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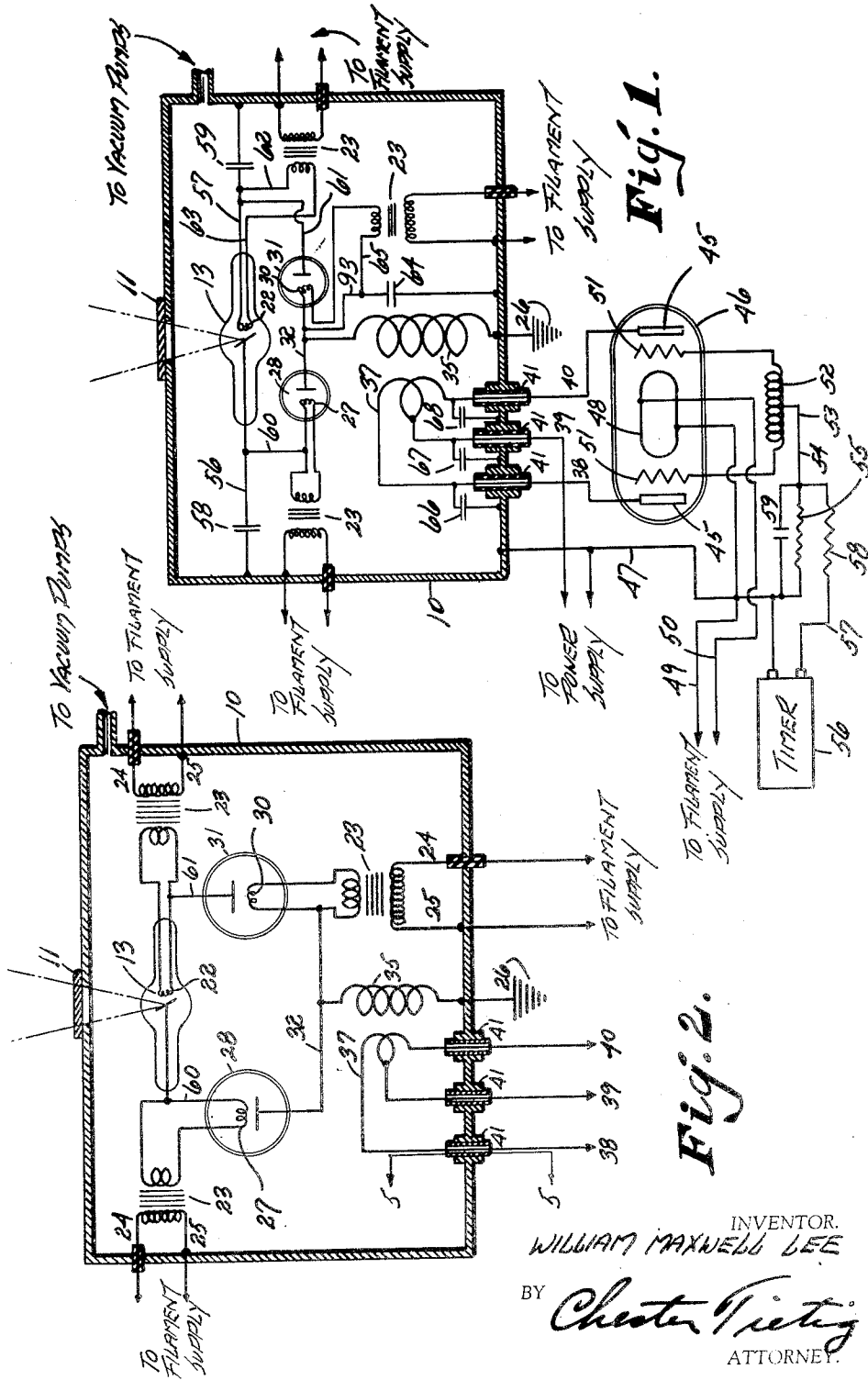
W. M. LEE

2,140,707

HIGH FREQUENCY X-RAY APPARATUS

Filed Jan. 8, 1936

3 Sheets-Sheet 1



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HIGH FREQUENCY X-RAY APPARATUS

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3 Sheets-Sheet 2

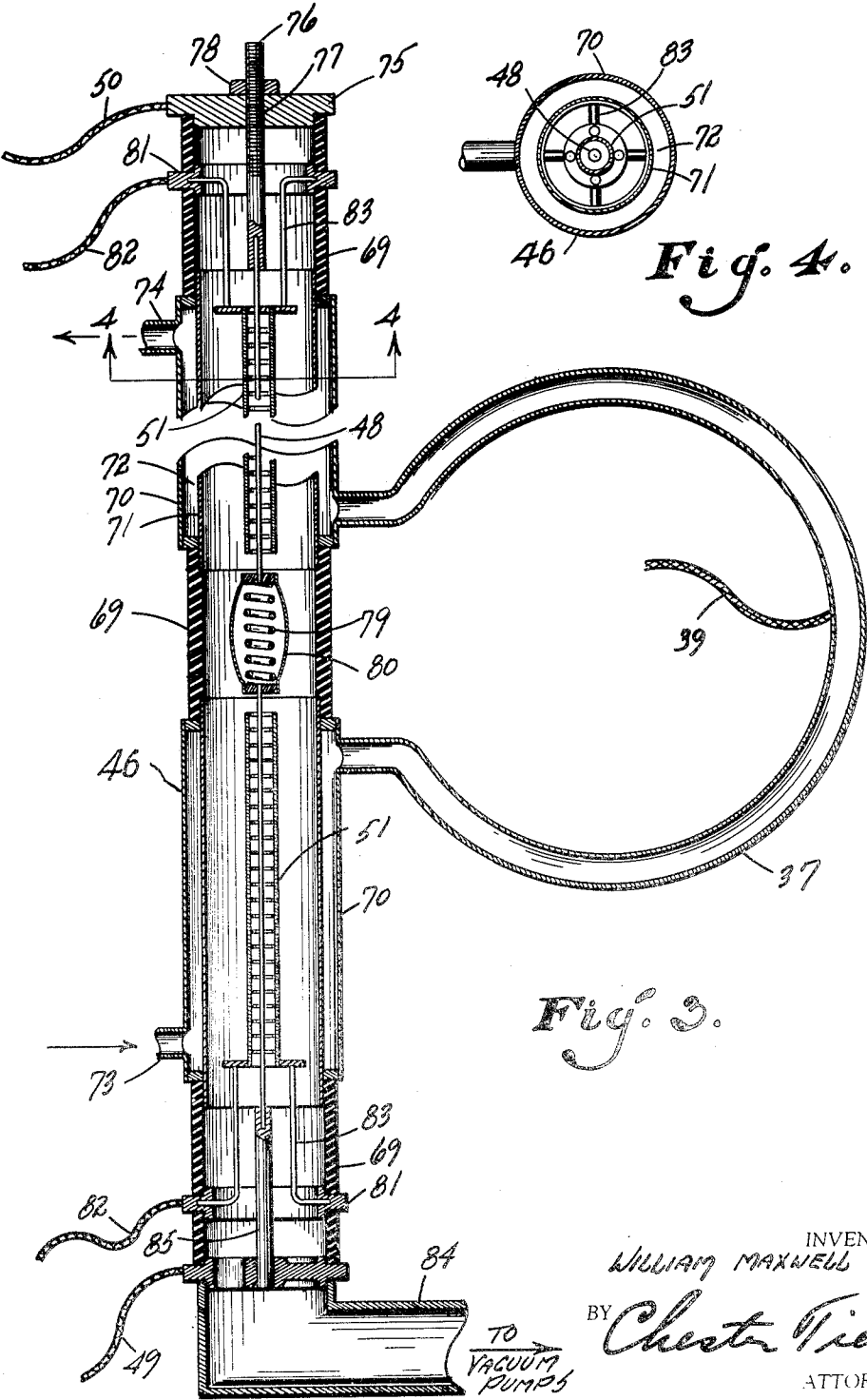


Fig. 4.

Fig. 3.

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3 Sheets-Sheet 3

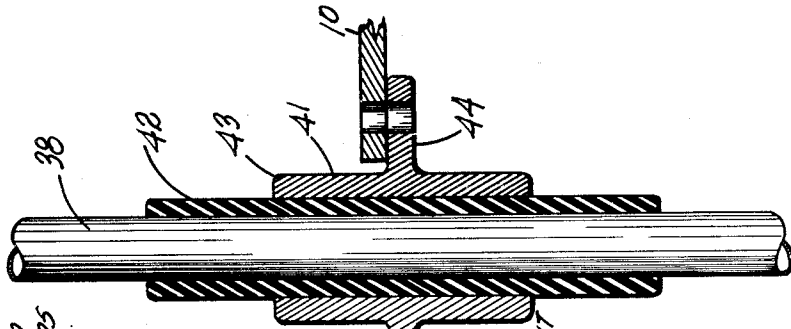
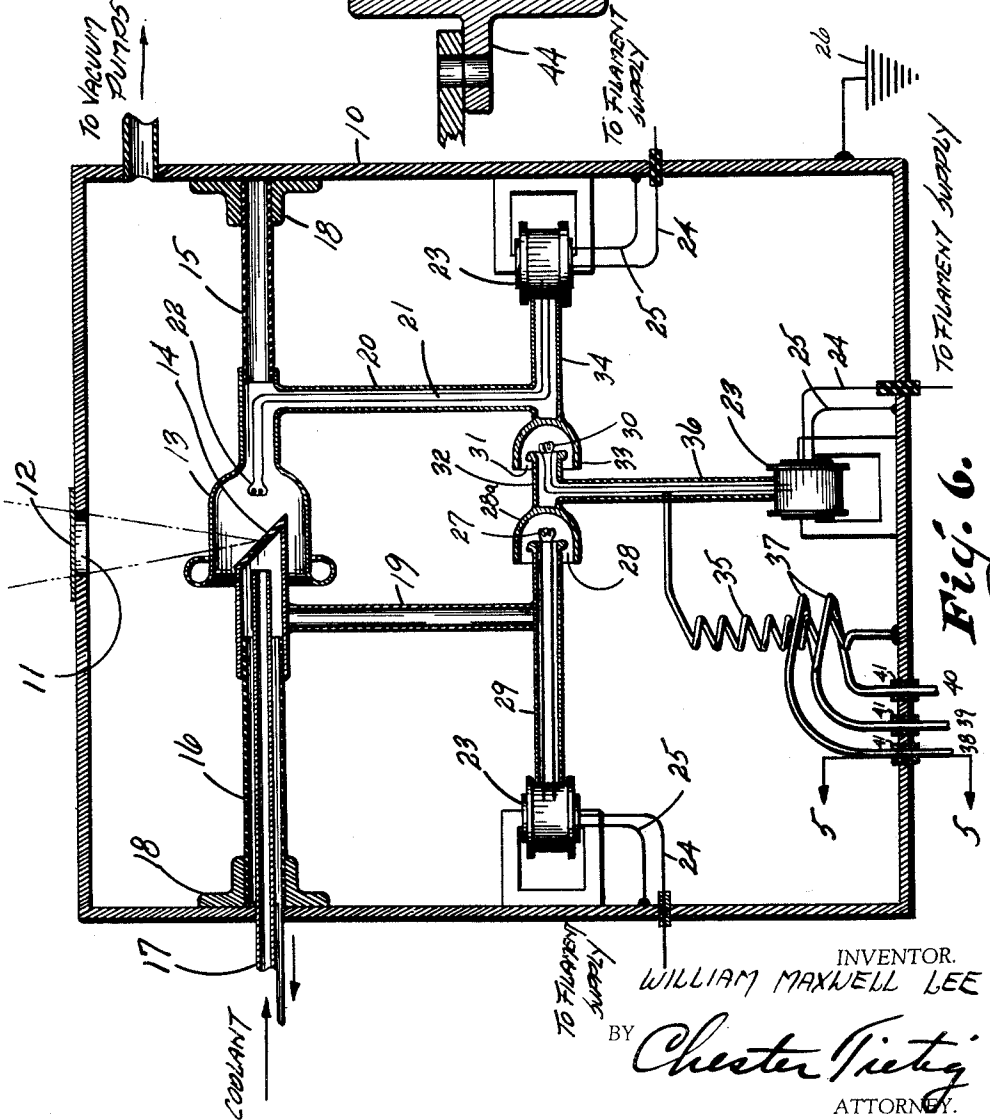


Fig. 5.



UNITED STATES PATENT OFFICE

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HIGH FREQUENCY X-RAY APPARATUS

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8 Claims. (Cl. 250—100)

This invention relates to a high voltage, radio frequency X-ray apparatus, which is intended to operate usually at constant potential.

Among the objects of the invention are to provide a means for producing high voltages of sufficient energy to produce X-rays of great energy and hardness, in a more convenient manner.

A further object of the invention is to provide means for holding the apparatus while operating, to a constant electrical output potential.

A further object of the invention is to provide a single container for the X-ray tube, rectifying tubes, filament transformers and step-up transformers and to provide means to inhibit short circuits within said container.

A further object is to use the filament transformers as condensers as well as transformers by using the capacity between the primary and secondary.

A further object is to provide an automatic means of controlling the duration of the time that X-rays are being generated.

A further object is to provide a unique double three electrode oscillator tube and a push-pull radio frequency circuit for same.

Referring to the accompanying drawings—

Figure 1 is a longitudinal cross section of the apparatus, including the oscillator circuit and the high voltage apparatus container.

Figure 2 is a longitudinal cross section thru the high voltage apparatus container showing filament transformers and bushings taking the place of the condensers. Figure 2 is the preferred form.

Figure 3 is a vertical cross section of my double oscillator tube.

Figure 4 is a horizontal cross section of the oscillator tube taken on the line 4—4 of Figure 3.

Figure 5 is a detail in section except for the conductor, of one of the condenser-bushings, taken on the line 5—5 of Figures 2 or 6.

Figure 6 is a view of the actual structure of my invention corresponding to Figure 2.

In Figures 1, 2 and 6, 10 is a housing made preferably of sheet steel and is intended, when all apparatus is in place, to be tight against vacuum or moderate internal gas pressure. A window 11 closed with a gas tight but radio-graphically transparent seal 12 is provided in the middle of one side of the emergence of X-rays. Within the housing, adjacent the window, is an X-ray tube 13 turned so that the anode 14 thereof is in position to radiate thru the window. The X-ray tube 13 is supported from both sides of

housing 10 by glass tubing; on the right side is a single tube 15 and on the left is a double concentric one 16, the inner tube 17 of which is arranged for delivery of a coolant to the rear of anode 14. The outer tube serves as a return pipe for the coolant. Pipes 15 and 16 are supported in metal sockets 18 on the inner sides of the housing.

Two upright tubes 19 and 20, preferably of copper support the anode and cathode ends respectively of X-ray tube 13. Tube 19 is of metal and performs the function of a mechanical strengthening member and electrical conductor, while tube 20 is in electrical contact with X-ray tube 13 and supports it. Tube 20 carries a pair of wires 21 which terminate in the cathode 22 of tube 13.

At a level with the lower ends of tubes 19 and 20 and at a distance about half way between the X-ray tube and the bottom of housing 10 there is a pair of filament transformers 23. On the bottom of the housing near the middle thereof is a third filament transformer 23.

One lead 24 extends from each transformer 23 to the outside of the housing 10 where they are each connected in parallel with the others to a 60 cycle A. C. main or other source of constant A. C. low voltage current. A second lead 25 is run from each transformer 23 to ground, this being the housing 10 which is in turn grounded at 26. The latter, together with one lead of the low voltage A. C. supply, which is grounded, completes the filament supply for the three filament circuits.

The transformer 23 on the right side of Figure 6 is arranged to supply current to the X-ray tube filament 22. The transformer 23 on the left side supplies a filament 27 for a rectifying valve 28. This filament extends thru a metal tube 29 and projects somewhat from the end thereof into a metallic bell 28a which is adapted to function as the plate of valve 28.

The filament 30 is part of a second rectifying valve 31 and is supplied with filament current from the transformer 23 at the bottom of housing 10. Filament 30 projects thru a metal tube 32 which is attached to the rear of the bell-shaped plate 28a. Filament 30 projects into a second bell-shaped plate 33 which is in turn supported by a metal tube 34 which carries the filament wires for filament 22. Tube 34 is integral with or at least in communication with tube 20.

At the bottom of housing 10 to the left of middle transformer 23 there is a high frequency transformer secondary 35 made of copper tubing,

one end of which is grounded to housing 10, the other end being in electrical communication with a metal tube 36 which extends from the middle transformer 23 to tube 32 and communicates with the latter. Tube 36 carries the wires for filament 30.

Encircling secondary 35 is a primary 37 also of copper tubing of a considerably smaller number of turns than the secondary. As shown, it comprises two turns with the center loop tapped. Three tubular leads 38, 39 and 40 respectively from left to right, are therefore in electrical contact with the turns of the primary 37.

These leads each extend into housing 10 through a special bushing 41 which is shown in detail in Figure 5. In that figure the conductor tube 38 is surrounded by an insulating sleeve 42, preferably of mica, and a metal sleeve 43 having a pair of pierced bolt lugs 44 by which it may be bolted to the housing 10. Such bushing 41 is attached to the housing in a vacuum tight manner.

Referring now to Figure 1, tubular leads 38 and 40 are attached to the two plates 45 of the double oscillator tube 46 which is shown in section in Figures 3 and 4. That part of the circuit of Figure 1 which lies outside of housing 10 also forms part of Figure 2. In other words, Figure 2 is to be completed by the addition of the electrical circuit of Figure 1 lying outside the housing. Such showing has not been made because it is a needless complication of the drawings.

Middle lead 39 is attached to one side of a power supply having preferably a constant potential of 10 to 20 k. v. and a current of 1 to 3 amperes. The supply may be of the same voltage and current but of 60 cycles A. C. The other side of the power supply is connected by a lead 47 to both the filament 48 of the oscillator tube and to the housing 10.

A low voltage 60 cycle A. C. filament supply current also feeds filament 48 through leads 49 and 50. Lead 49 connects with lead 47 but lead 50 runs direct to filament 48.

There are two grids 51 in the oscillator tube which are connected by an inductance 52. A fixed center tap 53 is provided for the latter and the lead 54 from said tap thru a grid leak 55 to both lead 47 and to one terminal of a timer 56. The timer may be of any type capable of opening and closing an electrical contact. The other terminal of the timer is connected by a lead 57 thru a resistance 58 to lead 54 and thence thru a condenser 59 to lead 47. That part of the circuit which includes the condenser 59 between leads 47 and 54 is therefore a by-pass for radio-frequency current around the grid leak 55.

It will be noticed that Figure 1 differs from Figures 2 and 6 by the addition to the latter of several condensers. While the elimination of these condensers is part of my invention, yet the circuit of Figure 1 including them, has points of novelty and invention, so a description of said circuit follows:—

Between X-ray tube 13 and both sides of housing 10 there are leads 56 and 57 left and right respectively, in which there are condensers 58 and 59 respectively. Between condenser 58 and the X-ray tube, lead 56 is joined by another lead 60, which also connects with one supply wire of filament 27. Between the X-ray tube and condenser 59, lead 57 is joined by lead 61 from the plate of valve 31 and 62 from one side of the secondary right hand transformer 23. The other side of this primary joins the X-ray tube filament

22 by a lead 63, thus completing the filament heating circuit.

Between the metallic connection 32 from valve 28 to valve 31 and between the connection to 32 of high frequency transformer 35 there is a lead 93 joining 32 with the housing 10. In this lead there is a condenser 64. A lead 65 joins one side of the secondary of the lowermost transformer 23 with lead 93 between the condenser 64 and connection 32.

In leads 38, 39 and 40 there are between them and housing 10, three condensers 66, 67 and 68 respectively, one to each lead, between the lead and the housing 10.

The functions of the various condensers in Figure 1 are as follows:—

Condensers 66 and 68 resonate the plate circuit of the oscillator tube 46, which circuit comprises the primary 37, the condensers mentioned, and the capacity between the plates 45 and the filament 48. 67 is a blocking condenser which provides a path for radio frequency currents without permitting the circulation of power currents i. e. currents coming directly from the power supply. 66, 67 and 68 are absent in Fig. 2 since the insulating bushings 41 are of an electrical capacity as great as the condensers which they replace, thus eliminating the need for separate condensers.

Since primary 37 is a tube and is in connection with the plate circuits, water or oil may be and preferably is circulated thru this circuit to cool the plates, which subject is further discussed in the description of Figure 3.

Figure 1 further differs from Figure 2 because condensers 58, 59 and 64 are omitted in the latter figure. They are left out because I have found that the capacity between the primaries and secondaries of transformers 23, when constructed in the conventional way, is great enough if the frequency thru the circuits is high enough. The capacity of the lowermost transformer 23 resonates the secondary circuit which comprises the secondary 35. The reason for desiring to resonate this circuit is to obtain a maximum voltage drop across the terminals of secondary 35.

The capacities of the side transformers 23 are used as storage condensers. Their function will be discussed under the heading "operation."

Referring now to Figures 3 and 4, 37 is the loop of tubing seen to the right of the tube and is the primary of the radio-frequency transformer shown in Figures 1 and 2. The tube 46 proper comprises a long cylindrical jacket made up of three glass or porcelain insulating cylinders 69 between which are two lengths of metal tubing 70 which have second wall 71 for water cooling purposes. At each end of the water cooling space 72 so created there is a port, 73 being an inlet port for water at the bottom and 74 an outlet port at the top. Loop 37 acts as a connecting channel between the upper and lower portions of the water jacket 72.

The top of the oscillator tube is closed by a metal cap 75 to which is attached a filament supply lead 50. A screw 76 extends thru cap 75 thru a hole 77 therein. Above the hole and surrounding the screw is an adjusting nut 78 by which the screw can be raised or lowered. At the lower end of the tube, the filament is held by a conductive rod 85. Screw 76 supports a filament 48 centrally in the tube. At the middle portion thereof is a spring 79 to keep the filament taut. Since it is undesirable that the spring should be incandescent, it is by-passed by a pair of flexible leads 80. This by-pass also prevents

heating of the glass section 99 which surrounds the spring 79.

Surrounding filament 48 are two cylindrical grids 51, one on each side of spring 79. They are supplied with current from metal sections 81 in the tube at the upper and lower portions of the tube. To these sections, leads 82 are attached, these leads being the ends of inductance 52. The grids are pieces of metal tubing, from each side of which semi-circular slots have been milled out. The grid pieces 51 are supported from sections 81 by four rod supports 83. The inner walls 71 of the jacketed metal sections 70 are the plates of the tube. During operation these plates are of different electrical sign, therefore the loop 37 which connects them is of sufficiently high impedance to prevent the charges from wholly neutralizing each other, while still acting as an efficient water transferring agent electrical connection.

The lower part of the oscillator tube is provided with an outlet portion 84 to which in operation, the vacuum pumps (not shown) are operatively connected. All places in which air can enter the tube are sealed with either shellac, alkyd resin varnish or sealing wax.

In operation, my apparatus functions as follows:—

Referring to Figure 1, first the oscillator tube filament is energized thru 49 and 50. Then a voltage which may approximate 20,000 volts D. C. is applied to the leads 39 and 47, the positive side being connected to 39. The grids 51 thereupon become alternately positive and negative in the well known manner, setting up oscillations in both the grid and plate circuits. The frequency of these oscillations is determined by the amount of inductance and capacity in the grid and plate circuits. These oscillations travel thru the plate circuit coil 37 which also acts as the primary of the step up transformer 35—37. An alternating voltage of high frequency is therefore induced in secondary coil 35. During one half of the cycle current then flows thru coil 35 to the ground, then during the other half thru the capacity 58, then thru valve 28, then completing the circuit to coil 35. On the reverse half cycle current flows from the ground thru valve 31, thru the capacity 59 and thence back to ground, completing the circuit. After a few cycles, each capacity 58 and 59 is charged up to full peak voltage of the transformer secondary 35. The X-ray tube 13 is connected across the ungrounded ends of the capacitors by means of leads 57 and 56. By this means the full voltage stored in the capacitors 58 and 59 is placed across the tube 13 and in this connection is additive so that double the peak voltage generated in coil 35 is applied. This follows from the fact that the capacities are connected in series.

In my apparatus, due to the fact that circuit 35—64 is resonated, voltages equal to fifty to seventy-five times the voltage which would normally be generated in coil 35 if the circuit were non-resonant, are obtained. In order to get efficient operation of the secondary, it is necessary to have capacities 66, and 68 in the primary circuit. 67 acts merely as a blocking condenser to provide a path for the high frequency currents to ground so that these currents will not interfere with the power supply.

Referring now to Figure 2, which is a preferred and simplified form, condensers 58, 59, 64, 66, 67 and 68 are eliminated, thus removing a source of considerable trouble since they are likely to short or puncture. The inherent capacity of the bush-

ings 41 are sufficient in this form to resonate the primary coil 37. To select such a capacity is within the skill of any competent electrical engineer in possession of this disclosure. Likewise it is possible for such a person to build his transformers 23 with the necessary capacity between primary and secondary to utilize them in place of the condensers 58, 59 and 64, after this invention is communicated to him. He must however design the apparatus with view to operating at radio frequencies, that is, not less than 100,000 cycles per second.

Referring to Figures 3 and 4, operation is started by evacuating the tube and then turning on the cooling water into inlet 73, filling primary inductance coil 37 and so reaching the jacket space 72 in the upper part of the tube and finally leaving thru exit 74. In this travel, plates 71 are cooled.

The filament 48 is next energized by applying a suitable low voltage current to leads 49 and 50. As the filament heats, it expands but such expansion is taken up by spring 79 which is in tension when the tube is cold. Current is by-passed around the spring by pig-tail conductors 80 of stranded copper. About 20,000 volts D. C. is now applied to lead 47 and lead 39 on coil 37. It is important that the plus potential is applied to lead 39. Electrons then flow from the filament 48 to the plate 71 thru grid 51. When electrons strike grid 51 current flows thru grid resistor 55 and lead 49 back to filament 48, completing the circuit. This flow of current causes a voltage drop across resistor 55, converting the potential of the grid to negative; therefore the flow of electrons between grid and plate stops. As soon as the electron flow stops, the grid loses its negative charge, becoming positive with respect to the filament. Electrons are now again able to flow between filament and plate. The value of resistance 55 determines how negative the grid can become; a high value of resistance will cause high negative potential. Preferably resistance 55 is made so high that it will never by itself permit the grid to become neutral or positive in respect to the filament. But a resistance 58 is provided which when the timer circuit is closed, is in parallel with 59. The total value of the resistance in the grid circuit is then reduced to such a value as to allow the grid to become positive. Electrons are then able to flow between filament and plate. Opening the timer therefore indirectly prevents the flow of electrons and stops operation of the apparatus. It is apparent therefore that timer 56 can be of any type capable of opening and closing a circuit and can in fact be a mere manually controlled switch.

I claim as my invention:—

1. In an X-ray apparatus, the combination which comprises the following apparatus in the relation named, contained within an electrically insulating space: an X-ray tube, a plurality of valve tubes arranged to supply direct current to said X-ray tube, a transformer comprising a primary and a secondary circuit adapted to supply high voltage current to said valve tubes and thence to said X-ray tube, means in the primary circuit thereof for resonating same, a plurality of transformers adapted to supply heating current to the filaments of said valve tubes and of said X-ray tube, said filament heating transformers having sufficient inherent capacity between primary and secondary to resonate the secondary of said high tension transformer at radio frequencies and being arranged to act as storage condens-

ers to supply substantially constant-potential current to said X-ray tube.

2. In an X-ray apparatus, the combination which comprises the following apparatus in the relation named, contained within an electrically insulating space: the electrodes of an X-ray tube, the electrodes of a plurality of valve tubes arranged to supply direct current to the electrodes of said X-ray tube, a transformer adapted to supply high voltage current to said valve tube electrodes and X-ray tube electrodes, a primary and a secondary for said transformer, means comprising a plurality of insulating bushings for resonating the primary thereof, a plurality of transformers each having a primary and secondary adapted to supply heating current to the valve and X-ray filaments, said transformers having sufficient inherent capacity between their primaries and secondaries to resonate the secondary of said high tension transformer at radio frequencies and being arranged to act as storage condensers to supply substantially constant-potential current to said X-ray tube electrodes.

3 In an X-ray apparatus, the combination which comprises the following apparatus in the relation named contained within an electrically insulating space: an X-ray tube, a plurality of valve tubes arranged to supply direct current to said X-ray tube, a transformer having a primary and a secondary adapted to supply high voltage current to said valves and thence to said X-ray tube, a plurality of transformers adapted to supply heating current to the filaments of said valve tubes and of said X-ray tube, said transformers having sufficient inherent capacity between primary and secondary to resonate the secondary of said high tension transformer at radio frequencies and being arranged to act as storage condensers to supply substantially constant-potential current to said X-ray tube, and in addition, external to said insulating space, an oscillator tube connected to the primary of said high voltage transformer to furnish high voltage current to same, a grid leak for said tube, an input circuit including a resistance and a capacity adapted to pass radio frequency current around said grid leak, a plurality of leads from said oscillator tube to said primary and a plurality of insulating bushings, one for each lead, at the boundary of said insulating space, said bushings having sufficient inherent capacity to resonate the plate circuit of said oscillator tube and to act as blocking condensers to provide a path for radio frequency current while inhibiting the circulation of low frequency power currents.

4. In an X-ray apparatus, a case, an X-ray permeable window therein, X-ray tube electrodes opposite said window, a plurality of valve tube electrodes comprising filament cathodes, a high frequency step-up transformer having a primary adapted to furnish said valve tube and thence the X-ray tube electrodes with high-potential current, a primary for said transformer, a plurality of insulating bushings in the primary adapted to resonate the latter, means for supporting said electrodes in said case, a plurality of transformers attached to said case for furnishing heating current to the filaments, of the valve and X-ray cathodes, one lead of each primary of said transformers being grounded to the case and the other lead of each primary being led thru said case thru an insulated bushing, the capacity of at least one of said heating transformers between primary and secondary being sufficient to resonate the sec-

ondary of said high frequency step-up transformer at more than 100,000 cycles per second.

5. In an X-ray apparatus, a case, an X-ray permeable window therein, X-ray tube electrodes including a filament type cathode opposite said window, a plurality of valve tube electrodes including filament type cathodes, a high frequency step-up transformer adapted to furnish said valve tube and thence the X-ray tube electrodes with high-potential current, means for supporting said electrodes in said case, a plurality of transformers attached to said case for furnishing heating current to the filaments of the valve tube and X-ray tube cathodes, one lead of each primary of said transformers being grounded to the case and the other lead of each primary being led thru said case thru an insulated bushing, the capacity of at least one of said heating transformers between primary and secondary being sufficient to resonate the secondary of said high frequency step-up transformer at more than 100,000 cycles per second, and in addition, external to said insulating space, an oscillator tube adapted to furnish high frequency current to the primary of said high voltage transformer, a plate circuit for said oscillator tube including the primary of said high voltage transformer, filament, plate and grid circuits for said tube and a plurality of insulating bushings, one for each lead of the plate circuit, at the boundary of said insulating space, said bushings having sufficient inherent capacity to resonate the plate circuit of said oscillator tube and to act as blocking condensers to provide a path for radio frequency current while inhibiting the circulation of low frequency power currents.

6. In combination in an X-ray apparatus, an X-ray tube, means including a transformer primary for supplying said tube with rectified high voltage current, means for supplying said tube with filament heating current, a filament transformer having a primary and secondary and sufficient inherent capacity between primary and secondary to resonate the high voltage supply, storage means for maintaining a substantially constant potential discharge across the electrodes of the X-ray tube when the latter is operating, an oscillator tube in the primary of said high voltage supply means, filament, plate and grid circuits supplying said tube, a grid leak in said grid circuit and a timer adapted to control the period during which said tube oscillates by its effect on the grid leak.

7. In combination in an X-ray apparatus, an X-ray tube, a transformer for supplying said X-ray tube through rectifiers with radio frequency high voltage current, said transformer having a primary and secondary, means for rectifying the high voltage current fed to the tube, means capable of performing the function of a condenser for storing high voltage current to bring it to approximately constant potential before it is applied to the X-ray tube, an oscillator in circuit with the primary of the high frequency high voltage supply transformer, grid-, filament-, and plate-circuits supplying said oscillator tube, said oscillator and its supply circuits being adapted to create radio frequency current from the current supplied by power mains, a timer in the grid circuit of said oscillator, a high resistance in said grid circuit capable of keeping the grid negative with respect to the filament and thereby preventing oscillation, a second resistance in said grid circuit adapted to be connected in parallel with the high resistance when the timer circuit is

closed, and thereby to reduce resistance in the grid circuit and permit oscillation.

8. In combination, a vacuum tight case, a window therein of X-ray permeable material, X-ray
5 electrodes including a filament type cathode substantially opposite said window and within said case, also therein transforming means for increasing the voltage of current supplied to said means from power mains, means for increasing
10 the frequency of the output of said transforming means to radio frequency, a plurality of rectify-

ing electrodes including filament type cathodes for rectifying at high potential the output of said frequency increasing means, filament-heating transformers for supplying heating current to the X-ray cathode and rectifying cathodes, all of
5 said electrodes being bare except for the common case housing them, said case having an opening through which it may be exhausted of air.

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