ray tube of the present invention is shown in FIGURE 10. Two tube sections (b) are used, which are connected to have a common vacuum space, the tube sections being arranged opposite each other and coupled by a vacuum-tight tube joint connection 38, e.g. a flexible tube.

It will be understood that the above description of the present invention is susceptible to various modifications, changes, and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

What is claimed is:

1. High-power X-ray tube apparatus for irradiating substances to change their physical, chemical or biological characteristics wherein the substance to be irradiated is passed through a radiation zone, said apparatus comprising, in combination: two spaced-apart tube means arranged on opposite sides of said reaction zone, each tube means having external anode means adjacent said radiation zone and cathode means spaced from said anode means for providing on the anode means a plurality of focal points for electrons emitted by said cathode means, which focal points are generally aligned to form, together, at least one composite focal point which is band-shaped and extends in the direction in which said individual focal points are aligned for uniformly distributing irradiation energy onto the substance passing through said radiation zone, said two tube means being arranged with respect to said radiation zone and to each other so that by superposition of the radiation fields of the individual tube means there is obtained a substantially homogeneous radiation effect in the substance to be irradiated, each of said tube means being composed of consecutive modular units which have flanges at their ends and which are joined together to have a common vacuum space, each unit containing a portion of the anode and cathode means of the particular tube means of which the respective modular unit is a part, thereby to enable the length of each tube means to be adapted to the width of the radiation zone.

2. Apparatus as defined in claim 1 wherein said two tube means are flexibly coupled to each other.

3. Apparatus as defined in claim 1 wherein the individual cathode portions are so arranged that the individual band-shaped focal points which they produce on the external anode means are, with their long side, substantially at right angles to the direction in which the material to be irradiated is being transported.

4. Apparatus as defined in claim 1 wherein one tube means has N number of cathode portions and the other tube means has N+1 cathode portions.

5. Apparatus as defined in claim 1 wherein the individual cathode portions and the individual focal points which are produced by these cathode portions on the external anode means are laterally displaced relative to each other.

6. Apparatus as defined in claim 1 wherein the individual cathode portions and the individual focal points produced thereby on the external anode means are so arranged that the lengths of the individual focal points are

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at an angle to the transport direction which is smaller than 90° and that the individual focal points so overlap each other in such direction that they have the same effect as if they were a single composite band-shaped focal point.

7. Apparatus as defined in claim 1 wherein the individual focal points are all of the same size and the cathode portions are so arranged that, with the width of the composite band-shaped focal point remaining constant, the ends of the composite focal point have a higher average specific surface load than in the middle.

8. Apparatus as defined in claim 1 wherein the surface loading of the composite band-shaped focal point is constant throughout and the cathode portions are so arranged that the individual focal points at the ends are wider than the other individual focal points.

9. Apparatus as defined in claim 1 wherein each cathode portion includes a heating filament arranged at an angle which is smaller than 90° with respect to the transport direction of the substance to be irradiated and said units of said two tube means overlapping each other in this direction that the individual focal points which are produced have the same effect as if they were a single composite band-shaped focal point.

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10. Apparatus as defined in claim 9 wherein the heating filaments are so arranged or fashioned that the composite band-shaped focal point at its ends has a higher average specific surface loading than in the middle.

11. Apparatus as defined in claim 10 wherein the heating filaments are similar and are arranged parallel to each other and their mutual spacing, toward the ends of the cathode means becomes successively smaller.

12. Apparatus as defined in claim 1 further comprising means for adjusting the spacing between said two tube means.

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