Jan. 28, 1941. A. BOUWERS ET AL 2,230,176

X-RAY APPARATUS

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Fig. 1

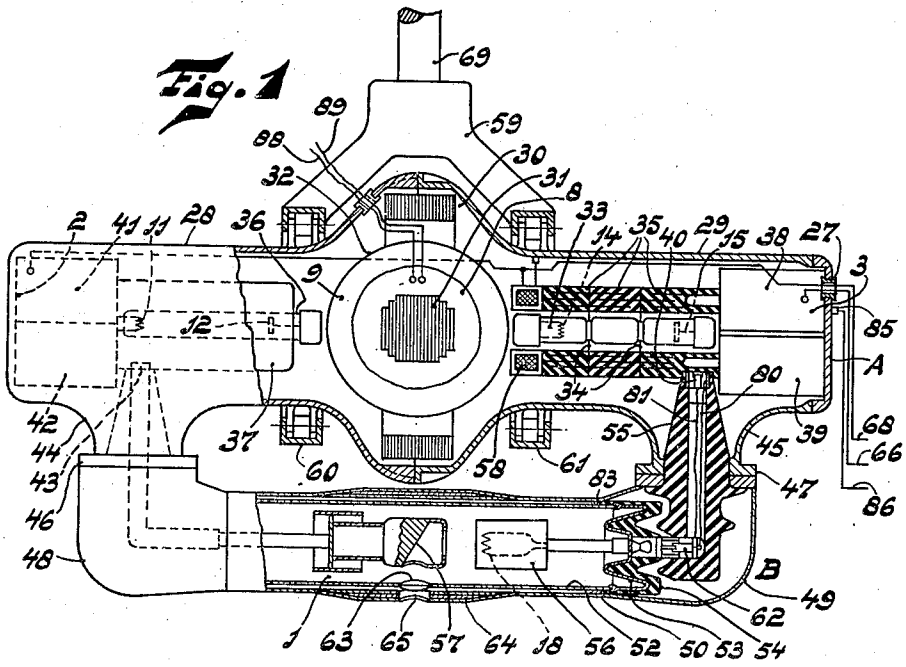
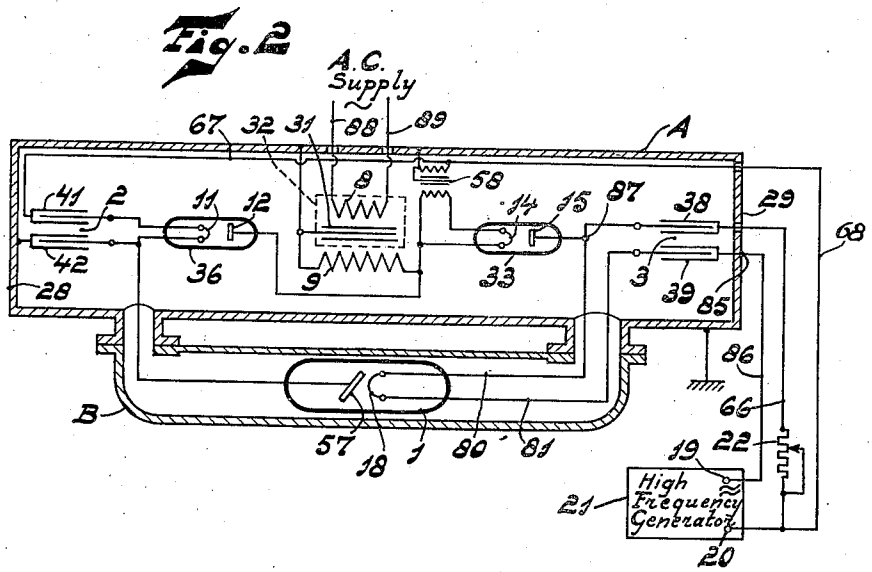


Fig. 2



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X-RAY APPARATUS

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Our invention relates to X-ray apparatus in which a high-tension supply transformer and an X-ray tube form a structural unit, and more particularly to apparatus for operation on high voltages, for instance above 150 kv.

With lower voltage, for instance below about 100 kv., there are no particular difficulties in keeping the weight of such apparatus within practical limits. However, with higher working voltages the dimensions of the apparatus are increased with the result that the tube and transformer are usually arranged separately and high tension is supplied to the X-ray tube by flexible cables. For deep-therapy installations, for example, the structural unit of X-ray tube and transformer assumes a large weight, and as such units are not readily movable, it is necessary to provide special supporting means which are complicated, expensive and bulky.

The main object of our invention is to eliminate the above drawbacks and produce a compact X-ray apparatus which is light in weight and readily supported. For this purpose we enclose the high-tension supply source in a metal envelope which forms a constructional unit with the X-ray tube, and for the source use a high-tension transformer and a voltage-multiplying circuit arrangement.

The idea of reducing the weight of an X-ray apparatus by the addition of a plurality of constructional parts determined by the voltage-multiplying circuit arrangement, such as condensers and rectifying tubes, might appear odd, but it is not easily effected without further means. It has previously been proposed, by locating transformers, condensers, rectifier valves and an X-ray tube together in a common grounded envelope, to house the X-ray installation within the treatment room, but such constructions have not made it possible to provide an apparatus having such low weight that it could be suspended as a unit in a movable manner.

The invention is based on the recognition of the fact that the voltage-multiplying circuit arrangement permits the obtainance of a substantial saving in weight provided that a further condition, which will be explained hereinafter, be fulfilled.

An apparatus according to the invention for a working voltage of 200 kv. has, for example, only about half of the weight of an apparatus constituted by a transformer and an X-ray tube directly connected thereto. This is due to the fact that the weight of an apparatus consisting substantially of an X-ray tube and a high-tension transformer in a common envelope rapidly increases according to the voltage, i. e. in case of voltages in excess of 100 kv. it increases more than proportionally to the voltage. This increase in weight is due mostly to the high-tension transformer, and by using a Greinacher circuit, as hereinafter described, a transformer for half of the voltage suffices and the weight of the transformer is thus reduced by more than one-half.

The X-ray tube also plays its part in the reduction of weight. In fact, if the tube is fed with direct voltage, the size of the tube, as is well known, may be materially smaller than in case of feeding with alternating voltage, and this results in a reduction of the dimensions of the apparatus. Also the security of service of the apparatus is increased by feeding with rectified voltage.

The use of a voltage-multiplying circuit arrangement requires not only the addition of condensers and rectifying tubes, but also of heating transformers. Apparatus for small powers having an X-ray tube fed directly from a high-tension transformer and in which a control of the current is not required, can be supplied without a heating transformer. In that case the heating current may be derived from part of the secondary winding of the high-tension transformer. However, when it is necessary to control the heating current, a heating transformer must be employed in the apparatus if the incandescible cathode is not grounded.

If a high-tension transformer is used in conjunction with a Greinacher circuit arrangement, an additional heating transformer must be added for supplying heating current to the incandescible cathode of the rectifying tube which is not connected to the high-tension transformer. If voltage control is not desired, the heating current of the second rectifier may be taken from the high-tension winding of the transformer. In most cases, however, the high tension must be adjustable and in such cases a separate heating transformer is required also for the second tube, because the heating current of the rectifier tube can not be varied by controlling the high tension.

When a plurality of condenser-valve groups is used it is necessary to use an additional heating transformer for each additional rectifier tube. These transformers have such a high weight that they would render illusive the reduction in weight with respect to apparatus having a tube directly fed from the transformer.

According to the invention this reduction in weight of the high-tension transformer may be

obtained by using a voltage-multiplying circuit arrangement in such manner that at least those cathodes of high-tension rectifiers which have a high potential difference with respect to ground and are not connected to the transformer, are energized with high-frequency current from a high-frequency generator arranged separately from the apparatus. The energy may be transmitted from the high-frequency generator to the incandescible cathode by means of heating transformers, and for high-frequency current, such transformers for a given power, have a much lower weight than for low-frequency current. Consequently it is advantageous for X-ray apparatus comprising a constructionally united tube and source of high tension to use a voltage-multiplying circuit arrangement.

The feeding of the high-tension circuit may also be effected with high-frequency alternating current. This requires a generator for a power of another order of magnitude (say 1 kw). This method of operation will be advantageous only with installations for higher voltages, for example above 300 kv.

Heating transformers for the incandescible cathodes which are directly connected to a high-tension condenser can be avoided in an apparatus according to the invention by passing the high-frequency filament current to the incandescible cathodes through the high-tension condensers of the voltage-multiplying circuit arrangement. In this case the economies in weight are still materially increased.

If the apparatus is provided with a Greinacher circuit arrangement having grounded condenser units, the arrangement is simplified when each of the condenser units comprises two condensers connected in parallel with respect to the current of the tube. These condensers are interconnected on their high-tension side by the adjacent incandescible cathode, and each of them is connected on the low-tension side to a terminal of the high-frequency generator so as to be series-connected with respect to the filament current.

In order that our invention may be clearly understood and readily carried into effect, we shall describe the same in more detail with reference to the accompanying drawing, in which

Figure 1 is a partly-sectionized side view of an X-ray apparatus according to the invention, and

Fig. 2 is a schematic wiring diagram of the apparatus illustrated in Fig. 1.

The apparatus illustrated in Fig. 1 comprises a metal housing having a portion A housing the voltage supply apparatus, and a portion B housing an X-ray tube. The portion A comprises two elongated cup-shaped metal members 28 and 29 which have flared ends secured together to form an enlarged central space 30, and have hollow extensions 44 and 45 respectively forming flanges 46 and 47. Member 29 has an open end provided with a removable cover 27. The apparatus is rotatably supported from an arm 69 of an adjustable stand (not shown), and for this purpose we use a yoke 59 rotatably mounted on arm 69 and having two extensions 60 and 61 which are provided with annular grooves cooperating in a slidable manner with rings mounted on portions 28 and 29.

Within the central space 30 is a high-tension transformer 32 of the shell type having a core 31, a low-tension primary winding 8 and a high-tension secondary winding 9. Suitably supported from member 29 are a condenser unit 3 comprising two high-tension condensers 38 and 39, and a high-tension rectifier tube 33 having an incandescible cathode 14 and an anode 15. Tube 33 is preferably of the ion rectifying type and is subdivided as regards voltage by a plurality of metal rings 34 and annular condensers 35, so that the tube can have a small weight and size. The cathode 14 is preferably of the activated type, as this reduces the heating current required. Tubes of this type are described in more detail in the U. S. Patent 2,020,077 to Mulder et al.

In a similar manner a condenser unit 2 comprising two high-tension condensers 41 and 42, a high-tension rectifier tube 36 having an incandescible cathode 11 and an anode 12, and condensers 37 for the subdivision of voltage across tube 36, are supported in the portion 28. Tube 36 and condensers 37 are similar to tube 33 and condensers 35 respectively.

An annular transformer 58 surrounds the end of tube 33 and serves to heat cathode 14 in a manner later to be described.

Portion B comprises a central cylindrical portion 50 and two apertured end portions 48 and 49 secured in a removable manner to the flanges 46 and 47 respectively. Supported within the central part 50 of portion B is an X-ray tube having an envelope comprising a central cylindrical metal member 52, to the ends of which are hermetically fused two glass re-entrant portions 53, only one being shown. Supported from the re-entrant portions are an anode 57, and a cathode structure 56 comprising an incandescible cathode 18. Member 52 is electrically connected through a metal ring 83 to the portion B which is grounded during operation. Member 52 is provided with a window 63 for the exit of the X-rays, and a ring 64 of lead provided with an aperture 65, which ring surrounds the central portion of the tube to absorb undesirable X-rays. A member 54 of insulating material, for instance a molded member of Bakelite, covers the outer surface of re-entrant portion 53 and extends slightly over the metal member 52 preferably with the interposition of a suitable insulating cement to avoid the occurrence of air spaces. Tubes of the above type have been described in detail in the U. S. Patent 2,110,259 to Albert Bouwers.

The cathode 18 and anode 57 are connected to the voltage supply apparatus contained in housing A, and the connections, which will be indicated in connection with Fig. 2, are made with the aid of suitable insulating members and contacts. More particularly, the terminals of cathode 18 are connected to the two contacts of a two-pole receptacle carried by member 54, which contacts cooperate with a two-pole plug 62 supported by a member 55 of insulating material. The two poles of plug 62 are connected through conductors 80 and 81, which pass through member 55 to two contacts of a second two-pole plug 40 mounted on the end member 55. Plug 40 cooperates with the two contacts of a receptacle mounted on condensers 35. These latter contacts are connected in a manner to be described, one to anode 15 and one terminal of condenser 38, and the other to one terminal of condenser 39. In a similar manner, and with the aid of a single-pole plug 43, anode 57 is connected to one terminal of condenser 42 and to one end of cathode 11. With such type of connections, and with a removable mechanical connection at flanges 46 and 47, the X-ray tube may be readily replaced.

The electrical connections of the apparatus

illustrated in Figure 1 are shown schematically in Figure 2 in which the same parts are indicated by the reference numerals used in Figure 1.

As shown in Figure 2, a Greinacher circuit arrangement is employed, and for this purpose the two condenser units 2 and 3 are charged by rectified alternating current. The alternating current at a voltage of about 100 kv. is supplied from the high-tension secondary winding 9 of transformer 32 whose primary winding 8 is provided with leads 88 and 89 which pass through the metal housing A in an insulating manner and are connected to a suitable supply of low-tension current supply. The rectifier tube 36 is located in the charging current circuit of condenser unit 2, and condenser unit 3 is charged by the antiphase of the alternating current through the rectifying tube 33.

Condenser 42 has one terminal connected to the grounded housing 28 and its other terminal connected to one end of cathode 11 and to the anode 57 of the X-ray tube 1. The other end of cathode 11 is connected to one terminal of condenser 41 whose other terminal is connected to a conductor 67 passing through the housing 28 and insulated therefrom. Condenser 39 has one terminal connected to the grounded housing 29 at a point 85 and its other terminal connected through conductor 81 to one end of cathode 18 whose other end is connected through conductor 80 to point 87. Point 87 is connected to anode 15 and to one terminal of condenser 38 whose other terminal is connected to a conductor 66 which passes through housing 29 and is insulated therefrom.

As a result of the above connection, the voltages applied across X-ray tube 1 is the sum of the voltages of the condenser units 2 and 3, and thus is twice the voltage produced by the high-tension winding 9.

The secondary winding 9 has one terminal connected to the core 31 and to the grounded housing 28, and has its other terminal connected to anode 12 and to one end of cathode 14. The secondary winding of transformer 58 is connected across cathode 14, whereas its primary winding has one end connected through a conductor 67 to one terminal of condenser 41 and to a conductor 68 which passes through housing 29 and is insulated therefrom for low voltage. The other end of the primary winding is connected to the grounded housing 28 to which the core of transformer 58 is also connected.

The conductors 86 and 68 are connected to the terminals 19 and 20 respectively of a high-frequency generator 21, and conductor 66 is connected through a regulating resistance 22 to terminal 20. The generator may be a tube transmitter, for say 100 watts having a wavelength, for example, of 300 meters. A current flows from the high-frequency generator 21 through the condensers 41 and 42 to the incandescible cathode 11 so that cathode 11 attains its emissive temperature. Furthermore, a high-frequency current flows through regulating resistance 22 and the condensers 38 and 39 to the cathode 18, to thereby heat the cathode to its emissive temperature.

From the above it is seen that condensers 41 and 42 and condensers 38 and 39 respectively are connected in series with the high-frequency heating current. More particularly, the heating circuit comprises two parallel branches. One branch can be traced from terminal 20, conductor 67, condenser 41, cathode 11, condenser 42, and back through ground to terminal 19. The second branch can be traced from terminal 20, resistance 22, conductor 66, condenser 38, conductor 80, cathode 18, conductor 81, condenser 39, and back through ground to terminal 19.

It should be noted that the high-tension sides of the condenser units 2 and 3 are connected to the anode 57 and cathode 18 respectively of the X-ray tube. Furthermore, the high-tension sides of condensers 41 and 42 are connected to cathode 11, and the high-tension sides of condensers 38 and 39 are connected to the cathode 18. The low-tension sides of condensers 41—42 and 38—39 respectively are connected to terminals 19 and 20 of the generator 21.

The voltage drop produced across condenser units 2 and 3 by the passage of the high-frequency current is practically negligible with respect to the high-tension of winding 9 because of the high frequency of the alternating current. For example, if each of the condensers 38, 39, 41 and 42 have a capacity of 0.5 microfarad and the high-frequency current has a frequency of about 10^6 cycles per sec., the wattless voltage drop will be only about 3 volts when the heating current is 10 amps., which has practically no effect on the voltage across the X-ray tube.

The heating transformer 58 serves to heat cathode 14 and for this purpose its primary winding has one end grounded and its other end connected to conductor 67, i. e., connected to the terminals 19 and 20 of the generator 21. This transformer requires only a very small iron core because it is used on high-frequency current. On the other hand, its windings must be insulated to withstand the full voltage of winding 9. Thus by using the high tension condensers 41, 42, 38 and 39 as supply conductors for the heating current of cathodes 11 and 12, two of these transformers are eliminated, which considerably reduces the size, weight, and cost of the apparatus.

The advantages of the invention are particularly marked when higher voltages are concerned. More particularly, for a voltage of 300 kv., the combination of transformer and X-ray tube of the prior art, weighs several hundred kgs. With this heavy weight the constructional union of X-ray tube and transformer is almost out of question for movable apparatus. However, an apparatus according to the invention comprising a transformer for 100 kv. and a corresponding voltage-multiplying circuit arrangement for a total voltage of 300 kv. weighs less than 100 kg.

For example, the apparatus illustrated in the drawing may have a weight less than 100 kgs., which makes it very suitable for therapy installations, is readily movable, and can be readily supported to the arm 69 which is adjustable in height, and if desired is also rotatable. In prior apparatus with D. C. feeding of the X-ray tube from a transformer for voltages in excess of 200 kv., an impracticable conveying device would be required, and adjustment in height had to be effected by raising or lowering the irradiation table. With the construction of the present invention the complete apparatus can be suspended in the same manner in which only the X-ray tube is usually suspended, and as a result the high-tension cables, which hindered the operation of previous apparatus, are eliminated.

While we have described our invention in connection with specific examples, we do not wish to be limited to the exact details of constructions illustrated and described, because obvious modifications will occur to a person skilled in the art.

What we claim is:

1. An X-ray apparatus comprising a housing having a metal surface adapted to be grounded during operation of the apparatus, an X-ray tube secured to said housing to form a structural unit therewith and having an incandescible cathode, means for supplying operating current to said X-ray tube comprising a high-tension transformer within said housing and voltage-multiplying means within said housing and including a plurality of high-tension discharge tubes having incandescible cathodes, the cathode of one of said discharge tubes being at a high-potential with respect to ground and being electrically separated from the transformer, and means for heating said latter cathode with high-frequency current including a high-frequency generator located outside the housing.

2. An X-ray apparatus comprising a housing having a metal surface adapted to be grounded during operation of the apparatus, an X-ray tube secured to said housing to form a structural unit and having an incandescible cathode, means for supplying operating current to said X-ray tube comprising a high-tension transformer and voltage-multiplying means within said housing, said voltage-multiplying means including a plurality of high-tension condensers and high-tension discharge tubes having incandescible cathodes, the cathode of one of said discharge tubes being at a high-potential with respect to ground and being electrically separated from the transformer, and means for heating said latter cathode with high-frequency including a generator located outside the housing and a heating circuit including one of said condensers.

3. An X-ray apparatus comprising a metal housing adapted to be grounded during operation of the apparatus, an X-ray tube including an incandescible cathode, said tube being secured to said housing to form a structural unit therewith, means for supplying operating current to said X-ray tube comprising a voltage-multiplying circuit arrangement including a high-tension transformer, a plurality of condenser units each having two condensers, and a plurality of high-tension discharge tubes having incandescible cathodes, the cathode of one of said discharge tubes being at a high potential with respect to ground and being electrically separated from the transformer, and means for heating said latter cathode with high-frequency current including a high-frequency generator located outside the housing, said means comprising a heating circuit having a plurality of parallel-connected branches each including one of the cathodes and the two condensers of one of the condenser units connected in series.

4. An X-ray apparatus comprising a metal housing adapted to be grounded during operation of the apparatus, an X-ray tube secured to said housing to form a structural unit and having an incandescible cathode, means for supplying operating current to said X-ray tube comprising a high-tension transformer, and a voltage-multiplying arrangement within said housing and including a plurality of high-tension ion rectifier tubes having incandescible cathodes, the cathode of one of said discharge tubes being at a high potential with respect to ground and being electrically separated from the transformer, means to subdivide the voltage across said rectifier tubes including metal members and annular condensers surrounding the tube, and means for heating said latter cathode with high-frequency current including a generator located outside the housing.

5. An X-ray apparatus comprising a metal housing adapted to be grounded during operation of the apparatus and comprising two portions secured together to form a structural unit, an X-ray tube in one of said portions and having an incandescible cathode, means for supplying operating current to said X-ray tube comprising a high-tension transformer, and a voltage-multiplying arrangement within the second portion and including a plurality of high-tension discharge tubes having incandescible cathodes, the cathode of one of said discharge tubes being at a high potential with respect to ground and being electrically separated from the transformer, and means for heating said latter cathode with high-frequency current including a high-frequency generator located outside the housing.

6. An X-ray apparatus comprising an elongated metal housing adapted to be grounded during operation of the apparatus and having two extending portions, an X-ray tube supported from said extending portions, means for supplying operating current to said X-ray tube comprising a high-tension transformer arranged in the central part of the housing, and a voltage-multiplying arrangement including a plurality of high-tension condensers and discharge tubes having incandescible cathodes, said condensers and discharge tubes being arranged at the sides of the transformer, the cathode of one of said discharge tubes being at a high potential with respect to ground and being electrically separated from the transformer, and means for heating said latter cathode with high-frequency current including a generator located outside the housing.

7. An X-ray apparatus comprising a metal housing adapted to be grounded during operation of the apparatus and having projecting portions, an X-ray tube supported from said projecting portions to form a structural unit, means for producing operating current for said X-ray tube comprising a high-tension transformer, and a voltage-multiplying arrangement within said housing and including a plurality of high-tension discharge tubes having incandescible cathodes, the cathodes of one of said discharge tubes being at a high potential with respect to ground and being electrically separated from the transformer, means for heating said latter cathode with high-frequency current including a high-frequency generator located outside the housing, and means for conducting the current to the X-ray tube including insulating members secured to the X-ray tube and contact plugs supported by said members.

8. An X-ray apparatus comprising a metal housing adapted to be grounded during operation of the apparatus, said housing comprising two elongated hollow members secured together and each having a projecting portion, an X-ray tube supported from said projecting portions to form a structural unit, means for supplying operating current to said X-ray tube, comprising a high-tension transformer in the central part of the housing, and a voltage-multiplying arrangement including a plurality of high-tension condensers and high-tension discharge tubes having incandescible cathodes, said condensers and discharge tubes being arranged within said housing and to the sides of said transformer, the cathode of one of said discharge tubes being

at a high potential with respect to ground and being electrically separated from the transformer, and means for heating said latter cathode with high-frequency current including a generator located outside the housing.

9. An X-ray apparatus comprising a metal housing comprising two elongated hollow members each having a tubular projection and flared ends, said hollow members being secured together at their flared ends, and a tubular member secured to said projections, an X-ray tube within said tubular member and having an incandescible cathode, means to produce operating current for said X-ray tube including a high-tension transformer within the space formed at the junction of said flared ends, and voltage-multiplying means including high-tension condensers and high-tension rectifiers having incandescible cathodes, said condensers and rectifiers being disposed within said hollow members to the sides of the transformer, the cathode of one of said discharge tubes being at a high potential with respect to ground and being electrically-separated from said transformer, means connecting said X-ray tube to said current-producing means and extending through said tubular projections, and means for heating said latter cathode with high-frequency current including a generator located outside the housing.

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