Aug. 12, 1941. R. L. SWEENY ET AL 2,252,530

X-RAY TIMING APPARATUS

Filed Sept. 6, 1940 4 Sheets-Sheet 1

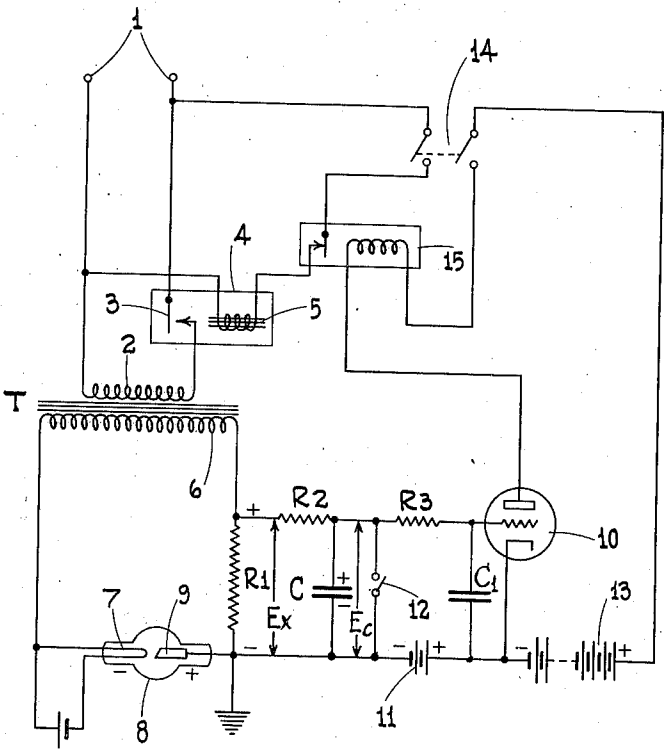


FIG. 1.

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X-RAY TIMING APPARATUS

Filed Sept. 6, 1940 4 Sheets-Sheet 2

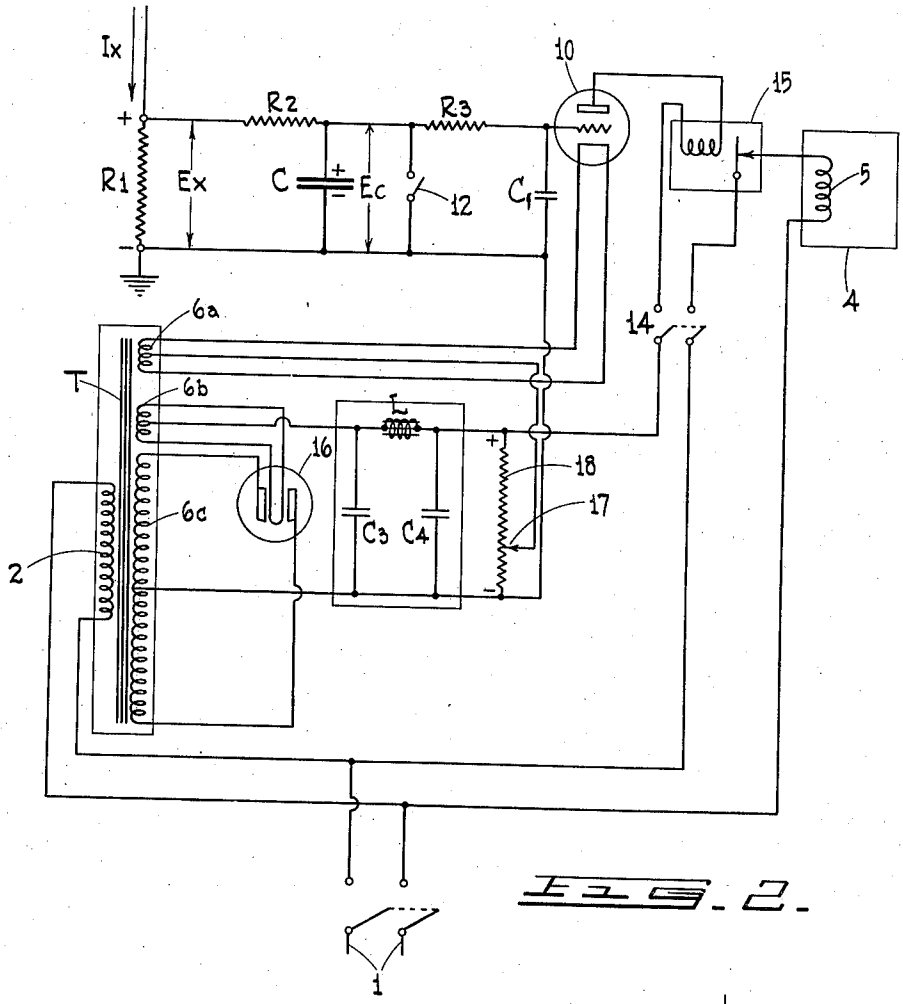


FIG. 2.

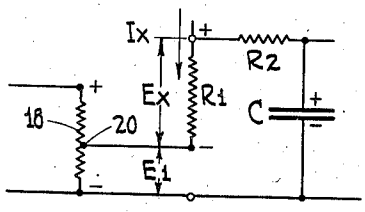


FIG. 3.

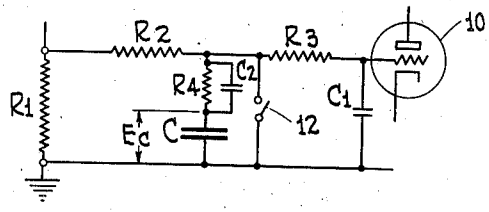


FIG. 4.

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X-RAY TIMING APPARATUS

Filed Sept. 6, 1940 4 Sheets-Sheet 3

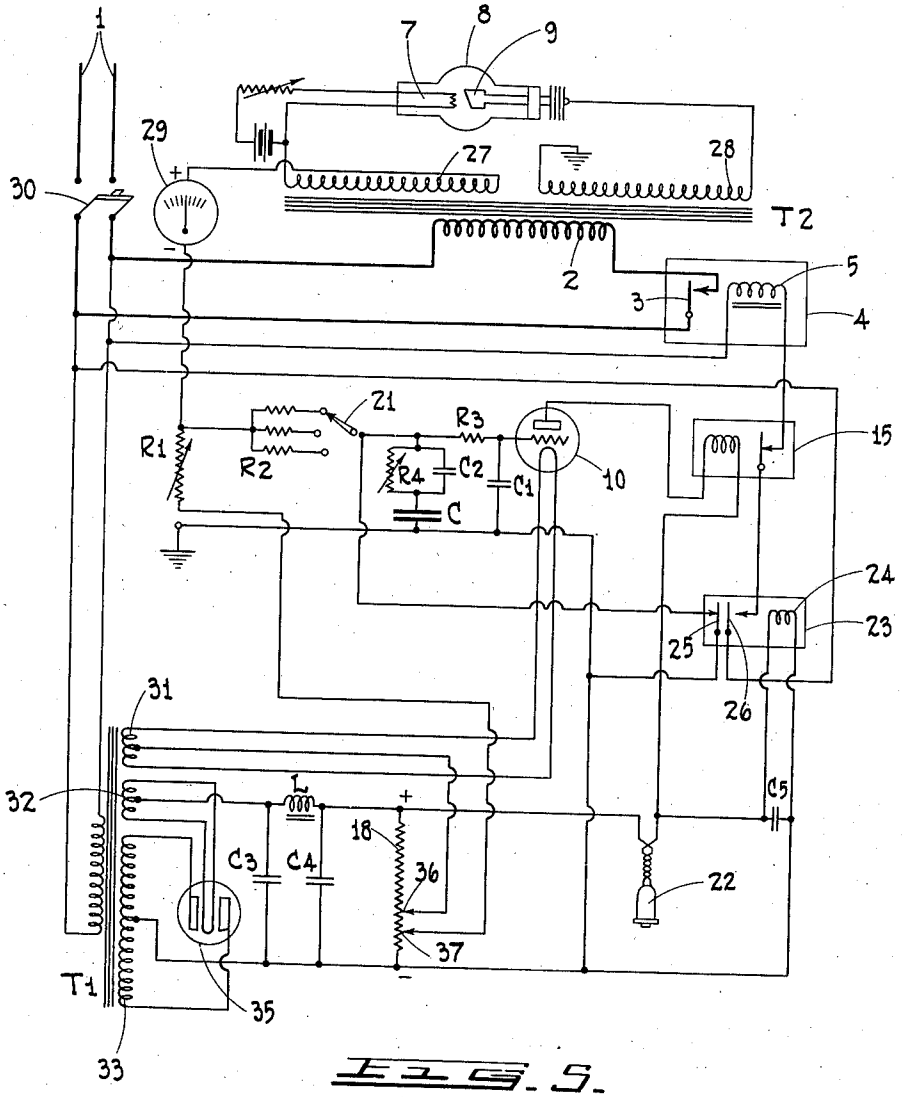


FIG. 5.

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X-RAY TIMING APPARATUS

Filed Sept. 6, 1940 4 Sheets-Sheet 4

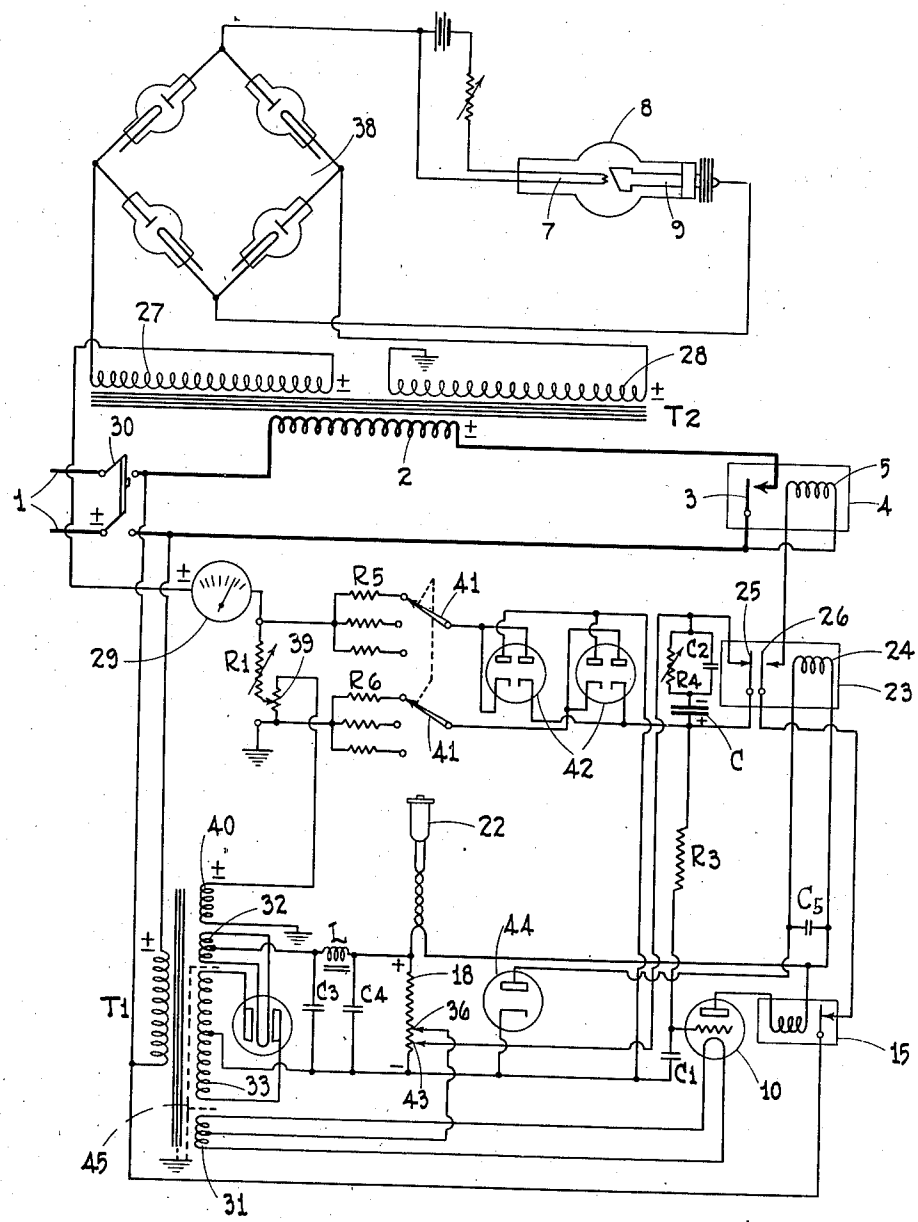


FIG. 6.

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Patented Aug. 12, 1941 2,252,530

UNITED STATES PATENT OFFICE

2,252,530

X-RAY TIMING APPARATUS

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Application September 6, 1940, Serial No. 355,702

16 Claims. (Cl. 250—95)

The present invention relates to apparatus for timing X-ray exposures.

In producing a satisfactory X-ray film, two principal factors determine the resultant quality of the film. The contrast is determined by the voltage used on the X-ray tube anode, and the density is determined by the total quantity of X-rays, which can be expressed in terms of the milliampere-second product. Milliamperes and time separately have no importance to film density; it is only their product that has significance in this respect.

The common method of securing a certain desired total number of milliampere-seconds has been to set the filament of the X-ray tube to a temperature which will produce a value of milliamperes anode current which, when multiplied by the time set on the timer, will produce the desired product of milliampere-seconds. This system has many disadvantages. The X-ray tube filament must be set accurately, usually necessitating one or more calibrating exposures, which may waste valuable film and which reduces the useful life of an expensive tube. Inaccuracies in setting the X-ray timer and milliamperage can form an additive error which will greatly overload the X-ray tube anode, particularly if the sometimes recommended procedure of operating the X-ray tube to its maximum loading is followed.

Therefore the object of the present invention is to provide a practical and reliable device which will time X-ray exposures in terms of milliampere-seconds. Not only is it possible, by the use of the present invention, to determine film density with one setting instead of two, but any fluctuations in line voltage, which would be magnified through the exponential filament characteristic to the anode current, are accurately compensated for. This ensures the production of a properly exposed film in all cases. Extreme accuracy of filament setting is not required, and calibrating exposures are thereby eliminated with corresponding increase in the life of the X-ray tube.

Despite the fact that time is an important factor in some cases, notably in chest work, this does not reduce the usefulness of applicants' milliampere-second timer, since a simple calculation will enable the proper time and milliamperage to be determined.

Since the product of milliamperes and seconds determines density, a calculation is implied in every case when the customary straight timer is used. Applicants' milliampere-second timer only requires this calculation occasionally and the dominant factor is always set with the subordinate factor calculated. The straight timer requires the setting of two subordinate factors to secure the desired dominant factor.

Attempts have been made to provide a milliampere-seconds timer but so far as applicants are aware no practical and accurate timer of this kind has hitherto been proposed.

The prime object of the present invention is to provide an accurate and relatively simple apparatus for use with an X-ray transformer unit, which will provide such milliampere-seconds timing with great accuracy and uniformity of operation.

A further object of the invention is to provide means for compensating for the non-linearity of the (exponential) charging curve of the condenser-resistance timing circuit so as to obtain the same operating characteristic as would be obtained with a linear charging curve, thereby making the device accurate over its entire range of operation.

A further object of the invention is to provide means for utilizing a very large portion of the charging curve of the condenser-resistance timing circuit so as to allow the use of a condenser-resistance timing circuit having a small time-constant in such a manner that the voltage appearing across the condenser is relatively large, thereby making for stable operation of the device.

A still further object of the invention is to provide means to allow the use of the heavy switchgear necessary to control the large primary currents which are used in high-power X-ray apparatus, and to provide means for compensating for the time lag inherent in the operation of such large heavy switchgear.

A still further object of the invention is to provide an accurate apparatus for use with an X-ray transformer unit, which apparatus will allow exposures to be timed in terms of milliampere-seconds in such a manner that the percentage error in setting the scale will be constant, rather than the amount of error as is the common practice.

A still further object of the invention is to provide means whereby the apparatus will not operate until the filaments of all electron tubes therein shall have come up to operating temperature, thereby eliminating the possibility of operation under conditions which might produce inaccurate results.

According to applicants' invention the actual X-ray tube anode current is utilized to actuate the timing device. The property whereby a condenser needs a certain definite time to acquire a certain definite charge is utilized to form the timing element. Various methods to make use of this property are hereinafter described.

The invention consists in the combination and arrangements of elements hereinafter described and more particularly pointed out in the appended claims.

Referring now to the accompanying drawings which illustrate diagrammatically, and by way of example only, various embodiments of the invention:

Figure 1 is a diagram illustrating the principle of the invention,

Figure 2 is a diagram similar to Figure 1 but showing an arrangement in which the use of batteries is eliminated,

Figures 3 and 4 are diagrams of detail modifications,

Figure 5 is a diagram of a preferred form of the invention for use with a half-wave X-ray machine.

Figure 6 is a diagram of a preferred form of the invention for use with a full-wave X-ray machine.

In Figure 1 the numeral 1 indicates the alternating current supply which is connected to the primary 2 of the X-ray transformer T through a switch 3 of the X-ray contactor 4 which includes a coil 5. The secondary 6 of the transformer T is connected at one end to the cathode 7 of the X-ray tube 8 and at the other end to the anode 9 and to ground through a resistance R_1. The top of the resistance R_1 is connected to the grid of a control tube 10 through resistances R_2 and R_3, and the lower end of the resistance R_1 is connected to the cathode of the tube 10 through a grid bias 11. A timing condenser C is connected at one side to a point between the resistances R_2 and R_3 and at the other side to the anode of the X-ray tube 8. A switch 12 is connected in parallel with the condenser C and preferably a condenser C_1 is bridged across the connections to the grid and cathode of the control tube 10. The plate battery, shown at 13, is connected to the plate of the tube 10 through one side of a switch 14 and the coil of a relay 15.

One of the supply lines 1 can be connected to the other through the other side of the switch 14, the movable element of the relay 15 and the coil 5 of the contactor 4.

Resistance R_2 is preferably large with respect to resistance R_1. The control tube 10 may be of either hot cathode or cold cathode type with an appropriate type of fixed bias of such value that with switch 12 closed, the tube 10 is in its non-conducting phase. Resistance R_3 is used to prevent the flow of excessive grid current when the tube 10 is conducting.

To obtain an X-ray exposure it is necessary either first to open switch 12 and then close switch 14 or to perform these two operations simultaneously, preferably using a suitable switch or relay as will be later described.

On closing switch 14, the coil 5 of the contactor 4 is energized to close the contactor switch 3 so that the exposure is thus initiated. Simultaneously, the closure of switch 14 also applies plate voltage to the tube 10 through the coil of relay 15. Thus far the tube 10 is non-conducting.

The X-ray tube current now flows through resistance R_1 in such a direction as to cause a voltage drop E_x of the polarity shown. E_x appears across the timing circuit which consists of resistance R_2 and condenser C. A current thus flows through resistance R_2 to charge up condenser C with the indicated polarity.

Instead of having voltage drop E_x appear directly across the timing circuit it can, if desired, be amplified by means of an amplifier of suitable design, not shown, so that the output of this amplifier appears across the timing circuit, as will be readily appreciated by those skilled in the art.

The voltage E_c, across condenser C, increases exponentially with time, and appears as a component of the total grid bias on the tube 10, acting in opposition to the fixed bias 11.

Instead of applying voltage E_c directly in the bias circuit of the tube 10 it can be applied to the grid of a D. C. amplifier of appropriate design, not shown, so that the output of this amplifier then acts in the grid circuit of the tube 10. Thus as voltage E_c increases, the total resultant bias decreases, and on reaching a predetermined value, the bias becomes insufficient to prevent the flow of anode current, and so the tube 10 begins to pass plate current. This plate current energizes the coil of the normally-closed relay 15, causing it to open, thereby automatically opening the circuit of the contactor coil 5, so that the switch element 3 opens and thus terminates the exposure. At the end of the exposure switch 14 is opened and switch 12 is closed and the closing of the latter switch discharges the timing condenser C in preparation for the next exposure.

With the arrangement just described, the condenser C_1 in the grid circuit of the tube 10 was found to be necessary to prevent surge impulses produced in closing switch 14 from reaching the grid.

The value of milliampere-seconds to be obtained can be determined by an adjustment of resistance R_1 or R_2 or condenser C, any one of which will affect the time required for the charge voltage E_c to build up across the timing condenser C to the required amount to cause the tube 10 to pass plate current.

Other methods of determining values of milliampere-seconds to be obtained are varying the grid bias voltage, anode voltage, or even the cathode heating current (in the case of a hot cathode control tube), thus changing the amount of charging voltage E_c required to operate the tube 10. These methods, however, are not as satisfactory as those described in the preceding paragraph.

A triode, tetrode, or other multi-element vacuum tube may be used in place of a gaseous discharge, grid controlled tube as the control tube 10. With the high vacuum type of control tube the action is slightly different. In that case the plate current builds up simultaneously with the condenser charge voltage E_c until it reaches such a value that it will be sufficient to cause the normally closed relay 15 to open. In such an arrangement it is found feasible to determine the milliampere-seconds value by adjusting the spring tension of the relay 15, as well as by any of the previously described methods.

Another method of using the vacuum type electronic tube is to allow this tube to be conducting during the exposure, operating a normally-open relay (or even operating the X-ray contactor 4 directly). In this case voltage E_c is added to the fixed bias in such a manner that the two are additive, so that as E_c increases, the vacuum type control tube current falls, finally reaching a value low enough to allow the relay or contactor to open.

For accurate operation of the circuit shown in Figure 1, it is assumed that the condenser voltage E_c increases in a linear relationship with time, assuming the voltage E_x is constant. Actually this increase is exponential, but if the operation of the circuit in Figure 1 is confined to a small portion of the beginning of the curve, then the increase is almost linear and reasonably accurate operation is obtained. In order to se-

cure substantially linear operation by utilizing this small initial portion of the curve, it is necessary to make the time constant of resistance R_2 multiplied by the capacity of condenser C quite large.

This product ($R_2 \times C$) should be numerically about 3 times as great as the desired longest exposure, measured in seconds. For instance, suppose it is desired to time a maximum exposure of 20 seconds, then $R_2 \times C$ should be:

$$(20 \times 3) = 60$$

If we let C=10 microfarads, then R_2 must be:

$$\frac{60}{10 \times 10^{-6}} = 6{,}000{,}000 \text{ ohms or 6 megohms}$$

to obtain a product of 60 as above.

Assuming then, that the circuit constants have been chosen so that the portion of the condenser charge curve used is substantially linear, a condition is obtained whereby for any given values of R_1, R_2 and C, the time required for E_c to increase from zero to a given value at which the exposure is terminated, is inversely proportional to the voltage E_x, and therefore is also inversely proportional to the X-ray tube current. In the form of an equation this becomes:

$$t = \frac{K}{I_x}$$

or

$$I_x \times t = K$$

where

t=time in seconds

I_x=X-ray tube current in milliamperes

K=arbitrary constant.

Since I_x is in milliamperes and t in seconds, this means that under the above conditions the value of milliampere-seconds obtained is constant, regardless of the magnitude of the X-ray tube current I_x.

By changing any of the circuit conditions, as previously described, it is possible to secure any desired value of milliampere-seconds.

In practice, it is desirable to eliminate batteries as a source of voltage supply, and to design the device for operation from any convenient alternating current supply service. An alternating current form of the circuit shown in Figure 1 is illustrated in Figure 2 in which the corresponding elements are indicated by the same numerals as in Figure 1 as far as possible. The supply leads 1 are connected to the primary 2 of a transformer T, and the filament of the tube 10 is connected to a secondary coil 6a. A secondary coil 6b is connected to the filament of a full-wave rectifier tube 16 the plates of which are connected to the ends of a secondary coil 6c. The middle point of the secondary 6a is connected to an adjustable tap at 17 to a resistance 18 which is connected to the centre points of secondaries 6b and 6c in parallel with a filter unit consisting of a choke coil L and condensers C_3 and C_4. The ends of the resistance 18 are also connected respectively to the grid, and to the plate of the tube 10 through the switch 14 and the coil of the relay 15.

In this particular arrangement, bias is obtained by making the cathode of the control tube 10 positive (rather than the grid negative) with respect to the common lead. Alternating current heating current is supplied to the filament and its electrical centre is obtained by means of the centre-tapped winding 6a or if desired by means of a centre-tapped resistor across the winding as is common practice.

D. C. for the anode and grid of control tube 10 is obtained from the output of the filtered full-wave rectifier system 16, C_3, C_4, L, T.

As previously stated, the curve of condenser charge voltage against time is not the ideal straight line, but an exponential curve. By using a combination of resistance R_2 and capacity C with a large time-constant, a straight line is quite closely approximated, but this arrangement has the disadvantage that the valve of E_c necessary to cause the control tube 10 to pass plate current is necessarily small, so long as the range of E_x is kept down within reasonable limits. Since such a small variation in grid bias is depended on to cause the control tube 10 to function, operation becomes somewhat critical, and quite sensitive to changes in tube characteristics, line voltage fluctuation, and the like. By decreasing the time-constant of the $R_2 \times C$ combination it is therefore possible to improve the stability of operation, but at the sacrifice of true linearity of operation. With a small time-constant combination the ratio of long to short exposures for any given milliampere-seconds setting is too great.

To overcome this, a circuit element may be added, in the form of a small fixed voltage supply in series with E_x. This additional voltage is supplied for example, from a tap at 20 on the same D. C. supply (see resistance 18, Figure 2) as is used for the plate and grid circuits of the control tube 10, and is so connected that it adds to the voltage E_x as shown in Figure 3.

This E. M. F., E_1 being fixed, will contribute an increasing proportion of the condenser charging voltage as E_x decreases. E_1 is only a fraction of one percent of the maximum value of E_x (that is during the shortest exposure) but amounts to possibly fifty percent of the minimum value of E_x (that is during the longest exposure). Thus E_1 acts to shorten the long exposures, and has a negligible effect on the very short exposures.

By properly adjusting E_1 it is thus possible to obtain almost perfect linearity over a whole range of exposures up to about 1.3 time-constants, for instance, with C equalling 10 microfarads and R_2 equalling 6 megohms, it would be possible to time up to about $1.3 \times 60 = 78$ seconds.

One feature that materially limits the sphere of accurate operation of any true milliampere-seconds timer is the lengthening of the very short exposures due to the slow action of most contactors in opening the circuit. With a milliampere-seconds timer the timing action does not begin until the contactor is closed, so that the time required for closure is of no consequence. However, at the end of the exposure, when the timer cuts off the contactor coil current, the X-ray current continues to flow until the contactor has opened. With the timer providing an exposure of $\frac{1}{25}$ second, and a contactor lag of $\frac{1}{50}$ second, say, an overall exposure time of $\frac{3}{50}$ second is obtained, or an error of 50%.

With the circuit modification shown in Figure 4 the lengths of all exposures provided by the timer can be shortened, by equal amounts.

This lag compensator circuit consists of a resistor R_4 and a condenser C_2 connected in parallel between the resistance R_2 and timing condenser C. With this arrangement, the E. M. F. appearing at the grid of the control tube 10 is the sum of the fixed bias, the condenser charge voltage, and the IR drop in resistance R_4. The rate of increase of E_c is directly proportional to the current through resistance R_4, and hence, to the

IR drop across resistance R_4. Also, during any given exposure, a given interval of time, say 1/60 second, is represented and accompanied by a certain increase in the value of E_c. The amount of this increase is directly proportional to the IR drop in resistance R_4. Thus, when this latter IR drop is added in series with E_c, the length of all exposures will be decreased by a constant amount. By adjusting resistance R_4 all exposures can be shortened by an amount equal to the contactor opening lag, and thus compensation can be obtained for this lag. The condenser C_2, is included to filter out any high peaks which may occur in the distorted X-ray current wave form. Without this condenser operation may be somewhat unstable.

A preferred form of the improved timer, for use in conjunction with a half-wave X-ray machine, is shown in Figure 5, including all the circuit features thus far discussed.

In this arrangement, resistance R_1 is used as the milliampere-seconds control. Resistance R_2 is arranged in a suitable number of sections and is used as a means of changing the range of operation which is set by means of a range switch **21**. In place of switches **12** and **14** shown in Figures 1 and 2, the desired operation is obtained by using a push-button or foot-switch **22** and a second relay **23**. The relay **23** comprises a coil **24** shunted by a condenser C_5 and connected to opposite ends of the resistance **18** through the push-button **22**. The relay **23** also comprises a pair of blades **25** and **26**, the former being normally closed and coacting with a contact connected to the grid of the tube **10** and the latter being normally open and coacting with a contact connected to the movable element of relay **15**.

The secondary of the X-ray transformer T_2 is divided into two parts **27** and **28** one of which is connected to the filament **7** and to the resistance R_1 through a direct current milliammeter **29**, while the other is connected to the anode **9** and to ground.

The primary **2** of transformer T_2 is connected across the A. C. source **1** through the normally open contactor relay **4**, the source being provided with a switch **30**. The source **1** is also connected to the primary of a transformer T_1, the secondary of which comprises three windings **31**, **32** and **33**. The ends of resistance **18** are connected respectively to the middle points of secondaries **32** and **33** through a filter consisting of a choke coil L and condensers C_3 and C_4. The ends of winding **32** are connected to the filament, and the ends of winding **33** to the plates of a rectifier tube **35**. The ends of winding **31** are connected to the filament of control tube **10** and the middle point of winding **31** leads to a tap **36** on resistance **18**. The lower end of resistance R_1 leads to a tap **37** on the resistance **18**, to supply the fixed voltage E_1. (See Figure 3.)

The following is a list of suitable values for the various elements in Figure 5, though the invention of course, is not limited to such values:

R_1—1,000 ohms variable	C_1—.001 microfarad
R_2—Range 1—100,000 ohms	C_2—1.0 microfarad
Range 2—500,000 ohms	
Range 3—2.5 megohms	C_3—4.0 microfarads
R_3—100,000 ohms	C_4—4.0 microfarads
R_4—5,000 ohms variable	C_5—0.25 microfarad
18—5,000 ohms total	C —10.0 microfarads
	L —30 henries

By way of example the voltage drop across winding **31** may be 2.5 volts, across winding **32**, 5 volts, and across each half of winding **33**, 125 volts. Tube **10** may conveniently be of type 2A4G and tube **35** of type 82.

The operation of this form of the invention is as follows:

The line switch **30** is closed to connect the whole apparatus to the A. C. line. The transformer T_1 is now energized and so supplies filament heating current to the control tube **10** and the rectifier tube **35** in the timer. Transformer T_1 also supplies A. C. to the plates of the rectifier tube **35**, and the latter converts the A. C. to pulsating D. C. The pulsating D. C. is filtered by unit L, C_3, C_4, thus giving substantially pure D. C. across C_4 and **18**, having the polarity indicated. This pure D. C. is required to supply the plate and grid circuits of the control tube **10**.

It will be noticed that with relay **23** in the normal position shown, the grid of control tube **10** is connected through resistance R_3 to the negative side of the D. C. supply, whereas the filament of control tube **10** is connected, through the transformer winding **31**, to the tap **36** on resistance **18**, thus making the filament positive with respect to the grid. In this way a fixed grid bias is obtained.

As yet no anode current flows in the X-ray tube **8**, since transformer T_2 is not yet energized. We do assume, however, that the filament of the X-ray tube is appropriately heated at this point.

Next the exposure push-button **22** is pressed to connect the D. C. supply directly to the coil **24** of relay **23** and at the same time to the plate of the control tube **10** through the coil of relay **15**. The fixed grid bias on the control tube is greater than the critical bias at this point, and so no plate current flows as yet. This closure of button **22** operates relay **23** and energizes the coil **5** of the heavy primary contactor **4** to cause closure of the normally-open contact **3**. The normally closed contact of relay **23** has, until now, acted as a short circuit across the combination of C, R_4 and C_2. This short-circuit is now opened. To simplify explanation, the lag compensator circuit which consists of R_4 and C_2 may, for the time being, be regarded as short circuited.

The contactor **3**, **4**, **5** is a heavy device with large contacts usually immersed in oil to carry the heavy primary current of the X-ray transformer. Although similar in diagrammatic representation, it must not be confused with the very much smaller and lighter relays **15** and **23**, which are parts of the timer itself.

On the closure of the primary contactor **3** the X-ray transformer T_2 is energized and so X-ray anode current is caused to flow.

Since current is now flowing in resistancce R_1 there is a voltage drop across it proportional to the current flowing and having the polarity indicated. To this voltage (E_x in Figure 3) is added the voltage (E_1 in Figure 3) in the small portion of resistance **18** between the lower tap **37** and ground, which drop is caused by the X-ray anode current plus the current flowing in resistance **18** from the rectifier tube **35**.

E_x plus E_1 now appears across the timing circuit (consisting of resistance R_2 and condenser C in series) and the condenser C begins to charge up at a rate depending on the values of R_2 and C, and the voltage E_x plus E_1. The charge voltage across C is of the polarity shown and so acts in opposition to the fixed bias voltage.

When the grid bias on the control tube **10** is decreased by the predetermined amount the point of critical bias is reached, the control tube ignites, and the plate current in the control tube **10** flows and energizes the coil of relay **15**. The

normally-closed contacts of this relay now open, thus de-energizing the coil of the primary contactor 4, thereby opening the primary circuit of the X-ray transformer T_1, and ending the exposure.

In the ideal arrangement the exposure would end at the instant when condenser C became charged up to the point of critical bias, whereas it will be seen that there are three steps that follow this, namely, ignition of tube 10, opening of relay 15 and opening of contactor 3. The first can be considered to take zero time, but the opening of relay 15 and especially the opening of contactor 3 take measurable periods and actually add to the exposure time. For this reason the lag compensator circuit, comprising resistance R_4 and condenser C_2 was devised, and the operation of this circuit has already been described with reference to Figure 4.

The lower tap 37 on resistance 18 is for the curve compensator, which has been described with reference to Figure 3.

After the exposure is completed the push-button 22 is released. This de-energizes the relays 15 and 23 so that they return to their normal positions shown in Figure 5. The normally-closed contact of relay 23 is used to short-circuit timing condenser C to remove its charge, in preparation for a subsequent exposure.

In the full-wave circuit shown in Figure 6 the secondary of transformer T_2 is connected to the X-ray tube 8 through a bridge rectifier circuit indicated at 38.

Transformer winding 27 is connected to resistance R_1 through an A. C. milliammeter 29. The lower end of resistance R_1 is tapped to curve compensator resistance 39 which is grounded at one end and connected at the other end to ground through a secondary winding 40 of transformer T_1.

The top of resistance R_1 and the bottom of resistance 39 are each connected to sets of resistances R_5 and R_6 provided with range selector switches 41, which are connected as indicated to double diode tubes 42, which are connected on one side to the bottom of condenser C and to the normally-closed contact 25 of relay 23, and on the other side to the lower end of resistance 18.

The top of the lag compensator circuit R_4, C_2 is connected to a tap 43 near the bottom of resistance 18 for cancellation of contact E. M. F. developed in the double diode rectifier tubes.

The relay coil 24 is connected to the bottom of resistance 18 through a slow heating rectifier tube 44.

An electrostatic shield may be provided in transformer T_1 as indicated at 45.

The following suitable values of the elements of Figure 6 are given by way of example only:

R_1—1,000 ohms variable
R_3—100,000 ohms
R_4—5,000 ohms variable
R_5—Range 1—50,000 ohms each and Range 2—250,000 ohms each
R_6—Range 3—1.25 megohms each
18—5,000 ohms total

C_1—.001 microfarad
C_2—1.0 microfarad
C_3—4.0 microfarads
C_4—4.0 microfarads
C_5—0.25 microfarad
C—10.0 microfarads
L—30 henries

For the full-wave form of the timer, the sequence of operations is the same as in Figure 5, except that in this case A. C. is flowing in resistance R_1, thus causing an A. C. voltage drop across it. Hence in order to use this voltage to charge up condenser C it must be rectified, and for this purpose the two double-diode tubes 42 are used. Since these tubes require a cathode heating period of about 15 seconds it is necessary to take precautions to avoid starting the exposure before this heating period has elapsed. This is done by providing, in the coil circuit of relay 23 the slow-heating rectifier tube 44.

One more point of difference between the two circuits is in the curve-compensator arrangement. In the half-wave form shown in Figure 5 a tap 37 on resistance 18 was used to supply D. C. which was added to the D. C. drop in resistance R_1. In the full-wave timer, since there is A. C. flowing in resistance 18, it is added to an A. C. voltage obtained from the additional winding 40 on transformer T_1.

For simplicity, in Figures 5 and 6 the primaries of both transformers T_1 and T_2 are both shown as being connected to a single A. C. source and this arrangement can be used in practice when desired, but a common arrangement is to connect the two transformers to separate sources, for example transformers T_1 to a supply at 110 volts and transformer T_2 to a supply at 220 volts.

It will be understood that the improved timer may be used in conjunction with any type of X-ray machine, whether the X-ray filament heating is adjusted by a continuously adjustable resistance or choke or by tapped resistances or otherwise.

It will also be understood that the lag compensating means will be required in the timer only when a contactor with relatively slow-moving parts is employed in the X-ray machine. Certain X-ray machines employ an electronic relay system in place of a mechanical contactor, and in such cases lag compensating devices are unnecessary.

The foregoing description and accompanying drawings are given by way of example only and any modifications within the scope of the appended claims may be resorted to without departing from the spirit of the invention.

What we claim is:

1. Apparatus for timing X-ray exposures comprising a low resistance to be connected in the secondary circuit of the X-ray tube high-tension transformer, a timing circuit including a relatively high resistance and a condenser in series and connected in parallel with said low resistance, a control tube having a voltage-sensitive element connected to said condenser so as to respond to changes in the voltage across said condenser, switching and relay means connected with said control tube and with the primary winding of the X-ray high-tension transformer to cause automatic opening of said primary winding when said condenser has attained a predetermined charge, and means for compensating for the non-linear charge curve of the timing condenser.

2. Apparatus as claimed in claim 1, wherein switching means are provided for short-circuiting said timing circuit after each exposure.

3. Apparatus as claimed in claim 1, wherein switching means are provided for automatically short-circuiting said timing circuit after each exposure.

4. Apparatus as claimed in claim 1, wherein a second high resistance is inserted between said timing condenser and the voltage-sensitive element of the control tube.

5. Apparatus as claimed in claim 1, wherein a second high resistance is inserted between said timing condenser and the voltage-sensitive element of the control tube, the timing condenser being bridged by a relatively low capacity condenser at a point between said second high re-

sistance and the voltage-sensitive element of the control tube.

6. Apparatus as claimed in claim 1, wherein said timing circuit includes also a rectifier connected between the relatively high resistance and timing condenser so that a unidirectional voltage is applied to said timing condenser.

7. Apparatus as claimed in claim 1, wherein means are provided for compensating for time lag caused by delay in the opening of relatively slow-moving parts of the circuit.

8. Apparatus as claimed in claim 1, wherein means are provided for compensating for time lag caused by delay in the opening of relatively slow-moving parts of the circuit, said means comprising a resistance and a condenser connected in parallel with each other and in series with the timing condenser.

9. Apparatus as claimed in claim 1, wherein said means compensating for the non-linear charge curve of the timing condenser, consist of means for adding a suitable fixed voltage to the voltage applied to the timing circuit by the voltage drop across the low resistance.

10. Apparatus as claimed in claim 1, wherein the high resistance in the timing circuit is arranged in a plurality of parallel sections cooperating with a range selector switch.

11. Apparatus as claimed in claim 1, comprising also a low-tension transformer, a resistance connected with secondary windings of said transformer, a rectifier between said windings and said resistance, a filter unit between said rectifier unit and said resistance, a normally open relay connected across said resistance through an exposure switch and a normally closed relay having a switch connected to said normally open relay and a coil connected to the plate of the control tube and to said exposure switch, said normally closed relay being also adapted to be connected to a normally open relay in the primary circuit of the high-tension transformer of the X-ray tube.

12. Apparatus as claimed in claim 1, comprising also a low-tension transformer, a resistance connected with secondary windings of said transformer, a rectifier between said windings and said resistance, a filter unit between said rectifier unit and said resistance, a normally open relay connected across said resistance through an exposure switch and a normally closed relay having a switch connected to said normally open relay and a coil connected to the plate of the control tube and to said exposure switch, said normally closed relay being also adapted to be connected to a normally open relay in the primary circuit of the high-tension transformer of the X-ray tube said normally open relay also comprising a normally closed switch arranged to short-circuit the timing circuit after each exposure.

13. Apparatus as claimed in claim 1, comprising also a low-tension transformer, a resistance connected with secondary windings of said transformer, a rectifier between said windings and said resistance, a filter unit between said rectifier unit and said resistance, a normally open relay connected across said resistance through an exposure switch and a normally closed relay having a switch connected to said normally open relay and a coil connected to the plate of the control tube and to said exposure switch, said normally closed relay being also adapted to be connected to a normally open relay in the primary circuit of the high-tension transformer of the X-ray tube the low resistance connected in the secondary circuit of the high-tension transformer being connected to a point adjacent the negative end of the resistance connected with the low-tension transformer.

14. Apparatus as claimed in claim 1, comprising also a low-tension transformer, a resistance connected with secondary windings of said transformer, a rectifier between said windings and said resistance, a filter unit between said rectifier unit and said resistance, a normally open relay connected across said resistance through an exposure switch and a normally closed relay having a switch connected to said normally open relay and a coil connected to the plate of the control tube and to said exposure switch, said normally closed relay being also adapted to be connected to a normally open relay in the primary circuit of the high-tension transformer of the X-ray tube the ends of a secondary winding of the low-tension transformer being connected to the cathode of the control tube and the centre point of said winding being connected to the resistance connected with the low-tension transformer.

15. Apparatus as claimed in claim 1, comprising also a low-tension transformer, a resistance connected with secondary windings of said transformer, a rectifier between said windings and said resistance, a filter unit between said rectifier unit and said resistance, a normally open relay connected across said resistance through an exposure switch and a normally closed relay having a switch connected to said normally open relay and a coil connected to the plate of the control tube and to said exposure switch, said normally closed relay being also adapted to be connected to a normally open relay in the primary circuit of the high-tension transformer of the X-ray tube a slow-heating rectifier tube being interposed between the coil of said normally-open relay and the resistance connected with said low-tension transformer.

16. Apparatus as claimed in claim 1, comprising also a low-tension transformer, a resistance connected with secondary windings of said transformer, a rectifier between said windings and said resistance, a filter unit between said rectifier unit and said resistance, a normally open relay connected across said resistance through an exposure switch and a normally closed relay having a switch connected to said normally open relay and a coil connected to the plate of the control tube and to said exposure switch, said normally closed relay being also adapted to be connected to a normally open relay in the primary circuit of the high-tension transformer of the X-ray tube electrostatic shielding being provided in the low-tension transformer.

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