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X-RAY TIMER

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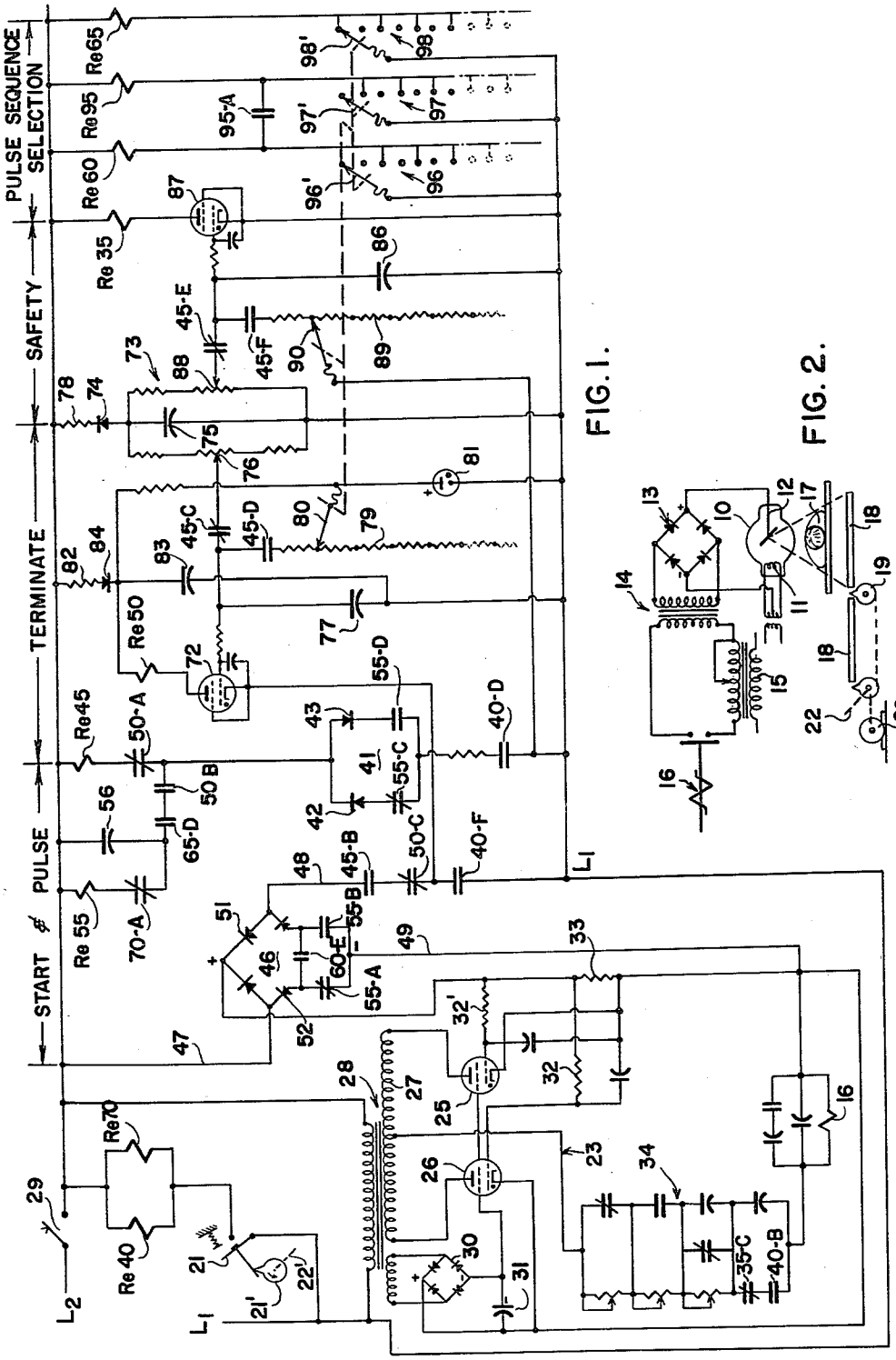


FIG. 1.

FIG. 2.

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X-RAY TIMER

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This invention relates to electronic means for measuring the duration of an X-ray exposure interval. More particularly, the invention concerns an X-ray timer that enables selection of intervals ranging from as low as the duration of a single half cycle of the line frequency to much longer intervals, measured in seconds, and wherein several short intervals can be carried on in extremely rapid sequence, this latter characteristic being particularly useful when radiographing body organs undergoing movement or change.

X-ray generating tubes are usually supplied from a full wave rectifier fed by a transformer whose primary voltage is selected on the movable tap of an autotransformer. Energization of the tube may be initiated by closing a contactor in the transformer circuit and terminated by opening the contactor. When the duration of each consecutive energized interval coincides with an even number of half waves of the line frequency, the net magnetic flux through the transformer core is at a minimum and there is little residual flux. On the other hand, when the interval constitutes an odd number of half cycles or pulses, the core may remain in a strong magnetically polarized condition between exposures. Then if the next train of pulses is randomly initiated, the first one may have set up an additive or substractive flux resulting in the flow of normal or greater than normal X-ray tube current and, accordingly, the quality of different films of the same radiographic subject would vary. This is more noticeable and less tolerable for short interval exposures and for high impedance lines where regulation is greater.

It is the general object of this invention to provide means for assuring uniform radiographic results for exposures consisting of any number of even or odd pulses and for insuring that the first pulse in any ensuing series will impress on the transformer a voltage of polarity opposite to that of the last pulse in a preceding series.

A further object is the provision of novel means for initiating each exposure interval in a predetermined phase relationship with respect to the line frequency.

Another object is the provision of an X-ray timer that has one mode of operation for time intervals corresponding with an even number of half cycles or pulses and another mode for intervals measured by an odd number of half cycles.

Yet another object is the provision of means for alternating the polarity of the X-ray tube transformer input voltage for exposures consisting in widely spaced single pulses between which several non-conductive half cycles or pulses occur. This object being significant when taking a rapid sequence of radiographs on individual film strips where exposure intervals persist for a duration no greater than the time of a single half cycle of the line frequency, for instance.

Another object resides in energizing the X-ray transformer with alternating current from a pair of push-pull connected thyratron tubes and de-energizing the transformer at the end of an exposure interval by a timing circuit that measures the interval without regard for any phase relationship between its energizing circuit and the pulses being delivered to the transformer. More specifically, this object involves the firing of an individual interval terminating thyratron under the influence of a direct current plate voltage. In another aspect, the present invention embraces interval terminating thyratrons

arranged in push-pull for alternatively energizing an X-ray tube according to which thyratron has a positive plate voltage so that all intervals for any like selector control setting are consistent.

A more specific object is to utilize a pulsed transfer relay for controlling the action of a biasing rectifier and its associated relays whereby only a single firing pulse is delivered to the power thyratron for a ½ cycle exposure and exactly an odd number of pulses is delivered for exposures consisting in a corresponding odd number of half cycles.

In general terms, the invention is characterized by a pair of push-pull connected thyratron tubes adapted to energize an X-ray transformer contactor for a selected time interval consisting in any whole number of half cycles. A control grid bias on the thyratron tubes is overcome by periodically applying an opposing direct current voltage to a bias resistor through a bridge type starting rectifier to cause the thyratron having a positive plate voltage to conduct. For any time interval consisting in an odd number of pulses, a pulse relay automatically conditions the circuit to initiate conduction, at the beginning of the next interval, by applying a first voltage wave on the X-ray tube transformer of opposite polarity with respect to the last wave in the preceding one of a series of odd pulses. When an exposure interval consisting in an even number of pulses is selected, the pulse relay is inactivated since no appreciable residual flux then exists in the X-ray transformer core and it is unnecessary to reverse polarity on the X-ray transformer primary.

The timer also features an interval terminating thyratron tube adapted to become conductive under the influence of direct current plate voltage and appropriate diminution of its constant direct current bias to allow direct current operation of the time interval terminating relay and to make termination independent of the phase angle at starting time.

A more specific description of what is now believed to be a preferred mode of practicing the invention will now be set forth in reference to the drawing in which:

FIG. 1 is a schematic diagram of an X-ray interval timer embodying the invention; and,

FIG. 2 is a schematic representation of an X-ray tube and its power supply which is controlled by the apparatus shown in FIG. 1.

In FIG. 2 is shown a conventional X-ray tube 10 having the usual heated filament 11 and to whose anode 12 is applied a full wave rectified accelerating voltage through a bridge rectifier 13. The rectifier is supplied from a step-up transformer 14 having a voltage selecting autotransformer 15 in its primary circuit. Energization of the X-ray tube is controlled by a contactor 16 whose closing initiates a radiographic exposure and whose opening terminates the exposure interval. The arrangement thus far described may project X-radiation onto a body 17, for instance, creating an X-ray shadowgraph on a film 18 or other X-ray image storage sensitive element. The present invention has special advantages where film strips 18 are to be subjected to short exposures and ejected for allowing another strip to take its position in the beam. This procedure may be utilized when performing cardiographic technic, for instance, or at any time that the radiologist wants to record rapidly changing conditions in the organs under surveillance. Means for transporting the consecutive film strips are symbolized by a pair of connected cams 19 driven by a motor 20. The film transport mechanism may be mechanically coupled to a timer control switch 21, upper left in FIG. 1, the connection being symbolized by a broken line 22—22'.

The novel interval timer will now be described in connection with FIG. 1 where X-ray contactor 16 is embodied in the timer in the lower left region and constitutes the

ultimate element to be controlled for establishing exposure intervals.

X-ray contactor 16 is connected with other circuit elements in the center leg 23 of a push-pull power supply comprising a pair of gas-filled thyratron tubes 25 and 26. The anodes of these tubes are respectively connected to opposite ends of the secondary 27 of a transformer 28 whose primary is fed from alternating current power lines L_1 and L_2 when line switch 29 is closed. When the circuit is inactive, but in readiness to make X-ray exposures, thyratrons 25 and 26 are maintained non-conductive by application of a strong negative bias on their screen girds with respect to their cathodes. This bias is obtained from full wave rectifier 30 whose output is filtered by a capacitor 31.

Grid bias resistors 32, 32' connected in parallel across the control grids of each thyratron 25, 26 have no voltage across them except when exposure interval has been started by means to be described. During an X-ray exposure, consecutive positive going pulses are fed through a bias overcoming resistor 33 so that its upper end becomes more positive than its lower. This causes a corresponding positive voltage to appear on the control grids of each thyratron 25 and 26, in which case the one having a positive plate at the time will conduct for a half cycle and terminate. On the next half cycle the adjacent tube conducts and terminates if current pulses continue to traverse the resistor 33. The voltage pulses appearing across resistor 33 raise the control grid potential sufficiently positive to overcome the negative bias due to rectifier 30 on the screen grids, but these pulses are in phase with the plate voltage of the conducting tube, so as each plate voltage passes through zero the negative screen grid takes over and renders that tube non-conducting.

In the center leg 23 of the push-pull power supply there is a series-parallel arrangement, identified generally by the reference numeral 34, of capacitors, contacts and resistors. By controlling certain of the contacts in a manner not essential to understanding the present invention, the pull-in and drop-out time of X-ray contactor 16 may be modified. This is more fully discussed in the co-pending application of the instant inventor, Ser. No. 708,442, filed January 13, 1958, now Patent No. 2,958,782, dated November 1, 1960 over which this invention is an improvement.

For present purposes it is sufficient to observe that series-parallel arrangement 34 includes a normally closed safety contact 35–C in series with X-ray contactor 16. Safety contact 35–C is adapted to be opened by a safety relay operating coil Re 35 in the event the regular exposure timer, yet to be discussed, fails to terminate or delays slightly beyond a preset time. The operating circuit for safety relay Re 35 will also be discussed in more detail later.

In series with safety contact 35–C is a normally open contact 40–B which when closed by its operating coil Re 40 completes the circuit through X-ray contactor 16 and the center leg 23 of the push-pull supply thus placing the circuit in readiness for becoming conductive when an exposure interval commences through the agency of a pulse traversing bias resistor 33.

In the illustrative circuitry of FIG. 1 all exposures are started by closing switch 21 either mechanically or by hand. As shown, the switch 21 is spring biased for opening by itself if manual pressure is relieved. It is also arranged to be operated by a cam 21', for instance, in which case it may be synchronized with film transport device 22, see FIG. 2, to close while exposing a film strip 18 and to open during film ejection. More frequently, switch 21 is operated manually in the nature of a dead-man switch in which case an exposure procedure is set in motion by its closure and as a result of connecting relay coil Re 40 between L_1 and L_2. This closes the circuit through X-ray contactor 16 by way of contact 40–B as discussed earlier and prepares the circuit for timing.

The circuitry may be considered most conveniently as being divided into sections identified in FIG. 1 as follows: Start and pulse; terminate; safety; and, pulse sequence selection. Elements in the "start and pulse" section will be identified concurrently with a description of their mode of operation.

A timed X-ray exposure interval commences when a start relay coil Re 45 is energized. As can be seen in the drawing, coil Re 45 is in series with a normally closed stop relay contact 50–A and is connected to line L_2. Also in series with coil Re 45 and contact Re 50–A is a start rectifier 41 which has at least one normally closed path at all times. Rectifier 41 is in series with a normally open contact 40–D from which a connection is made to line L_1. Thus, when hand switch 21 is closed, for instance, relay Re 40 is energized, by virtue of being connected between line L_1 and L_2, in which case contact 40–D closes to complete the circuit through exposure start relay coil Re 45 and an exposure commences.

Start rectifier 41 comprises parallel legs, one of which includes a diode rectifier 42 in series with a contact 55–C which is shown closed. The other leg includes an oppositely polarized diode rectifier 43 and a contact 55–D shown open. Contacts 55–C and 55–D are controlled by a transfer or pulse relay Re 55 to be described later. It will be shown that the last mentioned contacts may be alternately opened and closed for one mode of timer operation, that is, when a single or odd number of half-cycles constitutes the timed interval, but in the general case, when there are an even number of half cycles, one relay contact 55–C or 55–D will remain closed.

When exposure initiating contact 40–D closes, current flows from line L_1, serially through 40–D, 55–C, diode 42, 50–A and exposure start relay coil 45, energizing the latter.

Energizing exposure start relay Re 45 causes a number of simultaneous events in the circuitry. The effect on the circuit including push-pull bias rectifier 46 will first be examined. Note that alternating current is fed to bias rectifier 46 from lines L_1 and L_2 by leads 47 and 48. In lead 48 are three series connected contacts: 40–F, closed by closing the manual switch 21; normally open 45–B, closed by energizing exposure start relay Re 45; and normally closed contact 50–C which is opened to terminate all exposures as will be described later. Thus, when the three last mentioned contacts close, bias rectifier 46 has an alternating current input.

The direct current output of bias rectifier 46 is fed to the thyratron power supply bias resistor 33 and this output may comprise a single half wave pulse or a continuous series of positive pulses, depending upon the mode of operation selected. Rectifier 46 is fundamentally of the full-wave bridge type modified to suit the present invention. Accordingly, one junction of the rectifier is opened and has a normally open contact 60–E in the gap. As will be more fully expalined later, 60–E is usually closed during most operations but may be opened when it is desired to operate bias rectifier 46 as a half wave rectifier as is the case when a single exposure consisting in the same duration as a half wave of a line frequency is selected, and when an exposure consisting in an odd number of half cycles is underway. Also affiliated with bias rectifier 46 are a pair of relay contacts 55–A and 55–B, the former being shown closed and the latter opened, connected in parallel with each other and in series with a lead 49 feeding direct current pulses to thyratron bias resistor 33. Contacts 55–A and 55–B may be alternately opened and closed by pulse relay Re 55 during one mode of operation to be discussed later, but in any case, one or the other is closed to complete the direct current circuit of bias rectifier 46.

It is convenient at this point to assume, by means yet to be described, that through the timer an X-ray exposure interval consisting in an even number of half waves of line frequency has been selected. For instance, assume

a case where 1/15 second exposure or 8 half cycles of a 60 cycle line frequency takes place after which bias rectifier 46 would be disconnected from its A.C. input by opening of exposure stop relay contact 50–C. In such case, contact 60–E would be closed and contact 55–A may remain closed as shown, so that 8 unidirectional half cycle pulses would appear across bias resistor 33. This means that push-pull thyratrons 25 and 26 would conduct alternately for a total of 4 half cycles each and that X-ray contactor 16 would close for a total of the same even number of half waves. Consequently, X-ray transformer 14 would not have any significant residual flux in its core because the even number of pulses results in cancellation.

Exposure start relay Re 45 is characterized by it operating on the first pulse only if it integrates adequate energy from the first pulse it passes after its circuit is closed by contact 40–D. That is, if it does not integrate enough energy during the first quarter wave, or in other words, the first half of the first half wave starting pulse it will wait for the next half wave before it operates to initiate an exposure. It operates in point of time when the voltage applied to it is just beyond its peak and when it does operate it closes contact 45–B to energize bias rectifier 46. This causes bias rectifier 46, and accordingly, bias resistor 33 to be energized with a consistent grid signal. Any delay imposed by the time required to close contact 45–B is accounted for in the total interval by the termination circuit yet to be described.

If the chosen exposure interval consists in an odd number of half waves, such as only one half wave, means are provided for assuring that the first voltage half wave of a series that is impressed on the transformer 14 will be of opposite polarity to the last in the preceding series. For the time being it is sufficient to observe that pulse relay Re 55 may be activated for this purpose and that it may cause alternate opening and closing of its contacts 55–A and 55–B associated with bias rectifier 46 to bring this about. Assume that by appropriate setting, pulse relay coil Re 55 is activated for an odd cycle exposure at the beginning of which relay contact 55–A is closed. If the pulse series consists in single pulses such as a dozen or so half waves in a second, contact 60–E will start open and remain open. If the series is a continuous one totaling an odd number 60–E may be open at the start and closed with termination. Current then flows from the alternating current input line 48 through diode 51, from the D.C. positive terminal of rectifier 46, through bias resistor 33 to make its upper end positive, back through relay contact 55–A, through diode 52 and out at alternating current line 47. If there are, for example, 7 half wave pulses passed before termination of the interval by opening stop contact 50–C, one thyratron, either 25 or 26 would fire four times and the other three times and they would be phased with the line and X-ray transformer 14 voltages. At the end of the series, contact 55–A would open and contact 55–B would close by operation of pulse relay Re 55 so that bias rectifier 46 would have to first see the opposite half wave of A.C. input voltage before it conducted in order to first fire the thyratron that fired fewer times in the preceding series. This is controlled by the pulse relay Re 55 and start rectifier 41 now to be described in detail. For spaced half wave or 1/120 second exposures, 60–E would remain open but contacts 55–A and 55–B would alternate positions after each exposure so that bias rectifier 46 would operate on half waves through alternate branches.

When any odd or even number of pulses constitutes the exposure interval contact 50–B in the start and pulse circuit closes at termination, but on an odd number an automatically selected relay also closes contact 65–D at this time. It is desirable that these contacts 50–B and 65–D remain open during an exposure lest they affect the pull-in time of exposure start relay Re 45. When they close, a capacitor 56 is charged to a polarity dependent upon which contact 55–C or 55–D allows conduction through its associated diode 42 or 43, respectively. This charge is held on capacitor 56 until the manual or automatically driven switch 21 is opened in which case relay coil Re 70 is de-energized and relay contact 70–A, in series with pulse relay Re 55, closes. This permits capacitor 56 to discharge through pulse relay 55–A in the bias rectifier 46, and to close contact 55–D and open contact 55–C in the start rectifier 41. Thus, as described above, bias rectifier 46 and start rectifier 41 remain synchronized because the exposure start relay Re 45 must see an opposite polarity half cycle to start the next exposure because reversed diode 43 will be the first to conduct in the next series. At the end of the next odd series, pulse relay Re 55 will transfer back and repeat the alternation of the various contacts.

Pulse relay Re 55 is obtainable commercially and it may be of the latching type. One type, not shown in detail, includes a permanent magnet rotor which executes a half revolution and latches in response to its field winding being energized with current having one polarity. Upon current reversal in its field, such as results from oppositely directed discharge current from pulse capacitor 56 traversing its winding, the mutual forces of magnetic repulsion cause a half revolution and latching in a diametrically opposite rotor position.

Where an exposure interval consisting in a single half wave or 1/120 second is selected, by means yet to be described, contact 60–E in the bias rectifier 46 is open and the latter operates as a half wave rectifier. The purpose of this is to prevent more than one complete pulse from being delivered to bias resistor 33 lest the exposure period also persist beyond the intended one pulse due to inadvertent firing of both thyratrons in rapid succession. During the non-conductive half cycle immediately following the conductive single half cycle of bias rectifier 46, and in fact, during several ensuing half cycles, time is available to allow for the inertia and operating delay of the transferable contacts discussed above. A commercial form of the timer, nevertheless, allows as many as twelve 1/120 second exposures spaced by such inactive periods within one second. These inactive periods are convenient for transporting a new film 18 strip into the X-ray beam during rapid sequence radiography as explained earlier in reference to FIG. 2.

It will be observed that when contact 60–E is opened and contact 55–A closed as shown in FIG. 1, that if A.C. input line 48 is positive at the associated bias rectifier 46 terminal, that current will flow through diode 51 to the D.C. plus terminal, again making the upper end of bias resistor 33 positive from whence current returns to the rectifier through contact 55–A, and passes through diode 52, whereupon it returns to the then negative A.C. input wire 47. On the next half cycle, when the A.C. input voltage changes polarity on the rectifier, contact 55–A may still be closed and contact 55–B opened so that the return path is blocked by the reverse impedance of the other pair of diodes and because contact 60–E is open. Thus, any delay in the action of the terminating or exposure measuring circuit during half cycle exposures will not cause the interval to be extended and time to regain control is thereby allowed.

The duration of all exposure intervals are chosen by appropriate settings in the terminating portion of the circuit now to be described, it being recollected that termination is ultimately brought about in all cases by opening stop relay contact 50–C, thereby de-energizing the bias rectifier 46.

The terminating circuit includes a normally non-conducting tetrode thyratron 72 which energizes a relay coil Re 50 that opens contact 50–C when the tube becomes conductive. In order to hold the tube 72 non-conductive at all times except at the end of a measured interval, a constant negative bias of approximately 80

volts is applied to its control grid with respect to line L_1. This is achieved by a voltage divider bridge 73 that has a unidirectional voltage impressed on it by connecting it at one end to a series diode rectifier 74, attached to line L_2, and at its other end bridge 73 is attached to line L_1. A smoothing capacitor 75 is also connected across the voltage divider 73. An adjustable tap 76 in series with a contact 45–C impresses the proper negative bias on the control grid of tube 72 and it also allows timing capacitor 77 to charge to the same negative potential on its side which connects to control grid of tube 72 through a limiting resistor. When an exposure is started by energizing relay Re 45 as described earlier, contact 45–C opens, thus removing the constant negative bias on tube 72 and simultaneously a relay contact 45–D closes. This connects capacitor 77 for discharging through a part of a series of time selecting resistors collectively designated 79, through a movable tap 80, and a gas-filled regulator 81 which also connects to line L_2 through a limiting resistor 82. The time of discharge, and accordingly, the time interval elapsing before thyratron tube 72 conducts and stops the exposure depends upon the selected position of potentiometer tap 80 on the series resistance group 79.

Connected to the relay Re 50 and hence indirectly to the plate of tube 72 is a storage capacitor 83 whose one side is negatively charged and connected to line L_1, and whose other plate is positively charged by reason of being connected to line L_2 through a diode rectifier 84 and resistor 82. The positive potential on capacitor 83 appears on the tube 72 plate with respect to its cathode and is sufficient to fire the tube after timing capacitor 77 discharges to the critical firing voltage of the tube. Capacitor 83 is large enough to hold the plate of tube 72 positive during any conceivable interval, and the tube is effectively under the constant influence of a direct current plate potential during conduction despite rectifier diode 84 not conducting and not recharging capacitor 83 when L_2 passes through a negative half cycle. Thus, the terminating circuit does not require that its timing period be commenced in any particular phase relationship with the start of the exposure or in coincidence with the start of the first pulse through push-pull bias resistor 33 since it times on an absolute basis measured in terms of direct current flow rather than the number of pulses fed to the X-ray tube. Filter capacitor 83 has sufficient energy to hold the plate of thyratron 72 and gas-filled diode 81 positive during conduction. This also causes the grid of 72 to swing sharply positive by reason of the positive voltage on the anode of gas regulator tube 81 appearing on it through timing resistor bank 79 and contact 45–D. Hence, tube 72 is influenced by a sharply rising positive grid to reach full current flow immediately after passing through critical grid voltage, and terminating relay Re 50, therefore, operates with insignificant delay. This de-energizes bias rectifier 46 and instantaneously terminates the exposure interval for all modes of operation.

As can be seen, the time constant or the exposure interval is selected by positioning tap 80 on the various resistance steps of the group 79.

The timer is also provided with a safety circuit that assumes responsibility for terminating exposures if the main terminating circuit just discussed should over-time or fail to operate. In essence, it is like the former except that its resistance values as related to safety timing capacitor 86 yield a slightly longer time constant.

The safety timer includes a thyratron tube 87 which when rendered conductive energizes a relay coil Re 35 in series with it, causing opening of a contact 35–C residing in the center leg 23 of the push-pull supply and which is effectively in series with X-ray contactor 16.

Safety timer tube 87 is normally biased non-conductive by application of a negative potential to its grid, this potential being derived from a tap 88 on one side of voltage divider bridge 73 through a normally closed contact 45–E. The negative potential also appears on safety timing capacitor 86. When an exposure is started by energization of relay Re 45, contact 45–E opens, isolating the grid of 87 from its bias source. Contact 45–F closes, connecting the group of safety timing resistors 89 to capacitor 86. The capacitor 86 discharges through a resistor dependent upon the position of the movable arm 90 through line L_1 and to the opposite side of capacitor 86. This fires tube 87 as a safety back-up.

Attention is now invited to the "pulse sequence selection" section, at the far right in FIG. 1, where the timer is conditioned for its various modes of operation. That is, for spaced single half wave exposures, an odd number of continuous half waves, or an even number of half waves.

This section comprises three relay operating coils Re 60, Re 95 and Re 65 each of which has in series circuit an associated deck of contacts 96, 97 and 98, respectively, constituting selector switches. Each deck has movable switch arms 96', 97' and 98', respectively, that are coupled for joint operation with each other and with the selector arms 80 and 90 on the terminating and safety resistor groups 79 and 89.

Relay coil Re 60 is adapted to be energized for all exposures consisting in an odd or even number of half waves, except single half waves or $\frac{1}{120}$ second exposures if time is reckoned on the basis of a sixty cycle supply.

Relay coil Re 95 is adapted to be energized during any exposure consisting in an even number of half waves duration.

Relay coil Re 65 is adapted to be energized during exposures constituting any odd number of continuous half waves including single, intermittent half waves.

An exposure consisting in one half waves of one polarity followed by an off-time of several half waves and then another half wave of opposite polarity, and so on, will be considered first. For instance, a series of $\frac{1}{120}$ exposures spaced from each other or just one such pulse will be considered. In this case, contact 60–E in the bias rectifier 46 should open and remain open so that passing of consecutive pulses through opposite branches of the rectifier is possible. Thus, for single alternate pulses tap 96' rests on a dead terminal in deck 96 so that Re 60 remains de-energized. Bias rectifier 46 then operates as a half wave rectifier so that the alternate half waves it passes are phased with corresponding half waves supplied to X-ray transformer 14 in order to avoid magnetically saturating it. During this mode of operation it is also necessary to activate pulse relay Re 55 so it causes transfer of its contacts 55–A and 55–B associated with the bias rectifier 46, and contacts 55–C and 55–D associated with the start rectifier 41 as explained earlier. The total number of exposures may be controlled by sequencing switch 21 manually or automatically with film ejector cam 21'.

To condition Re 55 for pulsing, Re 65 coil is energized by connecting movable arm 98' to the topmost contact, for example, in deck 98 to complete a circuit through the coil between line L_1 and L_2. This closes contact 65-D in the start-and-pulse section and enables pulse capacitor 56 to charge after each single half wave exposure and to discharge through the pulse relay Re 55 by reason of contact 70–A closing when the manual or automatic switch 21 opens to deenergize coil Re 70.

When the pulse relay Re 55 operates, it may open contact 55–A and close 55–B so that bias rectifier 46 must wait until an opposite half of the A.C. input wave appears before it can conduit and deliver another bias pulse to bias resistor 33. Consequently, the thyratrons 25 and 26 will also fire alternately and in phase with the A.C. half wave supplied to bias rectifier 46 and the X-ray transformer 14.

On consecutive exposures, contacts 55–C and 55–D in the start rectifier 41 will also transfer, causing pulse

capacitor 56 to charge oppositely and pulse relay Re 55 to take opposite positions. Transfer of this pair of contacts 55–C and 55–D also assures that exposure start relay Re 45 will pick-up on an oppositely polarity half cycle when the next consecutive exposure takes place.

Recapitulating, exposure start relay Re 45, pulse relay Re 55, bias rectifier 46 and the X-ray transformer 14 all see the same consecutive different half wave voltages at the same time when a series of half wave pulses spaced from each other constitute consecutive exposure intervals.

The type of exposure interval now to be examined is one where a series of continuous half waves, totaling an odd number, measures the interval. In this case the line voltage may go through one additional positive or negative half wave. An example would be a 1/40 second exposure consisting in three half cycles at sixty cycle line frequency where the taps 80 and 90 of the coupled time selectors are moved to positions on their resistor banks 79 and 89 for yielding a time constant of that duration in conjunction with their timing capacitors 77 and 86, respectively. In this case selector arm 98' would be shifted to a corresponding live terminal in deck 98 and relay Re 65 would energize. This closes contact 65–D and prepares pulse capacitor 56 for being charged and operating pulse relay Re 55 at an appropriate time as is necessary for any odd pulse sequence.

By positioning tap 98', tap 96' in deck 96 will also be compelled to take a position on an appropriate line terminal so that relay coil Re 60 will energize. Relay Re 95 would not be energized because of tap 97' resting on a dead terminal.

With Re 60 energized, contact 60–E in bias rectifier 46 closes when the odd number of pulses time selection is made, thereby setting up bias rectifier 46 to operate full wave. When exposure start relay Re 45 picks up, a thyratron 25, for instance, will fire upon receiving a full half wave biasing pulse from rectifier 46. The polarity of the first half cycle passing from the fired thyratron to the X-ray transformer 14 will have been predetermined by the rest positions of contacts 55–C and 55–D, in start rectifier 41, which decide which half cycle of line voltage will bring in start relay coil Re 45. If 55–C were closed at the beginning it will continue to feed through diode 42 to operate Re 45 on pulsating direct current for the duration of the odd cycle exposure. When the exposure terminates by firing tube 72 and operation of Re 50 and its associated contacts, pulse relay Re 55 will operate to switch contacts 55–C and 55–D in start rectifier 41. Hence, the next exposure will begin when the line polarity is opposite of that at the beginning and end of the last exposure due to the first pulse in the second series being passed by contact 55–D and rectifier 43. The other thyratron 26, for instance, will then be the first to fire for passing a differently polarized voltage wave than the last in the last series to X-ray transformer 14 with the benefit of avoiding saturating its core.

The exposure is terminated by opening stop contact 50–C and cutting off the A.C. supply to bias rectifier 46. At this time relay contact 50–B closes to connect pulse capacitor 56 for charging with a very short time constant. When manual and automatic switch 21 is opened, contact 70–A closes to discharge capacitor 56 through pulse relay Re 55, thereby transferring contacts 55–A, B, C and D to condition start rectifier 41 and bias rectifier 46 to start conducting on an opposite half wave for the next exposure as explained above.

An exposure constituting an even number of half waves will now be considered. For instance, a 1/30 second or four half waves exposure interval. Here, no problem of transformer saturation arises, of course, so bias rectifier 46 operates full wave and pulse relay Re 55 may remain dormant.

In this mode of operation arm 97' in deck 97 may be connected with a live terminal at which time decks 96 and 98 remain open. Closing the circuit through deck 97 energizes relay coil Re 95 which in turn closes its contact 95–A so that relay coil Re 60 is connected between lines L_1 and L_2 also. Energizing coil Re 60 causes its contact 60–E in the bias rectifier 46 to close, thereby connecting the latter for full wave operation. When the timing interval starts after energizing start relay Re 45, bias rectifier 46 delivers a series of positive pulses to bias resistor 33 and thyratrons 25 and 26 continue to fire alternately according to which has a positive plate, until the exposure is terminated.

In summary, an X-ray exposure interval timer has been described that starts in response to the alternating current half wave it sees and terminates after a precise interval measured in terms of direct current flowing in an RC timing circuit. The invention assures that intervals comprising odd numbers of half waves are initiated on consecutively opposite polarities of line voltage for avoiding saturation of the X-ray transformer core. It allows as short as one 1/120 second exposure or a series of them within one second. A commercial form permits exposures up to twelve seconds duration with equal precision.

Although an embodiment of the invention has been described in considerable detail this is not to be interpreted as limiting, for the invention may be variously embodied by those versed in the art and is to be construed according to the scope of the claims which follow.

It is claimed:

1. An X-ray exposure interval timer comprising an X-ray tube supply transformer, switch means adapted to control energization of said transformer, a push-pull power supply including a pair of electron tubes in circuit with said switch means, means normally biasing said tubes non-conductive and a bias resistor across which a voltage may be developed to overcome said bias, rectifier means delivering a unidirectional output current that traverses said bias resistor in response to an alternating input voltage, start relay means adapted to close a circuit that impresses said input voltage, power lines providing a common source of alternating voltage to said start relay means and said rectifier means, means adapted to connect said start relay means to said power lines when said alternating voltage has a predetermined polarity at the beginning of one interval so as to apply said input voltage to said rectifier with the same polarity, and means operative when said preceding interval consists in an odd number of half-cycles for connecting said start relay means to said power line at the start of the next interval when said power line has an opposite polarity.

2. The invention set forth in claim 1 wherein said means for connecting said start relay means comprises a parallel loop circuit in series with said start relay means, each leg of said loop including an oppositely polarized rectifier and a contact in series therewith, and means simultaneously closing one contact while holding the other open to predetermine which polarized rectifier will conduct and energize said start relay means.

3. The invention set forth in claim 1 including means controlling said means for connecting said start relay means to said power lines at a predetermined polarity, said controlling means comprising an impulse relay having operated contacts in circuit with said connecting means and said impulse relay being adapted to change said contacts alternately open and closed, respectively, in response to single voltage impulses after termination of an X-ray exposure interval.

4. An X-ray interval timer comprising an X-ray tube supply transformer, switch means adapted to control energization of said transformer and to establish an exposure interval, a push-pull power supply including a pair of electron tubes in circuit with said switch means,

means normally biasing said tubes non-conductive and a biasing resistor across which a voltage may be developed to overcome said normal bias, rectifier means delivering a unidirectional output current traversing said bias resistor in response to an alternating input voltage, start relay means having a contact for closing circuit to said rectifier means to initiate a timed exposure interval, a common alternating current supply for said start relay means and said rectifier means, a pair of oppositely polarized rectifiers having in series respective alternately openable and closeable contacts and in parallel with each other in a series circuit with said start relay means, an impulse relay means operating said alternately openable and closeable contacts after an exposure interval to alternate positions whereby the start relay means will begin conducting at the next timed interval when the alternating supply voltage polarity is different than at the beginning of the preceding interval, thereby impressing a different initial polarity voltage on said transformer for consecutive intervals.

5. An X-ray interval timer comprising an X-ray tube supply transformer, switch means adapted to control energization of said transformer during an exposure interval, a push-pull power supply including a pair of electron tubes in circuit with said switch means, means normally biasing said tubes non-conductive and a bias resistor across which a voltage may be developed to overcome said normal bias, a first bridge rectifier means delivering a unidirectional current traversing said bias resistor in response to an alternating input voltage, a first contact interposed between a junction of said bridge rectifier means, an output line from said bridge rectifier, a first pair of alternately openable and closeable contacts in parallel with each other and respectively connected to opposite sides of said first contact in the junction and jointly to said output line, means for opening said first interposed contact to thereby open the bridge rectifier for half-wave rectification through one path thereof, an alternating power source for said bridge rectifier, means transferring said pair of contacts to alternate positions at the end of a timed interval whereby said bridge rectifier conducts through a different path and thereby conducts during the next interval when the alternating power source has a different initial polarity than at the end of the preceding interval.

6. The invention set forth in claim 5 including an impulse relay means operating said pair of contacts, said impulse relay means having a contact in series with it, a storage capacitor in parallel with said impulse relay means and said series contact, means for charging said capacitor at the end of a timed interval and means to close said series contact in sequence for discharging said capacitor through said impulse relay to cause transfer of said pair of contacts.

7. An X-ray interval timer comprising an X-ray tube supply transformer, switch means in circuit with said transformer, a power supply adapted to energize said switch means for a timed interval, first rectifier means controlling said power supply, start relay means including switch contact means for closing a circuit to said first rectifier means, an alternating current source, second rectifier means having two parallel paths that are alternately conductive and in series with said relay means across said source, means for closing said paths sequentially to energize said relay means in accordance with the polarity of the source, whereby said switch contact means connects said first rectifier means across said source in synchronism with said start rectifier means and consecutive intervals start with different polarity voltages being applied to said transformer.

8. The invention set forth in claim 7 including an interval terminating timer, said timer including an electron tube having a cathode, grid and anode, means applying a biasing voltage between said grid and cathode and means for overcoming said bias to render said tube conductive, a relay switch means in series with said anode and adapted to be energized when said tube conducts, and contacts controlled by said relay switch means for disconnecting said start relay means and said first rectifier means when said tube conducts at the end of an interval.

9. In an X-ray exposure interval timer, an X-ray source, a transformer for energizing said source, an alternating current power line, switch means for connecting said transformer to said power line, a power supply operating said switch means at the beginning and end of a timed interval, start relay means including switch contact means controlling said power supply, a pair of reversely polarized rectifiers each having an alternately openable and closeable contact in series therewith to form parallel branches in series with said start relay means and across said power line, said relay means thereby initiating its conduction in dependence upon the polarity of said power lines and upon which of said openable and closeable contacts is closed, an impulse relay means and a capacitor in parallel therewith, said impulse relay means operating said openable and closeable contacts, means for charging said capacitor at the end of an interval, means for discharging said capacitor to operate said impulse relay means and transfer said contacts and complete a different circuit through said rectifier means, whereby said start relay means will be energized at the beginning of the next consecutive interval when the power line voltage has a different polarity than at the end of the preceding interval.

10. In an X-ray interval timer, an alternating current power line, an exposure start relay means adapted to start an interval when energized, a pair of reversely polarized rectifier means each having an alternately openable and closeable contact in series therewith to form parallel branches jointly in series with said start relay means, the one rectifier whose series contact is closed being conductive at the start of an interval and determining the power line polarity at which the start relay begins conducting, an impulse relay means operable to transfer said contacts at the end of a timed interval to close the other rectifier circuit, whereby said start relay means will become energized when said power line has an opposite polarity at the beginning of the next successive interval than it had at the end of the last interval.

11. In an X-ray interval timer, an alternating current power line, means for determining the polarity of said power line at the beginning of a timed interval, said polarity determining means comprising a relay means connectable to said line to start a measured interval, a pair of reversely polarized rectifier means each having a respective normally open and closed contact in series therewith, the closed contact rendering its associated rectifier and the starting relay means conductive when the power line has one polarity of the beginning of one interval, means for transferring said contacts at the end of one interval to thereby close circuit through an alternate polarized rectifier whereby said relay means will begin conducting when said power line polarity is different than at the end of the last interval.

12. An X-ray exposure interval timer adapted to measure intervals consisting of individual half waves of a power line frequency, comprising, a power line, an X-ray source, a power supply for said source, said power supply including a pair of push-pull connected electron tubes normally biased non-conductive and adapted to be rendered selectively conductive in accordance with positive voltage appearing thereon, a bias resistor adapted to develop a voltage in response to being traversed by a signal that overcomes said normal bias and renders one of said tubes conductive, a bias rectifier of the bridge type for periodically energizing said bias resistor and having a controlled contact in a junction thereof, a normally open and a normally closed contact in parallel with each other and respectively connected to opposite sides of said con-

trolled contact to thereby establish one conduction path through said bias rectifier at the beginning of one interval, and means for transferring said contacts to establish a different conductive path through said bias rectifier at the end of said interval whereby an alternate of said tubes will conduct at the beginning of the next interval.

13. An X-ray interval timer comprising an X-ray source, a transformer for energizing said source, an alternating current power line, switch means connecting said transformer to said alternating current power line at the start of an X-ray exposure interval, start relay means which when connected to said alternating current power line operates said switch means to start a timed interval, an electronic interval terminating circuit including an electron tube having an anode, cathode and control grid, means applying a bias voltage between said grid and cathode for rendering said tube non-conductive, means for diminishing said bias voltage after a predetermined time to render said tube conductive, a terminating relay means in series with the anode and cathode of said tube and having a contact for opening to de-energize said transformer when said tube conducts, a storage capacitor in parallel with said tube and terminating relay for impressing a predetermined direct voltage thereon when the tube conducts, whereby the voltage applied to the tube is independent of phase relation and magnitude of the power line voltage at the beginning and end of an interval.

14. An X-ray interval timer including means for selecting exposure intervals consisting in individual alternate polarity spaced half waves, odd numbers of half waves and even numbers of half waves of an alternating power line voltage, a power line, an X-ray transformer, a power supply, means for periodically energizing said transformer from said power line through said power supply, start relay means connectable to said alternating voltage power line to activate said power supply upon initiation of an exposure interval, means for connecting said start relay means to said power line with a predetermined polarity, a plurality of jointly operable selector switches each having a relay means in circuit for connection to said power line in accordance with the selected positions of said selector switch, said start relay means having in circuit therewith a pair of alternate current paths conductive in dependence upon polarity of said power line at the start of an interval, said paths each having series contact means, a pulse circuit including impulse relay means and a capacitor in parallel therewith, means controlled by one of said selector switches for energizing said capacitor through one of said paths when individual or odd numbers of half waves constitute the interval, means for connecting said impulse relay means to said capacitor to operate the contacts in said paths and for changing their conduction polarity at the end of each interval.

15. The invention set forth in claim 14 wherein said power supply includes a pair of electron tubes in push-pull relationship, means biasing said tubes non-conductive, a bias resistor across which a voltage may be developed for overcoming said bias and firing whichever tube is positive, a bias rectifier of the bridge type having a contact interposed in a junction thereof, a pair of rectified current paths each having an open and a closed contact therein connected to opposite sides of said interposed contact, one of said selector switches controlling said contact to effect two paths through the bias rectifier whereby half wave unidirectional pulses may be delivered to the bias resistor, and said path contacts being transferable by said impulse relay means to change paths in synchronism with appearance of half waves of different polarity on said power line.

16. In an X-ray tube exposure interval timer circuit, wherein an X-ray tube may be energized during exposure intervals consisting of a continuous odd or even number of half cycles of a power line frequency or during spaced half cycles of alternate polarity, an A.-C. power line, an X-ray tube, a step-up transformer for energizing the X-ray tube from the power line, a bridge rectifier coupling the secondary winding of said transformer to said X-ray tube through the same direct current path for any of the aforementioned exposure intervals, contactor means in circuit with the primary winding of the transformer, said contactor means being adapted to close during any continuous interval and to open at the end thereof and to close and open for each interval consisting of spaced half cycles of alternate polarity, start relay means for starting an interval, a parallel circuit including means selectively conductive in accordance with power line polarity, said parallel circuit being in series with said start relay means and connected to a power line, transfer means for rendering conductive one of said parallel paths for one line polarity and the other path for another line polarity before an exposure interval, a control circuit supplying said contactor means, means for closing said control circuit under the control of said transfer means for initiation of conduction on a polarity corresponding with that during which the start relay begins conducting, whereby said contactor means may close the circuit through the primary winding of the transformer when the polarity of the voltage on the latter is opposite to that at the end of the preceding half cycle ending the previous interval.

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