

Sept. 13, 1938.

A. BOUWERS

2,129,646

X-RAY APPARATUS

Filed Nov. 22, 1935

2 Sheets-Sheet 1

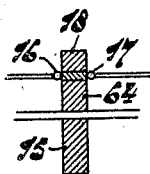
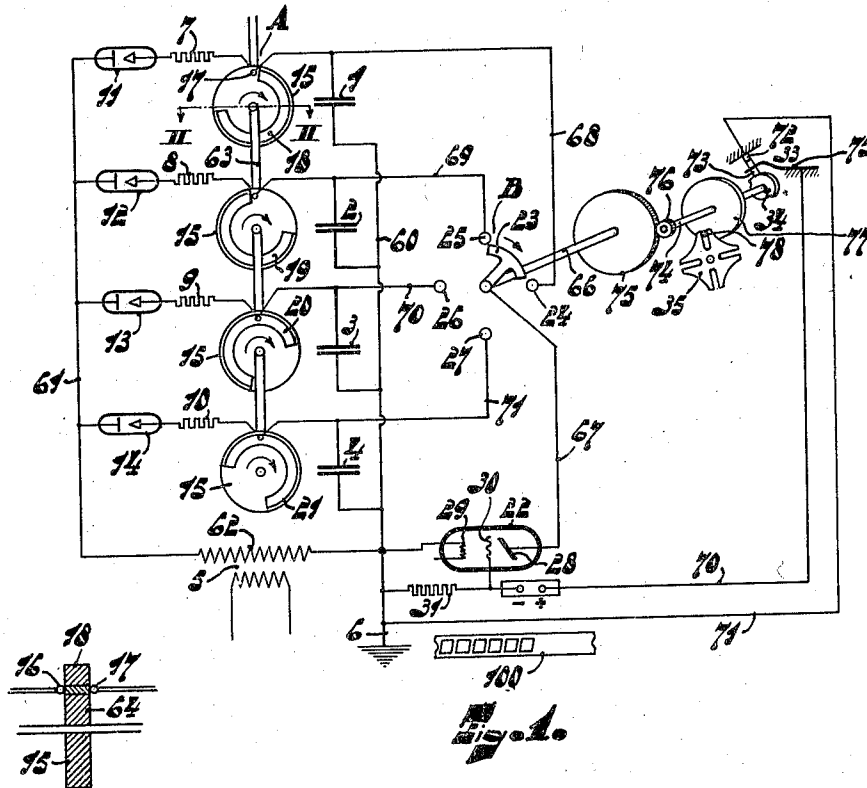


Fig. 2.

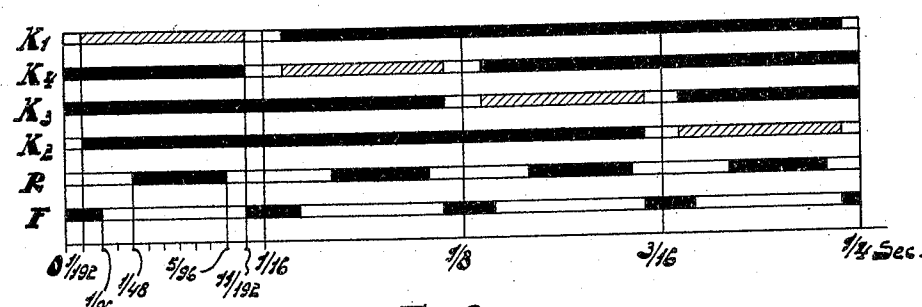


Fig. 3.

INVENTOR
ALBERT BOUWERS

BY *Albert B. Bouwers*
ATTORNEY

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2 Sheets-Sheet 2

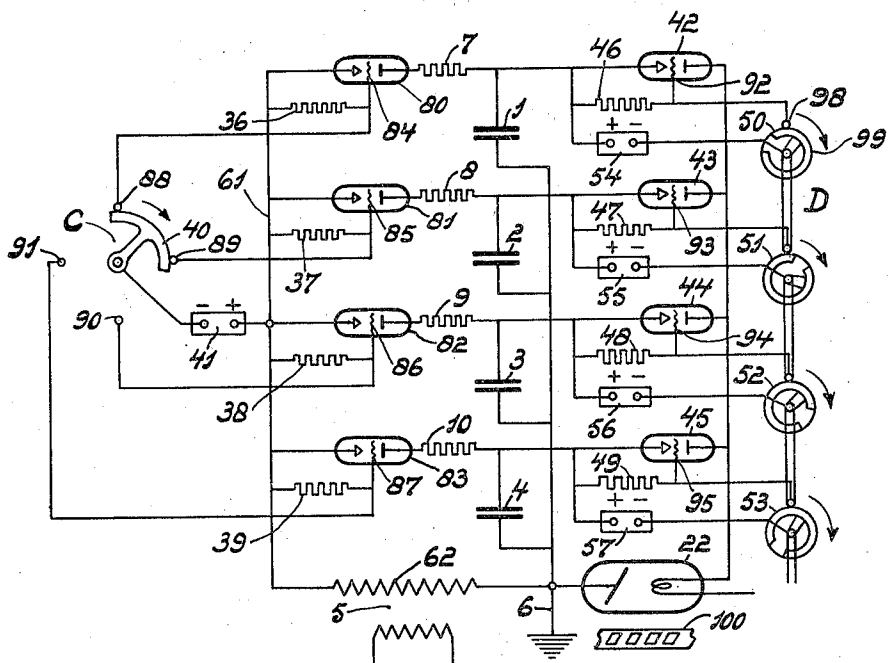


Fig. 4.

INVENTOR

ALBERT BOUWERS

BY

Edw. B. Kennan.

ATTORNEY

UNITED STATES PATENT OFFICE

2,129,646

X-RAY APPARATUS

Albert Bouwers, Eindhoven, Netherlands, assignor to N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands

Application November 22, 1935, Serial No. 51,167
In Germany December 6, 1934

11 Claims. (Cl. 250—34)

My invention relates to X-ray apparatus, and more particularly to X-ray apparatus for making series exposures.

In apparatus for taking instantaneous X-ray exposures, it is known to use a condenser as a source of operating current for the X-ray tube. Such a condenser is charged prior to the exposure over a period of time which is long relative to the exposure time and at a rate which is very low relative to the rate at which the condenser is discharged.

However, when using such a current source for taking series exposures, in which the exposures must be taken in rapid succession, for instance in cinematographic or stereoscopic exposures, the comparatively long charging time required is very disadvantageous in that the exposures can not be taken in rapid succession.

In accordance with my invention, the above drawback is eliminated by using a plurality of condensers which are successively discharged through the X-ray tube to make the separate exposures. Thus in taking a series of exposures in which the exposure time is half the total operating time, the condensers do not have to be charged in half the operating time, but the total operating time may be utilized for this purpose. Evidently a single condenser would be of no advantage in such case as the time available for the charging would not exceed the discharge time.

In accordance with the invention, each condenser after being discharged is immediately connected to a common charging current source whereby the condensers are charged with regularly overlapping charging times.

As the condensers are connected partially in parallel with a common charging-current source and may be at widely different states of charge, I provide in the high-tension charging circuit of each condenser a balancing resistance for the purpose of taking up the potential difference between the charging current source and the condenser. Furthermore, to prevent back discharge from one condenser through the other condensers, I prefer to provide each condenser with an individual rectifier connected in series therewith.

In order that my invention may be clearly understood and readily carried into effect, I shall describe same more fully in connection with the accompanying drawings, in which:

Figure 1 is a schematic diagram, partly in perspective, of an apparatus according to the invention;

Fig. 2 is a sectional view taken along line 2—2 of Figure 1;

Fig. 3 is a timing diagram for use in explaining the operation of the apparatus shown in Figure 1;

Fig. 4 is a schematic diagram showing another embodiment of the invention.

The apparatus shown in Figure 1 is used for taking a series of X-ray exposures on a film 100, and comprises four condensers 1, 2, 3, and 4 charged from a transformer 5 and serving as current supply sources for an X-ray tube 22 having a cathode 29, an anode 28, and a control electrode 30. While four condensers are shown in the figure and the invention will be described in connection therewith, it should be understood that two or more condensers may be used.

One electrode of each of condensers 1, 2, 3, and 4 is connected through a conductor 60 to ground at 6 and to one end of a secondary winding 62 of the supply transformer 5, whose primary winding is connected to a suitable alternating current source (not shown). The other electrode of the condensers is connected through a switching device A (later to be described), resistances 7, 8, 9, and 10 respectively, rectifiers 11, 12, 13, and 14 respectively, and a conductor 61 to the other end of the secondary winding 62.

Thus the condensers are connected partially in parallel and are charged with rectified current supplied from the transformer 5. The charging circuit of condenser 1, for example, includes the secondary winding 62, conductor 61, rectifier 11, resistor 7, switching device A, condenser 1, and back through conductor 60 to the other side of the secondary winding 62. The condensers 2, 3, and 4 are charged from transformer 5 through similar charging circuits.

The switching device A, which controls the charging of condensers, consists of four discs 15 mounted on a common shaft 63; however they may be separately mounted so as to rotate in synchronism. As shown more clearly in Fig. 2, each of the discs 15—which are of identical construction—consists of a circular plate 64 of insulating material containing a sector 18 of conductive material, which sector connects stationary contacts 16 and 17 during a portion of each revolution to establish the charging circuits of the condensers 1, 2, 3, and 4 for a predetermined period of time. The sectors 18 extend through an angle of slightly less than 270°, and the discs are so mounted on the shaft 63 that the center lines of successive sectors form an angle of 90° with each other. Thus, in the position shown, the charging circuits of condensers 3 and 4 are closed, whereas the charging circuits of condenser 1 has just been

interrupted, and the charging circuit of condenser 2 is about to be closed.

Mounted on a shaft 66 rotating in synchronism with the shaft 63 or forming a part thereof, is a contact arm 23 of a switching device B having stationary contacts 24, 27, 26, and 25 connected by conductors 68, 71, 70, and 69 respectively to one electrode of the condensers 1, 4, 3, and 2 respectively. The arm 23 is connected through a conductor 67 to the anode 28 and co-operates with the stationary contacts 24, 27, 26, and 25 to connect the charged condensers to the X-ray tube. The discharge circuits of the condensers are similar and in the case of condenser 1 includes the conductor 68, stationary contact 24, arm 23, conductor 67, anode 28, cathode 29, and back through conductor 60 to the other electrode of the condenser.

The sector portion of the arm 23 is less than 90°, whereby during each revolution of shaft 66 (and also shaft 63), each condenser is connected to the X-ray tube for less than one-fourth the time of one revolution. As shown, none of the condensers is connected to the X-ray tube; however upon clockwise rotation of shaft 66, condenser 1 is first connected, then condensers 4, 3, and 2 in succession.

The synchronously-rotating switching devices A and B run in time relation to a driving mechanism for driving the exposure film 100, whereby discs 15 periodically interrupt the charging circuits of the condensers for a definite length of time, and while the charging circuit of a condenser is interrupted, the switching device B establishes the discharging circuit of this condenser, this operation being successively carried out for all the condensers. The exposure film 100 remains stationary in the cone of X-rays of the X-ray tube 22 only during that period of time in which the discharge circuit is established by the switching device B. As switching devices of the type illustrated for device A have the disadvantage that flash-over may cause the current to flow in the charging circuits before the contacts 16 and 17 make contact with the sector 18 (see Fig. 2), I prefer to use switching devices which are more suitable for use in high-tension circuits, for instance vacuum switches or relays constructed in accordance with the U. S. Patent No. 1,946,324 to Alfred Kuntke. The actuation current of such relays may be controlled by switches operating in time relation to the film mechanism; for example, switches similar to device A, but of smaller dimensions.

Although switching devices of the construction shown for device B may be used for controlling the discharge circuits of the condensers, such devices have the drawback that flash-over may occur between the stationary contacts and the arm. Thus, also, in this case it is preferable to use switches which are more suitable for making high-voltage connections.

When it is desired to obtain a substantially constant operating voltage across the X-ray tube during the exposure by using only a portion of the condenser discharge, the switching device B must also be capable of breaking the high-tension. Although vacuum switches may be used for this purpose, I prefer to provide an additional switch to control the operating current of the X-ray tube either directly or by means of relay action. Such a switch establishes, while the exposure film is stationary in the cone of the X-rays, the discharge current of that condenser

which has already been connected into the circuit of the X-ray tube.

As shown in Figure 1, the X-ray tube is connected into the discharge circuits by relay action. For this purpose the control electrode 30 is connected through a resistance 31 to the cathode 29 and to the negative terminal of a direct voltage bias 32, for instance a battery or a charged condenser, whose positive terminal is connected through conductor 70, switch 33, and conductor 71 to ground at 6. Thus, with switch 33 closed as shown, the control electrode 30 is negatively biased in respect to the cathode 29 and the passage of electrons through the X-ray tube is prevented, whereas when switch 33 is open the control electrode 30 assumes the potential of cathode 29 and the X-ray tube becomes conductive. Such a method of establishing the current flow in an X-ray tube, as well as similar arrangements, are well known in the art.

Instead of providing a control electrode in the X-ray tube I may provide in series with the X-ray tube an electric valve having a control electrode.

The switch 33 consists of a stationary contact 72 connected to conductor 71, and a movable contact 73 mounted on a leaf spring 75 and connected therethrough to conductor 70. The contact 73 is actuated by a cam 34 insulatingly secured to a shaft 74. The shaft 74 is driven from shaft 66 by spur gears 75 and 76 fixedly secured on shafts 66 and 74 respectively; the relation of the rotational speeds of shafts 74 and 66 being equal to the ratio of the number of condensers used to 1—in the present instance 4 to 1.

Fixedly mounted on shaft 74 is a disc 77 provided with a pin 78 cooperating with a star wheel 35, whereby the star wheel is turned through about 90° during each revolution of shaft 74. The star wheel 35, in known manner, forms part of the driving mechanism for intermittently moving the film 100 past the window of the X-ray tube so as to be exposed only during the time at which it is stationary. In the position of the star wheel as shown, the film 100 is being moved and has traversed about 1/2 the distance between the preceding and succeeding exposure. Such arrangements for driving the film are well known in the art, and are described for example in U. S. Patent #1,184,126 to Power.

As shown, contacts 72 and 73 are closed and control electrode 30 is negatively biased. When shaft 74 has rotated counterclockwise about 30°, arm 23 cooperates with contact 24 to connect the charged condenser 1 across the X-ray tube; however, condenser 1 cannot discharge through the X-ray tube as the contacts 72 and 73 remain closed and the X-ray tube is nonconductive.

After the shaft 74 has rotated through about 120° (arm 23 in the meanwhile passing through about 30°), the contacts 72 and 73 break and the negative bias is removed from the control electrode 30, whereby condenser 1 discharges through the X-ray tube. During this movement of shaft 74 the pin 78 has moved the star wheel 35 to place the film in the X-ray cone; this action requiring a 60° rotation of shaft 74, beyond the position shown in Fig. 1, and a 90° rotation in total. The time during which the contacts 72 and 73 are disconnected may be readily given any desired value by changing the shape of the cam 34.

The sequential operation of the apparatus of Figure 1 will be more fully explained with reference to the timing diagram of Fig. 3, which

represents the taking of sixteen partial exposures per second. The ordinates represent time in seconds, whereas the strips K₁, K₄, K₃ and K₂, indicate the condition of the condensers 1, 4, 3, and 2 respectively; strip R indicates the condition of the X-ray tube, and strip F indicates the state of motion of the film.

In the strips K₁, K₄, K₃, and K₂ the darkened portions indicate that the condensers are being charged, whereas the hatched portions indicate that the condensers are connected to the X-ray tube.

In strip R the darkened portions indicate that the condenser is discharging through the X-ray tube. In strip F the darkened portions indicate that the film is being moved, and the remaining portions indicate that the film is stationary.

At zero time the apparatus has the condition shown in Figure 1. Condenser 1 is in its charged condition, condensers 3 and 4 are being charged, and condenser 2 is discharged. The switch 33 being closed, the X-ray tube as represented by R is nonconductive and the film as indicated by F is being moved.

After $\frac{1}{192}$ of a second, condenser 1 is connected across the X-ray tube, the charging of condenser 2 is initiated, while condensers 3 and 4 are still being charged.

After $\frac{1}{96}$ of a second the film comes to rest in the cone of X-rays which will afterwards be produced, and after $\frac{1}{48}$ of a second, switch 33 is opened, the X-ray becomes conductive, and condenser 1 starts to discharge through the X-ray tube.

After $\frac{5}{96}$ of a second the discharging of condenser 1 through the X-ray tube is interrupted by the closure of switch 33, and after $\frac{11}{192}$ of a second the condenser 1 is disconnected from the X-ray tube and the charging circuit of condenser 4 is interrupted; the charging of condensers 3 and 2 continuing. At the same time the movement of the film is initiated.

After $\frac{1}{48}$ of a second the exposure has been taken and the cycle repeats with the exception, however, that the condensers are interchanged; that is, condenser 4 will discharge in the next cycle, whereas condenser 1 will begin to be charged, and condensers 3 and 2 will continue their charging.

From Fig. 3 it is seen that condensers 1, 2, 3, and 4 are in different states of charge at the same time, and therefore have different voltages; however resistances 7, 8, 9, and 10 serve to balance this potential difference. Also, by using a separate rectifier in each charging circuit there is no possibility of one condenser discharging back through a condenser of a lower voltage.

The transformer 5 should preferably have a low voltage-drop in order that a plurality of condensers may be charged at the same time without the charge being retarded when an additional discharged condenser is connected to the transformer.

Due to the successive connecting-in of discharged condensers, the transformer supplies a pulsating current whose amplitude is increased every 16th of a second. However, with the use of sufficiently high resistances 7, 8, 9, and 10, the amplitude never becomes zero as at least two condensers are always being charged.

The time during which a discharge current of considerable strength flows depends upon the resistance of the X-ray tube and on the capacity and operating voltage of the condenser. In any case, however, the form factor of the transformer

current is substantially lower than that of the X-ray tube current, i. e., the power requirement of the transformer is substantially lower than the power used for the exposures.

It is not necessary to directly make and break the charging circuits of the condensers with high-tension switching devices of the type shown in Fig. 1 and for this purpose discharge tubes having control electrodes may be used. With such discharge tubes, the switches running in time relation to the film-driving mechanism vary the potential of the control electrodes.

Furthermore, a discharge relay may be used in the discharge circuit of each condenser, which relays are made conductive in succession by means of a switching device. By using such discharge relays in the discharge circuits, the auxiliary electrode of the X-ray tube, as well as the switching device 33, may be dispensed with. When using such discharge tubes between the condensers and X-ray tubes, the control electrodes are rendered sufficiently positive at the moment at which the partial exposure is to be made, whereby the discharge tubes become conductive. As discharge tubes, gas-filled, incandescent cathode tubes are preferably used.

In Fig. 4, which illustrates the use of discharge relays in the charging and discharging circuits of the condensers, similar parts are given similar numbers to those of Figure 1. In Fig. 4 the switching device A is replaced by discharge tubes 80, 81, 82 and 83 having control electrodes 84, 85, 86, and 87 connected to contacts 88, 89, 90, and 91 respectively of a switching device C and through resistances 36, 37, 38, and 39 respectively to the supply conductors 61.

The switching device C is provided with an arm 40 of conductive material, which arm is connected to the negative terminal of a direct current bias 41, for example a battery or a charged condenser, whose positive terminal is connected to the conductor 61. Thus the control electrode 84, 85, 86, and 87 are periodically and successively connected by arm 40 to the negative terminal of bias 41, whereby the charging circuits are interrupted.

With the apparatus in the position shown in Fig. 4, electrodes 84 and 85 have a negative bias in respect to the cathodes and the tubes 80 and 81 are nonconductive. In other respects the charging of the condensers takes place in the same manner as described in Figure 1, and further detailed description is believed unnecessary.

For controlling the discharge of the condensers through the X-ray tube, discharge tubes 42, 43, 44, and 45 having control electrodes 92, 93, 94, and 95 respectively, are used.

The control electrode 92 of tube 42 is connected through a resistance 46 to the cathode of tube 42 and also to the positive terminal of a biasing voltage 54, for example a battery or a charged condenser. The electrode 92 is also connected to a stationary contact 98 of a commutator switch 50 of a switching device D whose commutator segment 99 is connected to the negative pole of biasing voltage 54. Thus the commutator switch 50 controls the conductivity of the discharge tube 42 and the discharge current of condenser 1 through the X-ray tube 22. The conductivity of tubes 43, 44, and 45, and thus the discharging of condensers 2, 3, and 4 respectively, are controlled in a similar manner by means of commutator switches 51, 52, and 53.

The construction of switches 50, 51, 52, and 53 may be similar to that of switching device A

described in connection with Figure 1; however other constructions may be used, for example cam-operated switches similar to switch 33 of Figure 1. In any case, however, switches 50, 51, 52, and 53 serve to interrupt one of the negative bias circuits, every 16th of a second to allow the particular condenser to discharge through the X-ray tube.

The condensers may be charged from a transformer having a higher no-load voltage than the operating voltage, as has been described in my copending U. S. patent application Ser. No. 51,166, now Patent #2,102,883. In this case, however, the resistances in the charging circuits of the condensers must be sufficiently large to allow the charging circuits to be interrupted when the condenser voltage has reached the operating voltage of the transformer. Furthermore, for controlling the charging circuits in this case, a switching device capable of operating without sparking must be used, for instance the discharge relays shown in Fig. 4.

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

What I claim is:

1. An apparatus for taking series X-ray exposures, comprising an X-ray tube, a plurality of condensers, means for charging said condensers with overlapping charging times, and means for discharging the condensers directly through said X-ray tube one after the other and with independent and non-overlapping discharge periods.

2. In an apparatus for taking series X-ray exposures by means of a single X-ray tube, a source of operating current for the X-ray tube comprising a plurality of condensers, means for charging said condensers with overlapping charging times, and means for discharging said condensers directly through said X-ray tube one after the other with independent and non-overlapping discharge periods.

3. An apparatus for taking series X-ray exposures, comprising an X-ray tube, a plurality of condensers, means for independently charging said condensers over successively-starting and regularly occurring and overlapping charging times, and means for discharging the charged condensers through said X-ray tube one after the other and with non-overlapping discharge periods.

4. An apparatus for taking series X-ray exposures, comprising an X-ray tube, a source of operating current for said tube comprising a plurality of condensers, means for successively discharging the condensers through said X-ray tube, and means including a common charging-current source to initiate the charging of said condensers immediately after their discharge and to charge same over regularly overlapping charging times.

5. An apparatus for taking series X-ray exposures, comprising an X-ray tube, a plurality of condensers, means for successively discharging said condensers through said X-ray tube, and means for charging said condensers immediately after their discharge and over regularly overlapping charging times, said last means comprising a common current supply source, and a plurality of resistances each connected in series with one of said condensers.

6. An apparatus for taking series X-ray ex-

posures, comprising an X-ray tube, an operating-current supply for said tube comprising a plurality of condensers, means for successively discharging said condensers through said X-ray tube, and means for charging said condensers immediately after their discharge and over regularly-occurring and overlapping charging times, said latter means comprising an alternating current supply source, and a plurality of rectifiers each connected in series with one of said condensers.

7. An apparatus for taking series X-ray exposures, comprising an X-ray tube, a film, a driving mechanism for intermittently driving said film through the cone of X-rays of said tube, a charging circuit for said condensers including a common current supply source, a discharge circuit for said condensers including said X-ray tube, and two switching devices operating in time relationship with said driving mechanism to control the charging and discharging of said condensers in a predetermined sequence, one of said devices periodically interrupting said charging circuit for predetermined time intervals and the second device establishing the discharge circuit when the charging circuit is interrupted, said film being stationary in the cone of X-rays while said discharge circuit is conductive.

8. An X-ray apparatus for taking series X-ray exposures, comprising an X-ray tube, a film, means for intermittently driving said film through the cone of X-rays of said tube, a plurality of condensers, a charging circuit for said condensers including a common source of charging current, a discharge circuit for said condensers including said X-ray tube, two switching devices operating in time relationship with said driving mechanism, one of said devices periodically interrupting said charging circuit for predetermined time intervals, the other device successively connecting said condensers in the discharge circuit, and switching means to establish the discharge current of the condenser connected in the discharge circuit while said film is at rest.

9. An X-ray apparatus for taking series X-ray exposures, comprising an X-ray tube, a film, means for intermittently driving said film through the cone of X-rays of said tube, a plurality of condensers, a charging circuit for said condensers including a common source of charging current, a discharge circuit for said condensers including said X-ray tube, two switching devices operating in time relationship with said driving mechanism, one of said devices periodically interrupting said charging circuit for predetermined time intervals, the other device successively connecting said condensers in the discharge circuit, and a switch connected in series with said X-ray tube to establish the discharge current of the condenser connected in the discharge circuit while said film is at rest.

10. An apparatus for taking series X-ray exposures, comprising an X-ray tube, a film, a driving mechanism for intermittently driving said film through the cone of X-rays of said tube, a charging circuit for said condensers including a common current supply source, a discharge circuit for said condensers including said X-ray tube, and two switching devices operating in time relationship with said driving mechanism to control the charging and discharging of said condensers in a predetermined sequence, one of said devices periodically interrupting said charging circuit for predetermined time intervals, the second device establishing the discharge circuit

when the charging circuit is interrupted, at least one of said devices being a discharge relay having a periodically varied control electrode potential.

- 5 11. An apparatus for taking series X-ray exposures, comprising an X-ray tube, an operating current supply for said tube comprising a plurality of condensers, means for successively discharging said condensers through said X-ray

tube, and means for charging said condensers, immediately after their discharge and over regularly-occurring and overlapping charging times, said latter means comprising an alternating current source, and a plurality of discharge relays 5 each connected in series with one of said condensers.

ALBERT BOUWERS.