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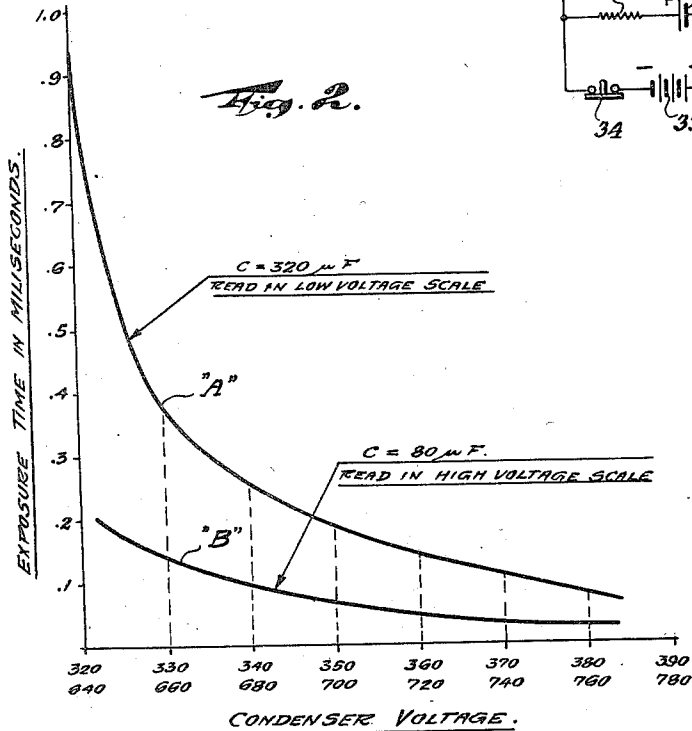
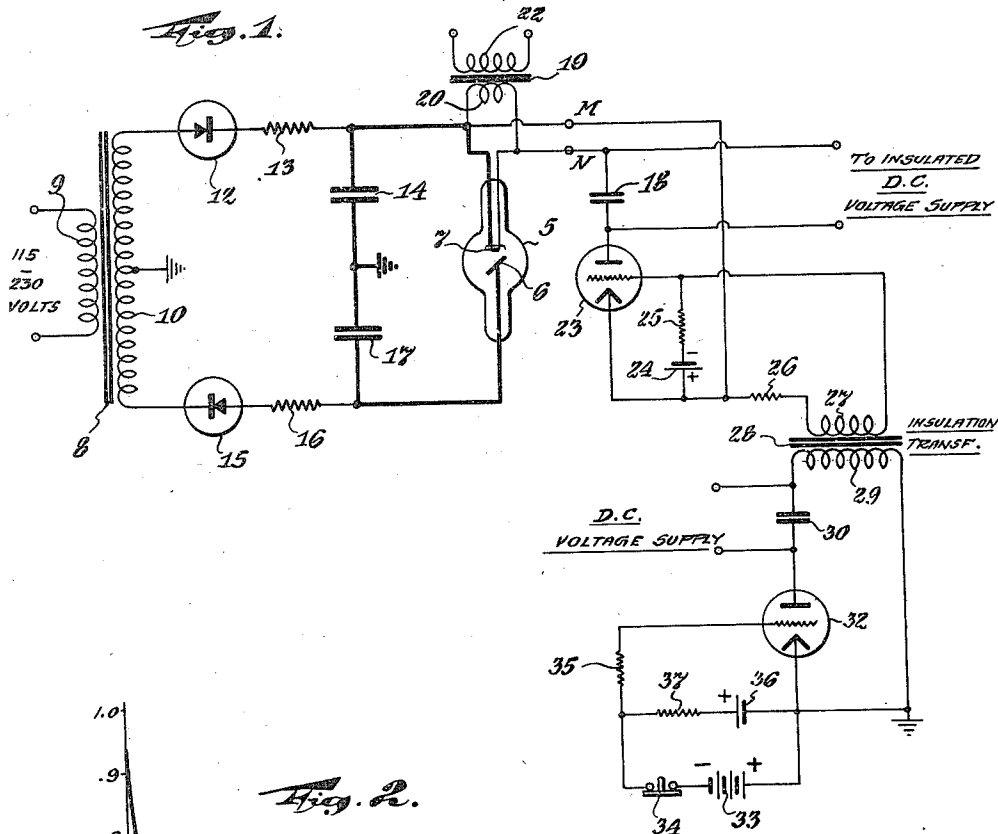
C. M. SLACK ET AL

2,420,845

SHORT EXPOSURE X-RAY APPARATUS

Filed June 15, 1944

2 Sheets-Sheet 1



INVENTORS  
C. M. SLACK,  
L. F. EHRKE.  
BY *gmj new hove*  
ATTORNEY

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2 Sheets-Sheet 2

Fig. 3.

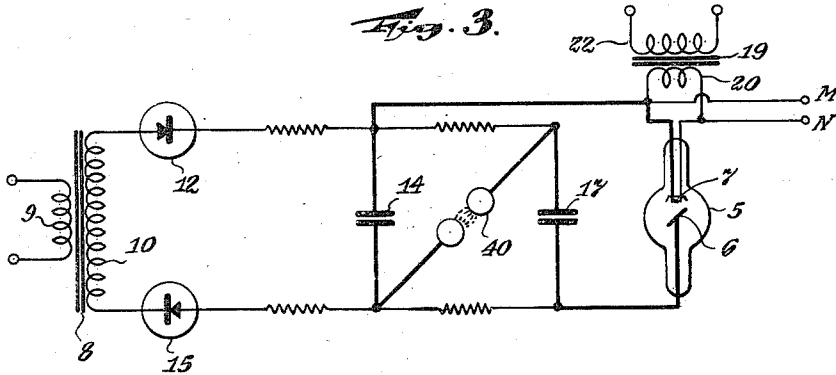


Fig. 4.

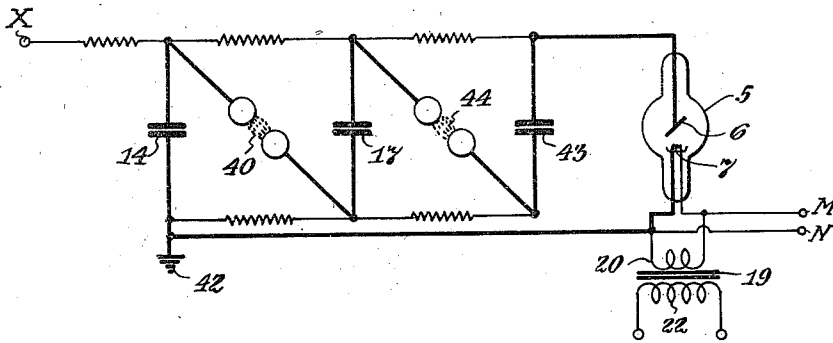


Fig. 5.

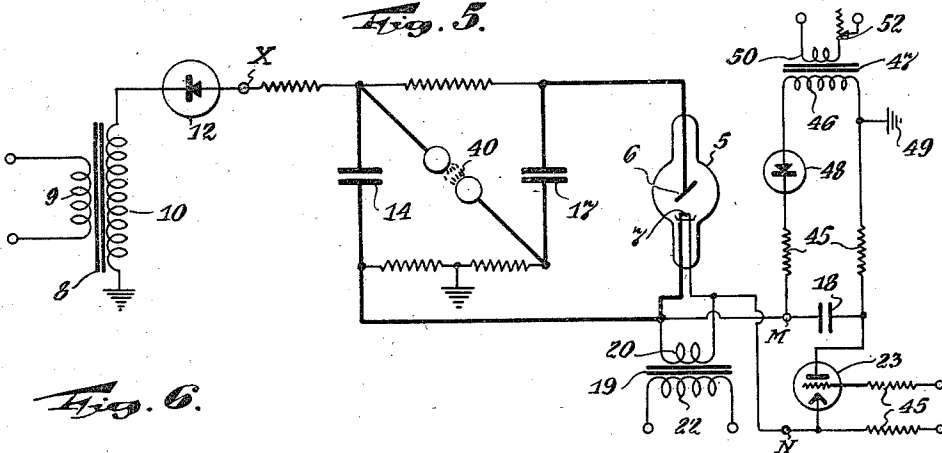
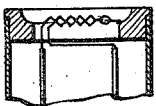


Fig. 6.



INVENTORS  
C. M. SLACK  
L. F. EHKE

BY *J. W. Newbourn*  
ATTORNEY

## UNITED STATES PATENT OFFICE

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## SHORT EXPOSURE X-RAY APPARATUS

Charles M. Slack, Glen Ridge, and Louis F. Ehrke,  
South Orange, N. J., assignors to Westinghouse  
Electric Corporation, East Pittsburgh, Pa., a  
corporation of Pennsylvania

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12 Claims. (Cl. 250—98)

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The present invention relates to X-ray apparatus and more particularly to such apparatus for the making of X-ray photographs in a time range not heretofore practical.

Apparatus for the making of short exposure radiographs is now well known to the art in which the X-ray tube excitation energy is stored in condensers until the making of the radiograph is desired. Some type of switching device, such as a control grid of the X-ray tube, a high voltage trigger tube, or a spark-gap, then operates to cause discharge of the condensers through the X-ray tube thereby energizing the latter.

Although each of the above types of apparatus are subject to certain inherent disadvantages, one common to all is that it is impractical to make an exposure in less than about one one-hundredth of a second because the cathode of the X-ray tube cannot be operated at a temperature high enough to obtain sufficient electron emission without greatly shortening the useful life of the tube. This can be readily appreciated by the fact that a cathode operating at a temperature sufficiently high to carry a current of one ampere would result in an X-ray tube life of only a few hours.

In prior Patent No. 2,311,705, issued February 23, 1943, to Charles M. Slack, one of the present co-inventors, and assigned to the same assignee as the present invention, an X-ray apparatus is shown and claimed for the making of short exposure radiographs wherein the X-ray tube operates on the principle of a field emission arc discharge, so that while the X-ray tube will carry thousands of amperes during an exposure, the electron discharge through the tube which produces the X-rays is uncontrollable, making it impossible with this latter type of apparatus to extend the exposure time much greater than one millionth (.000001) of a second. Moreover, the X-ray tube, as well as the apparatus, must be especially constructed, which is costly.

Yet in modern industry as well as in the medical field, it is becoming more and more important to make radiographs of moving objects such as machinery, conveyor belt carried products to be inspected, and the like, requiring the application of substantial X-ray tube current for periods of time ranging from .01 to .0001 second of exposure, which range could not be obtained with apparatus heretofore known to the art.

It is accordingly an object of the present invention to provide an X-ray apparatus for making radiographic exposures in an exceedingly short

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period of time ranging from .01 to .0001 of a second.

Another object of the present invention is the provision of an X-ray apparatus for making short exposure radiographs ranging from .01 to .0001 of a second in which the X-ray tube filament heating together with the voltage and capacities of the X-ray tube energizing condensers are used to control the exposure.

Another object of the present invention is the provision of an X-ray apparatus for making short exposure radiographs wherein the time period of exposure ranges from .01 to .0001 of a second with control of the X-ray tube being effected by the sudden heating of the filamentary cathode.

Another object of the present invention is the provision of an X-ray apparatus for making short exposure radiographs wherein the X-ray tube excitation energy is supplied by high voltage condensers with discharge thereof through the tube being controlled by the temperature of the filamentary cathode of the X-ray tube which is suddenly raised by discharge of a condenser there-  
through without distortion of the cathode.

Still further objects of the present invention will become obvious to those skilled in the art by reference to the accompanying drawings wherein:

Figure 1 is a diagrammatic illustration of our X-ray apparatus constructed in accordance with the present invention;

Figure 2 is a graphic illustration showing the relationship between exposure time and voltage of the filamentary cathode energizing condenser at different capacities.

Figure 3 is a diagrammatic view similar to Fig. 1 but showing a slight modification which the X-ray tube energizing portion of the apparatus may take;

Figure 4 is a view similar to Fig. 3 but showing another modification of the same portion of the apparatus;

Figure 5 is also a view similar to Fig. 3 but showing a still further modification which the X-ray tube energizing portion of the present X-ray apparatus may take; and

Figure 6 is a partial cross-sectional view showing a modification which the filamentary cathode of the X-ray tube employed with the apparatus of the present invention, may take.

Referring now to the drawings, the X-ray apparatus of the present invention as shown in Fig. 1 comprises an X-ray tube 5 provided with the usual anode 6 and filamentary cathode 7. Energy

for the X-ray tube 5 is shown as supplied by a high voltage transformer 8 having its primary winding 9 connected to a source of electrical energy of the customary potential of 115-230 volts. The high voltage secondary winding 10 is grounded in the center and one end thereof is connected, through a rectifying valve tube 12 and resistance 13, to one plate of a high voltage condenser 14, while the remaining end of the secondary winding is similarly connected, through an oppositely connected rectifying valve tube 15 and resistance 16, to one plate of another condenser 17. Since the remaining plates of the condensers 14 and 17 are grounded as shown, each condenser is charged during one half wave of the alternating current source with the full voltage available across the secondary winding 10. During energization of the X-ray tube 5, these condensers 14 and 17 discharge in series through the X-ray tube in the manner shown by the heavy lines in Fig. 1.

For the purpose of controlling the discharge of the high voltage condensers 14 and 17 through the X-ray tube and thus energization of the latter, the filamentary cathode 7 is arranged to be suddenly heated to an electron emitting temperature by energy received from a condenser 18, which may be made variable, if desired, as hereinafter explained. Although such condenser may be solely employed to supply all of the heating energy for the filamentary cathode 7, it is preferable to heat the same to a temperature just below that where any appreciable electron emission occurs since this enables the amount of energy otherwise required in the condenser 18 to be reduced.

Accordingly, the cathode 7 is shown in Fig. 1 as receiving a limited amount of energy from a low tension insulation heating transformer 19, the secondary winding 20 of which is connected to the filamentary cathode 7, while its primary winding 22 is connected to the same commercial source of supply as the primary winding 9 of the high voltage transformer 8. The condenser 18 is charged to a desired potential from any suitable source of direct current supply as indicated by the legend, which may comprise a rectifying arrangement similar to that shown for charging the condenser 14 and 17 but naturally of a much lower voltage, as will be hereinafter more fully explained. Moreover, the voltage at which the condenser is charged is variable by employing any suitable means, such, for example, as a variable resistance or auto-transformer 52, as shown in Fig. 5.

In the customary operation of an X-ray tube, its filamentary cathode is usually heated from a source of low voltage, i. e. about ten volts or less, which is sufficient to raise and maintain the cathode at an electron emitting temperature. Contrary to supplying the filamentary cathode with a voltage of the usual magnitude of ten volts or less, the voltage momentarily applied thereto, in accordance with the present invention, ranges from several times to several hundred times such voltage, depending upon the time period desired for the exposure and the capacity of the filament-energizing condenser 18, together with the ability of the cathode 7 to resist distortion. Although this voltage is "high voltage" in comparison with that customarily applied to a filamentary cathode, it will be hereinafter referred to as an "intermediate voltage" for the purpose of distinguishing not only from the usual low voltage of ten volts or less, but also to differentiate from the high

voltage supplied by the condensers 14 and 17, which is of the magnitude of many kilovolts.

In order to discharge the condenser 18 when an exposure is desired, a control arrangement is provided, which as shown in Fig. 1 comprises a three electrode tube 23 in series with the discharge circuit of condenser 18, which includes the filamentary cathode 7 of the X-ray tube 5. This tube 23 normally operates to prevent discharge of condenser 18 because of the application of a potential from a source, such as battery 24, through a resistance 25, to the grid electrode of the tube 23, which grid potential is negative with respect to the potential supplied by the battery 24 to the cathode of the tube 23. To reverse the polarity of the grid potential, the grid and cathode of tube 23 are connected through a resistance 26 to the secondary winding 27 of an insulating transformer 28.

Energization of the primary winding 29 of this insulating transformer 28 is obtained from the discharge of a further condenser 30 which includes a trigger tube 32 in the discharge circuit in series with the primary winding 29. The condenser 30 is charged with an unidirectional potential from a suitable source which may comprise a low voltage rectifying arrangement similar to that shown for charging the high voltage condensers 14 and 17 as well as for charging of condenser 18. The trigger tube 32, like the tube 23, normally operates to prevent discharge of the condenser 30 through the primary winding 29. For this operation the grid of this tube 32 is supplied with a biasing potential more negative than the potential supplied to the cathode from a suitable source, such as a battery 33 through a normally closed switch 34 and resistance 35.

When an X-ray exposure is desired and assuming that all the various condensers 14, 17, 18 and 30 have been charged to their respective voltages, the switch 34 is depressed, thus interrupting the supply of biasing potential to the grid of trigger tube 32 from the source 33. This causes a potential to be supplied to the grid of the tube 32 from a further source, such as a battery 36 through a resistance 37, which is more positive than the potential supplied by this same source to the cathode of tube 32. The latter immediately becomes conductive allowing the condenser 30 to discharge its accumulated energy through the primary winding 29 of the insulating transformer 28. The secondary winding 27 is accordingly energized by the impulse of energy passing through the primary winding 29 attendant discharge of the condenser 30.

Energization of this secondary winding 27 thus applies a momentary biasing potential to the grid of trigger tube 23, which is more positive than the potential supplied to the cathode, thus overcoming the biasing potential supplied thereto by the source 24, and making the tube 23 immediately conductive with attendant discharge of condenser 18 through the filamentary cathode 7 of the X-ray tube 5. The temperature of the X-ray tube cathode 7 is thus suddenly raised to a high value depending upon the magnitude of the intermediate voltage supplied with by condenser 18, with ensuing electron emission causing discharge of high voltage condensers 14 and 17 through the X-ray tube 5 and the making of a radiographic exposure.

The length of the exposure is controlled by either changing the capacity or the voltage, and preferably the latter, of the filamentary-cathode-condenser 18. This may be appreciated by ref-

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erence to Fig. 2 wherein the ordinate represents "exposure time in milliseconds" and the abscissa "condenser voltage." Curve A represents a filamentary-cathode-condenser 13 of approximately 320 microfarads capacity in which case the low voltage scale should be read whereas curve B is for a filamentary-cathode-condenser 13 of approximately 80 microfarads and taking the high voltage scale on the abscissa. In each instance, however, it will be noted that the time increases as the voltage decreases. Since the energy in a condenser equals  $\frac{1}{2} CV^2$  the curves A and B have been so plotted that points along the same ordinate represent equal energy discharged into the filamentary cathode and thus very closely the same maximum temperature of the filamentary cathode. From the above formula and the curves A and B, it will become obvious that the higher the voltage V and the lower the corresponding value of the capacity C, the shorter will be the exposure time. Conversely, for the same exposure time, the maximum temperature of the filament will be lower, the higher the value of the voltage V.

Since the temperature of the filamentary cathode naturally controls its electron emission, the total emission thereof does not limit the exposure time of the radiograph since the cooling time of the filamentary cathode is virtually uncontrollable and for any filamentary cathode of reasonable size it is entirely too slow for practical purposes. Consequently the exposure time of the radiograph is determined by the discharge of the high voltage condensers 14 and 17 but under control of the emission temperature of the filamentary cathode 7 as heated by the filament-energizing condenser 18. It is thus apparent that the discharge time of condensers 14 and 17 is controlled by the rate at which the filamentary cathode is heated and by its maximum temperature, or synonymously its electron emissive ability, as above noted, provided the high voltage condensers have not already discharged before the filamentary cathode reaches its maximum temperature.

The capacity and voltage of the filamentary-cathode - energizing - condenser 18 is governed more or less by the filamentary cathode 7. For example, with an ordinary X-ray tube filament as commonly used in present types of X-ray tubes comprising a coil of wire, the latter offers an inductive path to the flow of current and consequently there is an attractive force between the turns or helices which varies as the square of the current, and which tends to distort the filamentary cathode. Tests have shown that with the customary type of filamentary cathode if the voltage is above 500 volts, the filament begins to distort and at 1000 volts this distortion is such that the total life of the tube is only about one hundred exposures with exposure times of .0001 second. If, however, the capacity of the filamentary-cathode-condenser is increased and the voltage applied thereto is kept below this critical value, distortion of the filament is greatly minimized and the life thereof prolonged.

For exposures of short duration ranging from .001 to .0001 second or shorter, it may be desirable for the purpose of increasing filament life to utilize a filamentary cathode structure wherein the magnetic or electrostatic forces applied to the helices are eliminated or at least balanced out so as to avoid possible distortion at high voltage. This may be accomplished in several ways either by stretching the filament to further separate the

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individual loops or helices, by employing alternate loops and V's, or by utilizing a double wound non-inductive loop as shown diagrammatically in Fig. 6 wherein the filamentary cathode 7 is wound back upon itself in a direction opposite to the initial winding.

In order to determine an appropriate cathode, the loss of energy due to radiation in the short period of heating of .001 second is such a small percentage of the energy supplied that it may be neglected in calculations. Accordingly, the maximum temperature rise of the filamentary cathode 7 is dependent only on the energy discharged through it and its heat capacity, without an ensuing distortion, and not appreciably upon the voltage of the filament-energizing-condenser 18 when voltages of the magnitude employed are so many times higher than the voltage normally required to maintain the cathode continuously at an electron emitting temperature. This will become obvious when it is appreciated that the power radiated by the filament at its melting point is less than one percent of the power applied to filamentary cathode at the lowest charging voltage employed.

From the foregoing it becomes obvious to those skilled in the art that an X-ray apparatus for the making of short exposure radiographs is herein provided with range from .01 to .0001 of a second duration, thus covering a range not heretofore practical with prior apparatus. Although the triggering arrangement for suddenly heating the cathode as shown in Fig. 1 is insulated from the high voltage, it is possible to so arrange the apparatus that it operates at or near ground potential, thus dispensing with the necessity for an insulating transformer. Also, the charging circuit for the high voltage condensers can be made so as to charge the same in parallel while they discharge in series through the X-ray tube.

For example, in Fig. 3 a charging circuit for the high voltage condensers 14 and 17 is shown wherein the latter are charged in parallel. Upon suddenly raising the temperature of the cathode in the manner previously explained, these condensers discharge in series, as shown by the heavy lines in Fig. 3, with the voltage of condenser 17 breaking down a spark-gap 40, and the X-ray tube being thus supplied with a voltage higher than that available from the transformer 8 with the total voltage dependent upon the number of condensers employed. The triggering arrangement in this instance is identical to that shown in Fig. 1 and connects to the remaining portion of the apparatus at the points M and N as noted in both Figs. 1 and 3 for purposes of illustration. Such an arrangement has certain advantages over that shown in Fig. 1 in that the high voltage transformer 8 in the circuit of Fig. 3 need only be a fraction of the total voltage required, thus materially reducing size and insulation requirements, and the voltage on the X-ray tube is likewise reduced to a fraction of its total energizing voltage until the discharge of condensers 14 and 17 is initiated.

This circuit arrangement is only applicable to an X-ray apparatus of the type of the present invention wherein the discharge current passed through the X-ray tube is sufficiently large so that the leakage losses through the various resistances are a small portion of the total current, whereas in attempting to apply the circuit to ordinary X-ray tubes emitting milliamperes of current as is customary, the leakage back through the resistances is sufficient to seriously impair

or in fact prevent altogether the production of X-rays. Moreover, one less spark-gap is required than the number of condensers, in lieu of one spark-gap for each condenser as would be normally required with surge generators, since the X-ray tube itself replaces the additional spark-gap because of its triggering action which greatly simplifies the triggering arrangement.

In Fig. 4 a modification of the high voltage portion of the present invention is shown which enables the triggering and filament discharge portions of the circuit to be at or near ground potential and wherein the total excitation voltage for the X-ray tube can be increased as desired by the addition of condensers. Inasmuch as the point X as shown in Fig. 4 corresponds to the same point X in Fig. 5, reference may be had to this latter figure for the charging of the condensers. It should accordingly suffice to say that since one end of the high voltage secondary winding of the energizing transformer is grounded, as are the various condensers and the filamentary cathode 7 at the point 42, the condensers 14, 17 and the additional condenser 43 are charged in parallel during one half wave of the alternating current cycle, and discharge in series in the same manner as in Fig. 3. When the temperature of the filamentary cathode is suddenly raised by the triggering portion as previously explained, and which connects at the points M and N in Fig. 3 in the same manner as shown in Fig. 1, the condensers 14, 17 and 43 all discharge in series through the X-ray tube 5, as shown by the heavy lines in Fig. 4, with the spark-gaps 40 and 44 breaking down simultaneously with the X-ray tube becoming conductive. The various resistances show present discharge of the condensers from imposing an inverse potential upon the secondary winding 10 of transformer 8 by auto-emission through valve tube 12, and also prevent the pulsating D. C. source supplied through the valve tube 12 in the forward direction from being supplied to the X-ray tube as the voltage of the condensers falls to a low value. Since the cathode 7 is at ground potential, the triggering arrangement likewise is at the same potential, thus eliminating the necessity for an insulating transformer 28 as shown in Fig. 1.

In the modification of Fig. 5 the X-ray tube is at high potential during the discharge of condensers 14 and 17, but the triggering arrangement is at low voltage, except during the actual period of discharge of the high voltage condensers, enabling the various resistances 45 to protect the otherwise vulnerable parts of the circuit and thus eliminating the necessity for an insulating transformer, such as the transformer 28 of Fig. 1. Also, it will be noted that one end of the high voltage secondary winding 10 of transformer 8 is grounded and only one rectifying valve tube 12 is employed as previously mentioned in connection with the modification of Fig. 4.

As shown in Fig. 5, the filamentary energizing condenser 18 is charged from the secondary winding 46 of a transformer 47 through a rectifying valve 48 and the resistances 45, with the secondary winding being grounded at 49. The primary winding 50 is connected to a suitable source of the customary commercial potential through an adjustable resistance or an autotransformer 52, for the purpose of varying the charging potential of the condenser 18, as previously mentioned. This accordingly enables the trigger tube 23 to be operated at low voltage, using the same arrangement on Fig. 1, except that the in-

sulating transformer 28 may be entirely dispensed with, thus causing the condenser 39 (Fig. 1) to discharge and change the biasing potential on the grid, in the same manner as the impulse of energy from the secondary winding 27 of the insulating transformer 28, as previously described.

It thus becomes obvious to those skilled in the art that an X-ray apparatus for the making of short exposure radiographs is herein provided and in which the duration of the exposure ranges from .01 to .0001 second, thus utilizing a time range not heretofore possible to employ. Moreover, energization of the X-ray tube is obtained from energy storage means, such as a condenser, with control of the discharge thereof being effected by suddenly raising the X-ray tube cathode to an electron emitting temperature, thereby controlling the exposure time by the rate at which the X-ray tube cathode is heated and by its maximum temperature, thus regulating the time of discharging of the high voltage energizing condensers.

Although several specific embodiments of the present invention have been shown and described, it is to be understood that still further modifications thereof may be made without departing from the spirit and scope of the appended claims.

We claim:

1. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy for energizing said X-ray tube, means for applying a voltage to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, and means to suddenly energize said filamentary cathode by superimposing a higher voltage thereon to suddenly raise said filamentary cathode to an electron emitting temperature to cause energization of said X-ray tube by said high potential source.
2. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy including energy storage means adapted to discharge its accumulated energy through said X-ray tube, means for applying a voltage to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, and means to suddenly energize said filamentary cathode by superimposing a higher voltage thereon to suddenly raise said filamentary cathode to an electron emitting temperature to cause discharge of said energy storage means with attendant energization of said X-ray tube.
3. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy including energy storage means adapted to discharge its accumulated energy through said X-ray tube, means for applying a voltage to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, and means to suddenly energize said filamentary cathode including energy storage means for momentarily superimposing a higher voltage on said filamentary cathode to suddenly raise the latter to an electron emitting temperature to cause discharge of said high voltage energy storage means with attendant energization of said X-ray tube.
4. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube

provided with an anode and a filamentary cathode, a source of high potential electrical energy including energy storage means adapted to discharge its accumulated energy through said X-ray tube, a source of energy connected to said filamentary cathode to preheat the same to a temperature below that of electron emissivities, a source of electrical energy adapted to be suddenly supplied to said filamentary cathode including energy storage means for momentarily superimposing a higher voltage on said filamentary cathode to suddenly raise the latter to an electron emitting temperature with attendant discharge of said high potential energy storage means and energization of said X-ray tube, and means interposed between said filamentary cathode and said last mentioned energy storage means and operable at will to cause the latter to suddenly energize said filamentary cathode.

5. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy adapted to energize said X-ray tube for a predetermined period of time including energy storage means adapted to discharge its accumulated energy through said X-ray tube, a source of energy connected to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, means for controlling the period of energization of said X-ray tube by said high potential source comprising a source of electrical energy adapted to be suddenly supplied to said filamentary cathode including energy storage means for momentarily superimposing a higher voltage on said filamentary cathode to suddenly raise the latter to an electron emitting temperature with attendant discharge of said high potential energy storage means and energization of said X-ray tube for a period of time dependent upon the rapidity with which the temperature of said filamentary cathode is raised sufficient to obtain the total required electron emission for the desired exposure, and a control tube interposed between said filamentary cathode and said last mentioned energy storage means and operable at will to cause the latter to suddenly energize said filamentary cathode.

6. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy adapted to energize said X-ray tube for a predetermined period of time including energy storage means adapted to discharge its accumulated energy through said X-ray tube, a source of energy connected to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, means for controlling the period of energization of said X-ray tube by said high potential source comprising a source of electrical energy adapted to be suddenly supplied to said filamentary cathode including a condenser charged at various preselected potentials and operable to momentarily superimposing a higher voltage on said filamentary cathode to suddenly raise the latter to an electron emitting temperature determinable by the potential supplied thereto by said condenser to cause discharge of said high potential energy storage means and energization of said X-ray tube for a period of time dependent upon the rapidity with which the temperature of said filamentary cathode is raised sufficient to obtain the total required electron emission for the desired exposure, and a control

tube interposed between said filamentary cathode and said condenser and operable at will to cause the latter to suddenly energize said filamentary cathode.

7. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy adapted to energize said X-ray tube for a predetermined period of time including energy storage means adapted to discharge its accumulated energy through said X-ray tube, a source of energy connected to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, means for controlling the period of energization of said X-ray tube by said high potential source comprising a source of electrical energy adapted to be suddenly supplied to said filamentary cathode including a condenser of variable capacity and operable to momentarily superimposing a higher voltage on said filamentary cathode to suddenly raise the latter to an electron emitting temperature determinable by the capacity to which the condenser is previously adjusted to cause discharge of said high potential energy storage means and energization of said X-ray tube for a period of time dependent upon the rapidity with which the temperature of said filamentary cathode is raised, sufficient to obtain the total required electron emission for the desired exposure, and a control tube interposed between said filamentary cathode and said condenser and operable at will to cause the latter to suddenly energize said filamentary cathode.

8. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy adapted to energize said X-ray tube for a predetermined period of time including energy storage means adapted to discharge its accumulated energy through said X-ray tube, a source of energy connected to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, means for controlling the period of energization of said X-ray tube by said high potential source comprising a source of electrical energy adapted to be suddenly supplied to said filamentary cathode including energy storage means for momentarily superimposing a higher voltage on said filamentary cathode to suddenly raise the latter to an electron emitting temperature with attendant discharge of said high potential energy storage means and energization of said X-ray tube for a period of time dependent upon the rapidity with which the temperature of said filamentary cathode is raised sufficient to obtain the total required electron emission for the desired exposure, and a control arrangement operable at will to cause said last mentioned energy storage means to suddenly energize said filamentary cathode comprising a three element discharge device having its output electrodes in circuit with said last mentioned energy storage means and said filamentary cathode, a source of energy connected to the control electrode of said three element discharge device for normally applying a biasing potential thereto to render said tube non-conducting, and a switch operable to cause an alteration of the biasing potential applied to the control electrode of said three element discharge device to cause the latter to become conductive with attendant sudden energization of said filamentary cathode by said last mentioned energy storage means.

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9. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy for energizing said X-ray tube including a high voltage transformer and energy storage means chargeable by said transformer in electrical parallel with each other and adapted to discharge in series through said X-ray tube to supply the latter with a voltage higher than that available from the transformer, means for applying a voltage to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, and means operable to cause the sudden discharge of said energy storage means through said X-ray tube.

10. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy for energizing said X-ray tube including a high voltage transformer and energy storage means chargeable by said transformer in electrical parallel with each other and adapted to discharge in series through said X-ray tube to supply the latter with a voltage higher than that available from the transformer, a source of energy connected to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, a source of electrical energy adapted to be suddenly supplied to said filamentary cathode including energy storage means for momentarily superimposing a higher voltage on said filamentary cathode to suddenly raise the latter to an electron emitting temperature with attendant discharge of said high voltage energy storage means and energization of said X-ray tube, and means operable at will to cause the sudden discharge of said last mentioned energy storage means through said X-ray tube.

11. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy for energizing said X-ray tube including a high voltage transformer and a plurality of condensers chargeable by said transformer in electrical parallel

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with each other and adapted to discharge in series through said X-ray tube to supply the latter with a voltage higher than that available from the transformer, at least one less spark-gap than the total number of condensers and included in the series discharge circuit of the latter, means for applying a voltage to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, and means operable at will to cause the sudden heating of said cathode to electron emissivity and the discharge of said condensers through said X-ray tube with attendant energization of the latter.

12. An X-ray apparatus for making short exposure radiographs comprising an X-ray tube provided with an anode and a filamentary cathode, a source of high potential electrical energy for energizing said X-ray tube including a high voltage transformer and a plurality of condensers chargeable by said transformer in electrical parallel with each other and adapted to discharge in series through said X-ray tube to supply the latter with a voltage higher than that available from said transformer, a ground connection for said transformer, said condensers and said filamentary cathode, to reduce the insulation requirements of said apparatus, means for applying a voltage to said filamentary cathode to preheat the same to a temperature below that of electron emissivity, and means having a portion thereof at ground potential and operable at will to cause the sudden heating of said cathode to electron emissivity and the discharge of said condensers through said X-ray tube with attendant energization thereof.

CHARLES M. SLACK.  
LOUIS F. EHRKE.

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