

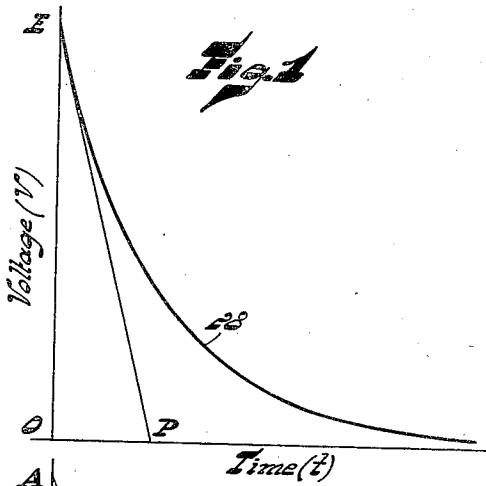
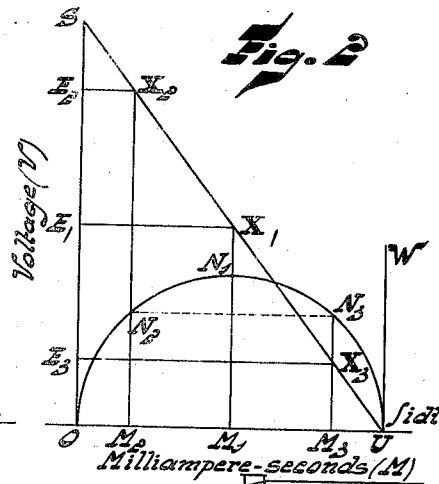
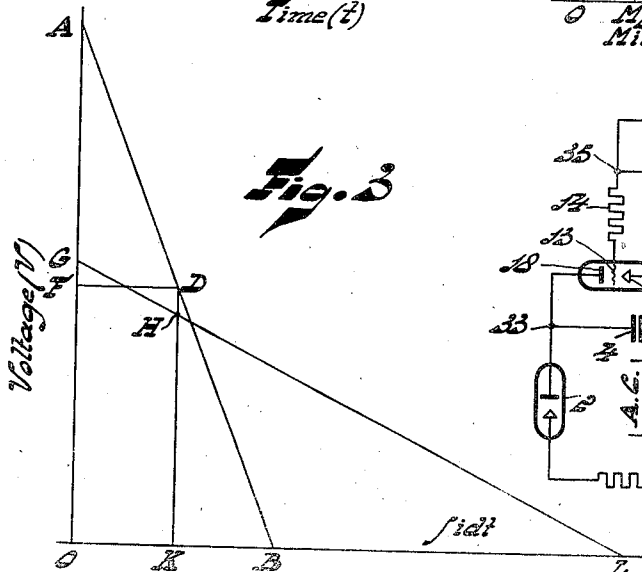
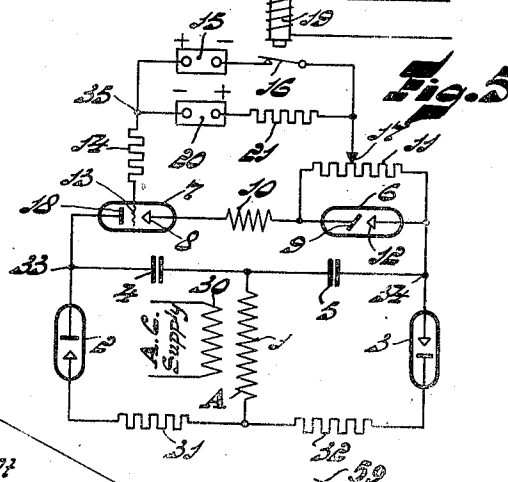
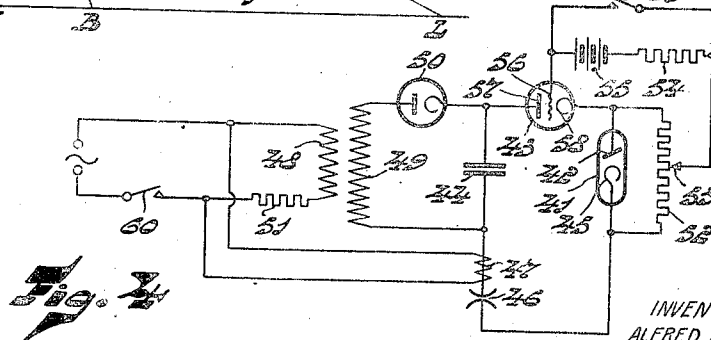
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X-RAY APPARATUS

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X-RAY APPARATUS

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10 Claims. (Cl. 250—97)

Our invention relates to X-ray apparatus of the type in which energy is supplied to the X-ray tube by a previously-charged condenser.

With such apparatus, the condenser is charged to a predetermined voltage from an A. C. supply with a low charging current which flows during numerous cycles of the supply voltage, and it is possible to take instantaneous radiographs with very high power without overloading the supply mains. The duration of the active discharge through the tube depends upon the initial voltage of the condenser and the intensity of the filament-heating current of the tube, and the discharge current through the tube may be many times greater than the charging current. Thus, it is possible to take a radiograph of very short duration with a current which is large and is limited only by the capacity of the X-ray tube.

Such apparatus, however, have the disadvantage that the condenser voltage, and thus the operating voltage, of the X-ray tube decreases during the discharge in accordance with a potential curve whose shape is unfavorable for the efficient utilization of the energy stored within the condenser. It has been proposed to improve the shape of this potential curve by using a second accumulator of energy, such as a choke coil, which is connected in series with the condenser. This choke is given such an inductance that it will absorb part of the voltage at the beginning of the discharge, and accumulate a part of the energy output of the condenser with gradually decreasing wattage to return this energy to the X-ray tube after the tube voltage has increased to a value equal to the condenser voltage. As a result, the curve of the voltage across the X-ray tube has a convex shape in which the central portion slowly rises to and recedes from a maximum value to form a portion in which the voltage is substantially constant.

Although this choke coil improves the shape of the curve of the discharge current and voltage through the tube, it cannot in any case bring about a sufficiently high degree of invariability of the voltage taken over the duration of the exposure.

The main object of the present invention is to make the terminal voltage of the X-ray tube, during a considerable portion of the exposure time, substantially independent of the variation in terminal voltage of the condenser.

Another object of the invention is to decrease the necessary value of the capacity of the condenser supplying the X-ray tube with current.

A further object of the invention is to easily

control the exposure time and the X-ray energy in an X-ray installation operating with a condenser discharge.

A still further object of the invention is to adjust the terminal voltage of an X-ray tube energized by a charged condenser to a predetermined value which is independent of the voltage to which the condenser is charged up.

A still further object of the invention is to more efficiently utilize the energy stored within the condensers of such apparatus.

Further objects of the invention will appear as the description progresses.

In accordance with the invention we connect in series with the X-ray tube an impedance which, in contradistinction to the choke coil, is an energy consumer and has a variable resistance. This impedance absorbs a portion of the condenser voltage and also consumes a part of the energy stored within the condenser, and its resistance is so varied relatively to the condenser voltage, that the absorbed voltage decreases in such a manner that the voltage across the X-ray tube remains substantially constant as long as the condenser voltage exceeds a given value.

The energy consumer may consist of a conductor having a variable resistance which depends on the voltage applied to it, so that when it is connected in series with a constant ohmic resistance it keeps the current constant. Conductors like these are generally known as "variators."

We prefer, however, to use as an energy consumer a grid-controlled discharge tube—hereinafter referred to as a control tube—because the resistance of such a tube can be readily controlled in an inertialess manner and the tube may also be used to control the discharge current through the X-ray tube. The potential variations at the X-ray tube are transmitted in an amplified manner by the control tube—which acts as a direct current amplifier—to that part of the circuit which is connected in series with the X-ray, i. e., when the condenser voltage decreases the voltage at the control tube also decreases, but the voltage across the X-ray tube decreases only slightly.

For the above purpose, the grid of the control tube is preferably connected through a source of constant positive bias to a point whose potential relatively to the cathode of the control tube is negative and varies in the same manner as the voltage across the X-ray tube. Thus, by making the positive bias and/or the ratio between the negative supplemental voltage and tube

voltage adjustable, it is possible to select at will, within wide limits, the voltage at the X-ray tube.

We prefer to charge the condenser to a voltage which is about twice the voltage across the X-ray tube, because this gives the optimum ratio between the energy consumed in the X-ray tube and that accumulated in the condenser. Thus, the voltage to which the condenser is charged should be twice the mean value of desired range of voltage to be used across the X-ray tube.

In order to more clearly set forth the invention and to point out its advantages over the prior art, we shall describe the same in more detail with reference to the accompanying drawing in which:

Figs. 1 to 3 are graphs for use in describing the invention, and

Figs. 4 and 5 are schematic diagrams of X-ray apparatus embodying the invention.

As stated above, if a condenser is allowed to discharge directly through an X-ray tube, the voltage of the condenser, as well as the voltage across the X-ray tube, will decrease during the discharge. More particularly, as the charge Q of a condenser, having a capacity C decreases, the voltage V across the condenser—which is related to the charge by the equation

$$V = \frac{Q}{C}$$

—also decreases. If the voltage to which the condenser is charged is E , the voltage V during the discharge through a fixed resistance R varies with the time t in accordance with the equation

$$V = Ee^{-\frac{t}{CR}}$$

This is illustrated in Fig. 1 in which the abscissae represent time, the ordinates represent the voltage across the condenser, and reference numeral 28 indicates the voltage-time curve of the condenser. A line EP tangent to curve 28 at a point E intercepts the abscissa axis in a point P.

To maintain the voltage within certain limits during the radiographic exposure, the capacity of the condenser may be increased. Thus curve 28 will become flatter and line OP will intercept the abscissa axis further to the right, and the voltage will decrease more slowly. Thus, the smaller are to be the voltage variations permitted during an exposure of a given duration and with a given number of milliamperes-seconds, the larger must be the capacity of the condenser. In any case only a relatively small part of the energy stored within the condenser is effective in producing useful X-rays, and the major part of the energy remains in the condenser if the tube is disconnected from the circuit, or is lost if the tube remains connected.

In Fig. 2 the ordinates represent the voltage V across the condenser and the abscissae represent the number of milliamperes-seconds passing through the X-ray tube. If Q_1 is the charge of the condenser at the beginning of the discharge, the charge present after a time

$$T \text{ is } Q = CV = Q_1 - \int idt$$

The ratio between the condenser voltage and the milliamperes-seconds is consequently substantially linear as indicated by line SU.

If, in accordance with the invention, the tube voltage E_1 is made constant and equal to OE_1 , the area of rectangle $OE_1X_1M_1$ represents the energy in watt-seconds consumed by the tube.

If OE_1 equals $\frac{1}{2}OS$, as is the case in Fig. 2, this

energy is equal to $\frac{1}{2}$ the energy content of the condenser. A parabolic curve, which deviates only slightly from a semi-circle having a center M_1 and a radius OM_1 , represents the energy available in the condenser ($\int v idt$) as a function of the milliamperes-seconds, and the ordinates of the points on the curve line are a measure of the joules.

If, for the given initial condenser voltage OS , a tube voltage OE_2 is selected, the area of rectangle $OE_2X_2M_2$ represents the useful energy available at a constant tube voltage OE_2 , and if a tube voltage OE_3 is selected, the useful energy is represented by the area of rectangle $OE_3X_3M_3$. The ordinates M_2N_2 and M_3N_3 for $\int idt$ equal to OM_2 and OM_3 respectively are proportional to the areas of rectangles $OE_2X_2M_2$ and $OE_3X_3M_3$ respectively. In the Fig. 2 M_2N_2 is chosen equal to M_3N_3 , to show that at the different tube voltages E_2 and E_3 , radiographs may be taken with the same number of watt-seconds.

When the tube voltage is OE_1 and the current consumer according to the invention connected in series with the condenser absorbs the remaining voltage, the energy represented by the area of triangle E_1X_1S is consumed in the series-connected consumer and the energy represented by rectangle $OE_1X_1M_1$ is consumed in the X-ray tube. If the tube is cut out of circuit in time, the energy represented by triangle X_1M_1U remains in the condenser, and thus for the next exposure it is necessary to supply to the condenser only the energy represented by the area of figure OM_1X_1S .

The advantages as regards efficiency of an apparatus according to the invention over an apparatus in which a current-controlling consumer is not used, will be pointed out with reference to Fig. 3 in which the abscissae represent milliamperes-seconds and the ordinates represent the condenser voltage. Assuming that, in an apparatus without a current consumer, the voltage across the tube must not decrease more than 20% during the exposure, it is possible to use a condenser charged to a voltage OG and having a capacity C equal to

$$\frac{OL}{OG}$$

and to interrupt the current from the condenser when its voltage has dropped to KH equal to 80% OG . In this case the area of triangle OGL represents the total energy of the condenser, and the area of portion $OKHG$ thereof indicates the consumed part of the energy which is about 36% of the total energy.

When using a current consumer according to the invention, the condenser may be given a capacity C_2 which is much lower than C_1 and, as indicated in Fig. 3, is equal to

$$\frac{OB}{OA} = 0.2C_1$$

This condenser is charged to a higher voltage shown as OA , which is equal to $OG + HK$. If the tube voltage is adjusted to a value OF equal to $\frac{1}{2}OA$, i. e., so that it has the same average value as in the first case, about 50% (rectangle $OFDK$) of the energy stored in condenser C_2 (triangle OAB), is efficiently utilized, whereas the number of watt-seconds is the same in the first case, and this is obtained with $\frac{1}{2}$ of the capacity of condenser C_1 .

As a specific example, assume that condenser C_2 is given a capacity of $4\mu F$. and the voltage OA

is given a value of 100 kv. In this case the total energy of the condenser will be 20 kw.-sec. of which 10 kw.-sec. will be efficiently consumed at a tube voltage of 50 kv. To obtain the same energy by means of a voltage which is not maintained constant by the means according to the invention and whose initial value is 55 kv. and final value is 45 kv., the condenser would have to have a capacity of 20 μ F and 28 kw.-sec. would have to be accumulated therein.

From the above it appears that an apparatus according to invention has numerous advantages over prior art condenser apparatus. For example, the tube voltage is more favorable because it decreases to only a slight degree during exposure, the energy to be supplied from the mains may be lower, and it is possible to take exposures of a given number of watt-seconds with a condenser of much lower capacity. Moreover the voltage across the tube may be regulated by adjusting the characteristic of the series-connected current consumer.

During the condenser discharge the charging-up device may be disconnected from the discharge tube, and Figures 2 and 3 refer to such a case.

Referring to Fig. 4 which shows the main parts of a circuit diagram for an X-ray apparatus of this kind, an X-ray tube 41 has its anode 42 connected through the triode 43 to one terminal of condenser 44. The cathode 45 of the X-ray tube 41 may be connected through switch device 46 with the other terminal of condenser 44. Switch device 46 is controlled by a magnet winding 47 and may be of the type described in the U. S. patent specification 1,946,329 to Alfred Kuntke of February 6, 1934. A transformer having a low voltage primary winding 48 and a high voltage secondary winding 49 serves for charging up the condenser 44 to a voltage considerably higher than the desired terminal voltage of X-ray tube 41.

The primary winding 48 is energized by an A. C. supply when switch 60 is closed. Condenser 44 is then charged up with direct current, because the current supplied by transformer 48, 49 to the condenser is rectified by the diode 50. Primary resistance 51 and the resistances of diode 50 and transformer 48, 49 limit the current, so that only after a large number of cycles of the A. C. current, for example after a few seconds, the condenser voltage will have attained the desired value, which is slightly below the maximum no-load voltage of secondary winding 49.

Magnet winding 47 is supplied with current from the A. C. network, to which it is connected through switch 60. When energized it keeps switch device 46 open.

In shunt with X-ray tube 41 is a resistance 52 having a tap 53. The latter is connected through resistance 54 and battery 55 to the grid 56 of triode 50. The anode 57 of the triode is connected to transformer winding 49 and the cathode 58 is connected to the anode 42 of X-ray tube 41. Battery 55 imparts a positive bias to grid 56.

After the condenser 44 is duly charged up, switch 60 is opened, whereby energization of transformer 49, 48 ceases. At the same time magnet winding 47 is deenergized so that it no longer keeps switch device open and the discharge current circuit is established. Current flows now from condenser 44 through triode 43 to X-ray tube 41 and from there through switch device 46 back to condenser 44. Triode 43 acts therewith as a control tube. Tubes 43 and 50 are

preferably incandescent cathode tubes. The heating circuits for the cathodes of tubes 41, 43 and 50 are omitted for simplicity.

During the discharge the condenser voltage falls rapidly and thus the voltage at the X-ray tube decreases. However the grid voltage of the control tube 43 becomes slightly less negative, and when the condenser voltage V drops to a value only slightly higher than the tube voltage E_a , the conductivity of the control tube starts to increase appreciably; the voltage still present being practically entirely in favor of the X-ray tube. It is recommendable not to use this part of the condenser discharge for the exposure, because in this case the voltage at the X-ray tube falls quickly to a value which is low enough for the tube to become inactive as a source of X-rays. For this reason the tube should be made inactive previously, for example by eliminating the positive bias of grid 56. For this purpose a switch 59 may be provided by which battery 55 and resistance 54 may be shunted.

If desired, the charging-up device may remain connected and the internal resistance of the X-ray tube may be increased in the manner set forth in the U. S. patent application Ser. No. 11,355 to Albert Bouwers filed March 15, 1935, now Patent No. 2,157,474. In such cases the voltage drop in the supply device should remain low enough for the voltage at the tube to suffice for the emission of X-rays in the condition of equilibrium set up when the condenser obtains in each cycle of the alternating current supply a charge which is equal to the charge delivered from the condenser to the X-ray tube.

If the internal resistance of the X-ray tube is not increased during the condenser discharge, there will be generally set up—after a large part of the energy accumulated in the condenser has been consumed—a condition of equilibrium in which the voltage across the tube is too low for the emission of rays. This results from the fact that the condenser is used so that it may be possible to use a comparatively feeble supply device which itself, in the case of a load having a low resistance, consumes by its impedance the major part of the produced electromotive force. In this case it is not necessary to cut out the current quickly, it being assumed that the charging device delays the short-circuit-like low-resistance load of the X-ray tube and the load of the mains is not made too intense.

Fig. 5 illustrates the circuit arrangement of an X-ray apparatus according to the invention in which the supply device remains connected to the X-ray tube during the discharge of the condenser. The apparatus comprises a high-tension supply transformer A having a primary winding 30 connected to a suitable A. C. supply, and a high-tension secondary winding 1. Winding 1 has one end connected to one electrode of condensers 4 and 5, and its other end connected through resistances 31 and 32 and rectifiers 2 and 3, which are preferably incandescent cathode tubes, to points 33 and 34 connected to the other electrodes of condensers 4 and 5 respectively.

Connected in series across points 33 and 34 are an energy-consuming impedance in the form of a grid-control discharge tube 7 having an anode 18, a control grid 13 and a cathode 8, a choke coil 10 which serves to protect tube 7 from disruptive discharges, and an X-ray tube having an anode 9 and a cathode 12. Cathodes 8 and 12 are of the incandescent type, and the heating circuits therefore are omitted for simplicity. Thus it is

possible for condensers 4 and 5 to discharge through the discharge tube 7 and X-ray tube 6.

Connected across anode 9 and cathode 12 of X-ray tube 6 is a resistance 11 provided with a variable tap 17. Grid 13 is connected through a fixed resistance 14 to a point 35 which point is connected to tap 17 through two parallel branches, one comprising a source of constant positive bias 15 and the contact 16 of a normally-closed relay 19, and the other comprising a source of negative bias 20 and a high resistance 21.

If we assume the X-ray tube voltage as E, the voltage between anode 9 and the point 17 as

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$$\frac{E}{n}$$

and the voltage of the source 15 as g, the grid voltage of tube 7 will be equal to

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$$g - \frac{E}{n}$$

It is thus possible to express the X-ray tube voltage by the following formula:

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$$E = \frac{(g + VD)n}{1 + nD}$$

in which D is

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$$\frac{1}{\text{amplification factor}}$$

of tube 7, n is a constant depending upon the adjustment of potentiometer 11, and V is the voltage between the anode 18 and cathode 12. If VD is made very small relative to g, E will be substantially constant. Generally, nD will be small compared with 1, and E will be substantially proportional to n. The biasing voltage supplied by the source 20 may be regulable. By changing this voltage, the tube voltage E may be adjusted to a predetermined value.

Assuming that the no-load voltage of transformer A is equal to 0.5V₁, the voltage V between anode 18 and cathode 12, with which the load starts, will be approximately equal to V₁. A part 45 E_r thereof is in favor of the X-ray tube, which part is, for example, 50% of V₁.

What happens to the voltages after the discharge current is established, depends on the value at which the internal resistance of the X-ray tube is adjusted. If this resistance is sufficiently high, a condition of equilibrium is set up in which the condenser voltage V always exceeds E_r, and the voltage at the X-ray tube E remains about equal to E_r. This may be made effective for taking radiosopes or radiographs of prolonged duration with low power and a voltage E_r that may be adjusted at will.

If, however, the current through the X-ray tube is adjusted to a value at which the potential drop in the charging circuit exceeds the difference between V₁ and E_r, as long as the condenser voltage is higher than E_r a larger amount of watts will be supplied by the condensers to the tube than is supplied to them by the charging device and the condenser voltage falls. As long as V remains considerably higher than E_r, voltage E remains substantially constant. The more the difference between V and E decreases, the greater is the extent to which also E decreases. Due to this the negative grid bias obtained from the potentiometer 11 becomes considerably smaller and the conductivity of tube 7 becomes higher, so that at last the voltage E falls back with the condenser voltage and recedes to a value below E_r, and the higher is the adjusted

current strength of the X-ray tube, the lower will be this value which may be insufficient for the emission of X-rays to occur.

In the above equation, the voltage g is a relatively large percentage, for instance 10% of the voltage V. On the other hand D is only a fraction of 1, with the result that VD may be small with respect to g, although V is larger than g.

In the specific example g may equal 10,000 volts, D may equal 0.005 and n may equal 5. In this case if V varies from 100,000 volts to 60,000 volts, substitution in the above equation shows that the initial voltage E of the X-ray tube equals

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$$\left(\frac{10,000 + 0.005 \times 100,000}{1 + 0.025} \right)^5$$

or 51,200 volts. This voltage E decreases to a value of

20

$$\left(\frac{10,000 + 0.005 \times 60,000}{1 + 0.025} \right)^5$$

or 50,250 volts. Thus, the voltage E decreases only about 2%, i. e., from 51,200 volts to 50,250 volts whereas the condenser voltage V decreases by about 40%.

Relay 19 serves to interrupt the flow of current through the X-ray tube, and may be controlled by an automatic device (not shown), for example, a time switch or a milliamper-second relay. As soon as the contact 16 is opened, the grid 13, which is connected through the source of negative bias 20 and high resistance 21 to the tap 17, becomes negative, and the control tube 7 becomes non-conductive and interrupts the current through the X-ray tube. The number of milliamper-second may thus be limited at will.

Rectifiers 2 and 3 may preferably be used to protect the A. C. supply mains or transformer A from being overloaded by limiting the charging current by their saturation current. For this purpose the incandescible cathodes of these rectifiers are so heated that even if condensers 4 and 5 are short-circuited or in a discharged condition they will absorb a current which is no higher than that corresponding to the highest permissible loads of the mains or the transformer. In this case, it may be desirable that the rectifiers be surrounded by an X-ray-absorbing screen, since inter alia the voltage at the valves may increase to a value at which appreciable radiation occurs, when the point of saturation is reached.

To obtain directly from the main supply loads a current-load exceeding that which can be supplied by the charging device at an efficient tube voltage as well as an efficient current supply, the resistance of the X-ray tube may be increased during the discharging of the condenser in the manner described in the above mentioned U. S. patent to Albert Bouwers, and the equilibrium may thus be displaced to a higher voltage at which serviceable X-rays are produced.

While we have described our invention in connection with specific examples and applications, we do not wish to be limited thereto, but desire the appended claims to be construed as broadly as is permissible in view of the prior art.

What we claim is:

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1. An X-ray apparatus comprising an X-ray tube, a condenser for storing energy to be supplied to said tube, means including a supply source for charging said condenser to a predetermined voltage, an energy consumer of vari-

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able ohmic resistance connected in series between said X-ray tube and condenser, and means associated with said energy consumer and said X-ray tube for decreasing the ohmic resistance of the energy consumer with decreasing voltage across the condenser to thereby maintain the voltage across the X-ray tube at a substantially constant value as long as the voltage across the condenser exceeds a given value.

2. An X-ray apparatus comprising an X-ray tube, a condenser for storing energy to be supplied to said tube, means including a supply source for charging said condenser to a predetermined voltage, a grid-controlled discharge tube connected in series between said X-ray tube and condenser and having a cathode, and means to automatically vary the potential difference between the grid and cathode in accordance with the decrease in the condenser voltage to thereby decrease the impedance of said tube to maintain the voltage across the X-ray tube at a substantially constant value as long as the voltage across the condenser exceeds a given value.

3. An X-ray apparatus comprising an X-ray tube, a condenser for storing energy to be supplied to said tube, means including a supply source for charging said condenser to a predetermined voltage, a discharge tube connected in series between said X-ray tube and condenser and having a control grid and a cathode, a grid circuit for said discharge tube including a source of constant voltage connected to raise the potential of the grid, and means associated with said X-ray tube and including a portion of said grid circuit to set up in said circuit a voltage which lowers the potential of the grid and varies in the same sense as the voltage across the X-ray tube.

4. An X-ray apparatus comprising an X-ray tube, a condenser for storing energy to be supplied to said tube, means including a supply source for charging said condenser to a predetermined voltage, a discharge tube connected in series between said condenser and the anode of the X-ray tube and having a control grid and a cathode, a grid circuit for said discharge tube including a source of positive grid bias, and means associated with said circuit to produce therein a source of negative grid bias, said latter means including a potentiometer connected across said X-ray tube.

5. An X-ray apparatus comprising an X-ray tube, a condenser for storing energy to be supplied to said tube, means including a supply source for charging said condenser to a predetermined voltage, a discharge tube connected in series between said X-ray tube and condenser and having a control grid and a cathode, a grid circuit for said discharge tube including said grid and said cathode, a source of constant positive bias and a second source of potential in said grid circuit, means associated with said X-ray tube to set up in said grid circuit an electromotive force derived from the voltage across the X-ray tube and varying therewith in the same sense and negatively biasing the grid, and means to make the latter source operative to further negatively bias the grid to counteract the constant potential source and prevent energization of the X-ray tube by the condenser.

6. An X-ray apparatus comprising an X-ray tube, a condenser for storing energy to be supplied to said tube, means including a supply source for charging said condenser to a prede-

termined voltage, a discharge tube connected in series between said X-ray tube and condenser and having a control grid and a cathode, a grid circuit for said discharge tube including said grid, said cathode and a source of constant positive grid bias, and adjustable means associated with said X-ray tube and said discharge tube to set up in said circuit a negative grid bias which varies in the same sense as the voltage across the X-ray tube.

7. An X-ray apparatus comprising an X-ray tube, a condenser for storing energy to be supplied to said tube, means for charging said condenser to a voltage about double the mean value of the range of voltage to be applied across the X-ray tube and including a supply source whose no-load voltage is substantially the same as said first voltage, a discharge tube connected in series between said X-ray tube and condenser and having a control grid and a cathode, a grid circuit for said discharge tube including said grid, said cathode, and a source of constant positive grid bias, and means associated with said X-ray tube and said circuit to set up in said circuit a source of negative grid bias derived from the voltage across the X-ray tube and varying in the same sense as said latter voltage.

8. An X-ray apparatus comprising an X-ray tube, a condenser for storing the energy to be supplied to said tube, means for charging said condenser to a predetermined voltage including a supply of A. C. voltage and a rectifier tube whose saturation current limits the maximum value of the charging current, a discharge circuit for said condenser and including said X-ray tube and an energy consumer of variable impedance connected in series with said X-ray tube and condenser, and means associated with said energy consumer and connected with said discharge circuit to automatically decrease the impedance of said energy consumer in substantially direct proportion with the decrease in the condenser voltage as long as said latter voltage exceeds a given value.

9. A method of energizing an X-ray tube from a previously-charged condenser comprising the steps of, discharging the condenser through the X-ray tube while absorbing a part of the condenser voltage in an energy consumer of variable ohmic resistance disposed between the X-ray tube and condenser, and decreasing the ohmic resistance of the energy consumer to maintain the voltage across the X-ray tube substantially constant as long as the condenser voltage exceeds a given value.

10. An X-ray apparatus comprising an X-ray tube having a cathode and an anode, a condenser for storing the energy to be supplied to said X-ray tube, means for charging the condenser to a predetermined voltage, a discharge circuit for said condenser and including said X-ray tube and a discharge tube having an anode, a cathode and a control grid, said discharge tube being connected in series with said X-ray tube with the cathode of the discharge tube connected to the anode of the X-ray tube, a resistance connected between the anode and cathode of the X-ray tube and having an adjustable tap, an electrical connection between said tap and said control grid, and a source of positive grid bias in said connection.

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