Oct. 8, 1957 R. GODBARSEN, JR 2,809,296

SWITCHING SYSTEM

Filed July 14, 1953 2 Sheets-Sheet 1

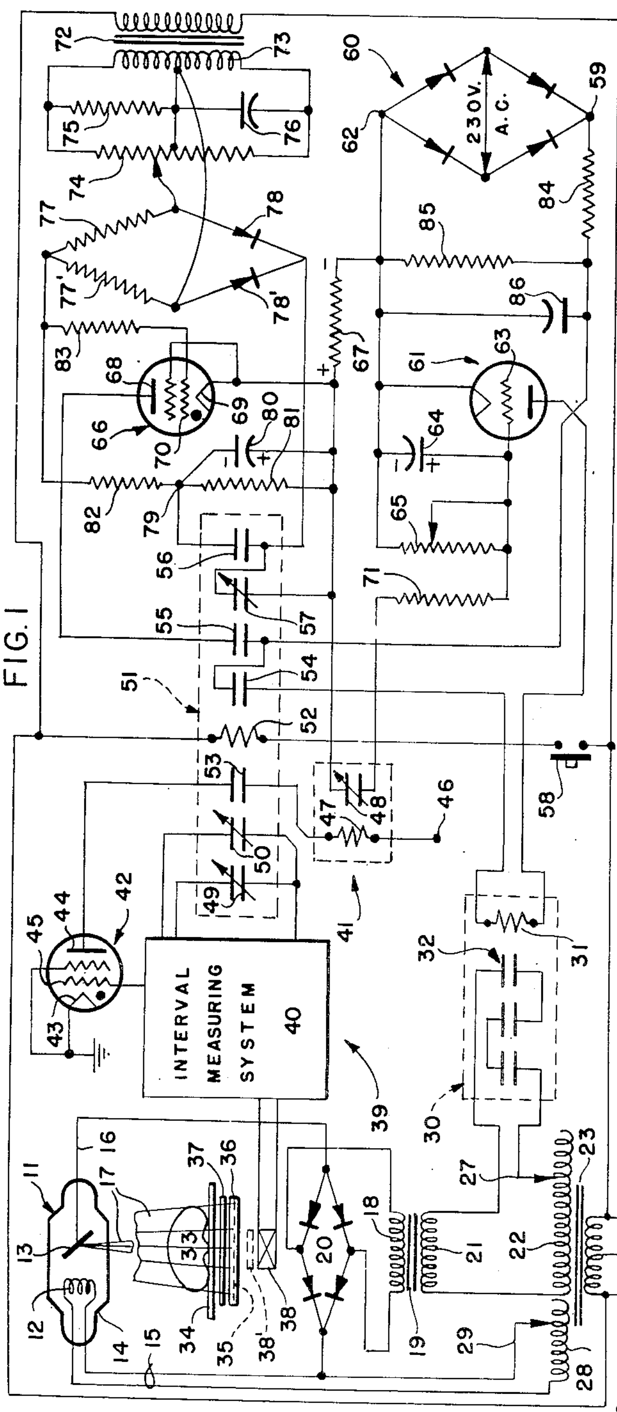

FIG. 1

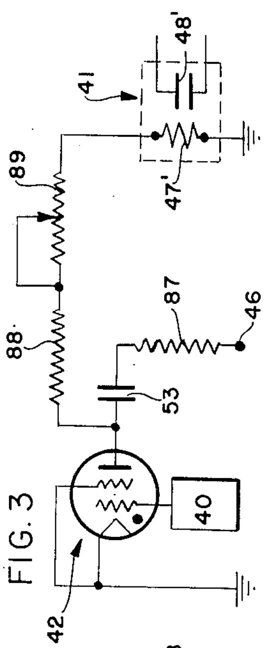

FIG. 3

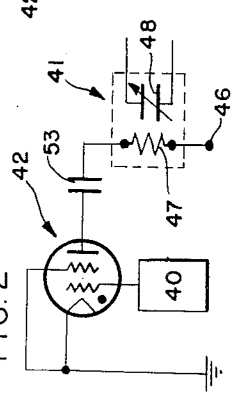

FIG. 2

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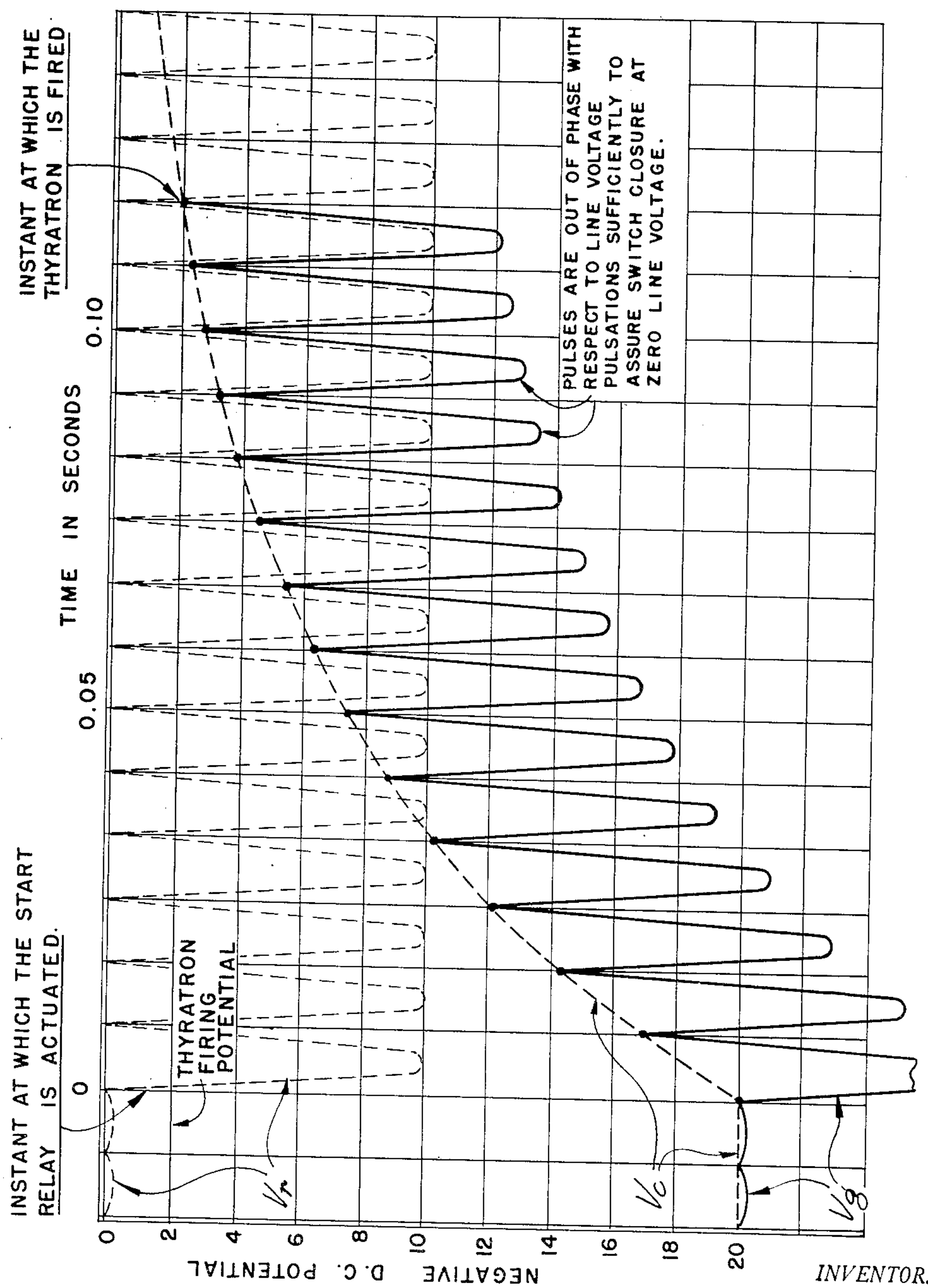

FIG. 4

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SWITCHING SYSTEM

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7 Claims. (Cl. 250—95)

This invention relates generally to improvements in electrical switching and more particularly to a high speed switching system adapted for the control of an energizing circuit for X-ray or other equipment.

An important object is to provide an improved switching circuit for initiating operation of an X-ray tube or other device operable from an A. C. supply line in synchronized relation to current and voltage waves in the supply line.

A more specific object is to provide an improved switching system for the control of X-ray apparatus of the type including interval measuring means for timing exposure intervals.

Another object is to provide, in a circuit including electromechanical switches and adapted for use with a device, the operation of which is controlled by an interval timer, improved means for inactivating the device following cut-off by the timer and independently of the drop-out delay intervals of the switches or other circuit components and in measured timed relation to current or voltage fluctuations in an A. C. supply line, thus permitting addition of a uniform and measured drop-out interval to the operating interval measured by the timer for accurate computation of total operating time.

In the drawings:

Figure 1 illustrates diagrammatically a switching circuit adapted for the control of X-ray equipment and embodying the invention.

Figure 2 (not used—same as Fig. 1 circuitry).

Figure 3 shows a modification of a portion of the circuit of Figure 1.

Figure 4 illustrates graphically the operation of the circuit of Figure 1.

Figure 1 may conveniently be divided into major subcircuits for simplification of the principles of operation. The circuitry shown at the left illustrates a conventional X-ray tube 11, autotransformer 23 fed from an A. C. power line 25 which is common to all of the circuit components, a step-up transformer 19 and an optional rectifier 20. Primary 21 of transformer 19 is controlled by an electro-magnetic switch 30 having plural contactors 32 series connected to secondary 22 of autotransformer 23. Table 34 provides support for object 33, grid 37 and cassette 36 being conventionally positioned. A sensing device 38 which may change impedance in response to the magnitude of detected X-radiation is in circuit with an interval measuring system 40 of known type which feeds an output signal to fire thyratron 42 in response to an amount of X-radiation to which detector 38 is exposed. The above X-ray circuit is well known and is illustrated merely to teach one application of the invention which has equal utility in respect to the control of various other types of devices.

Identification of circuit components

The sub-circuit shown in the upper right hand portion of the drawing is a phase shiftable D. C. bias supply and below it is shown a rectified source of voltage

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to provide D. C. anode potential for the triode 61 and thyratron 66, plus triggered actuating potential for electro-magnetic switch 30. The other major components of the circuit consist of a plural contactor electromechanical switch 51 (to the right of system 40), operable from the position shown with contactors 53, 54, 55 and 56 open and contactor 57 closed, to a reversed position upon closure of switch 58 and resulting excitation of coil 52. A second electro-mechanical switch 41 is D. C. operated from a source 46 upon closure of contactors 53 to supply anode potential to thyratron 42 and effect the firing thereof in response to an output signal from system 40. The third electro-mechanical switch 30 includes, in addition to contactors 32, abovementioned, a coil 31 actuated by D. C. through the triggering of a triode 61, as later described. With the major circuit components thus in mind, their interaction can best be understood by first considering the novel end results obtained and later examining the contributing operation of the sub-circuits.

What the invention accomplishes

The ultimate purpose of the invention is to apply a D. C. signal to coil 31 of switch 30, timed in respect to supply line current fluctuation to effect closure of contactors 32 and the resulting application of anode potential to X-ray tube 11 at or near zero line current, thus reducing transients and increasing timing accuracy. While the circuit operation will hereafter refer only to fluctuations in line current, it will be apparent to persons familiar with power factor considerations that the circuit may be synchronized for an optimum line condition mathematically obtained from the relation of current to voltage waves, but not coincident with either. The circuit is compensated for drop-out lag of both switches 30 and 41 as later explained. Coil 31 of switch 30 receives its D. C. actuating signal through triode 61 when that tube is triggered conductive by the firing of thyratron 66 in synchronized phase relation to the line current, but normally shifted in respect thereto. The firing of thyratron 66 is accomplished in a novel manner later described in detail, but can only fire at certain phase positions in respect to supply line voltage fluctuations.

The phase shiftable bias supply

Brief consideration of the phase shift network shown in connection with the bias supply is now in order. Transformer 72, fed from the common supply line 25 has a tapped secondary 73 with resistive and capacitive elements 75 and 76 of equal impedance connected across the half sections. Potentiometers 74, of much higher impedance than elements 75 and 76, reflects the phase displacement across these series connected elements, any displacement between 0–180° thus being obtainable between the secondary center tap and the potentiometer brush. This phase shiftable signal is full-wave rectified by the network comprising resistors 77—77[1] and dry rectifiers 78—78[1] or by any other suitable full-wave rectifier to provide tube biasing potential. The point of novelty resides in the concept of providing a D. C. biasing source which is phase shiftable in respect to the voltage wave in a common A. C. line and in the manner in which that source is employed to effect the desired actuation of switch 30, hence any other phase shifting network can be employed without departure from this concept.

How the device being controlled is switched on

With power line 25 connected through switch 26, rectifier 60 operates to establish steady D. C. across capacitor 86, but that D. C. is isolated from the anodes of triode 61 and thyratron 66 by open contactors 54 and 55, and is further prevented from establishing current flow through coil 31 by triode 61, since that tube is cut off with the grid 63 thereof at cathode potential. The bias supply is however not equally idle under the circuit conditions shown, since capacitor 80 charges, being series connected with resistor 82 across the bias rectifier through closed contactors 57, but nothing else happens, circuitwise. The circuit is thus shown in a pre-operative condition required for the charging of capacitor 80 by the drop across resistors 81 and 82 and requires the closure of line switch 58 to be rendered fully operative. Upon closure of switch 58, all contactors 53, 54, 55, 56 and 57 are reversed from the condition shown, with contactors 54 bringing anode potential to triode 61, which still remains cut-off, hence no current flows through coil 31. The lower positive end of the bias rectifier is switched from the lower to the upper end of resistor 81 by reversal of contactors 56 and 57 to terminate current flow through capacitor 80 which starts discharging through resistor 81 simultaneously with the application of a full-wave rectified but unfiltered signal across resistor 82. Since capacitor 80 and resistor 82 are series connected through resistor 83 to grid 70 of tube 66, the applied negative voltage is instantaneously cumulative, with the charge on capacitor 80 decaying exponentially, as shown at V_c, Fig. 4.

Triode 61 has been thus far cut-off, since the cathode and the grid are at the same potential, but it is rendered conductive in the following manner. As condenser 80 dissipates its charge exponentially through resistor 81, it approaches the firing point of tube 66 as shown in Fig. 4, however the negative going pulses V_r impressed across resistor 82 by the bias rectifier in effect prevent grid 70 from reaching the cut-off point except at positions near the base of the successive negative going pulses, since both the rectified signal and the charge from condenser 80 are impressed on grid 70 through resistor 83, as shown in heavy lines, Fig. 4. Since the negative going pulses are phase shiftable in respect to line voltage fluctuations by adjustment of the potentiometer brush, it is apparent that the circuit may readily be adjustable to effect the firing of tube 66 at any point through 0–180° phase displacement in respect to line voltage and it is this basic concept which governs the actuation of switch 30 to switch on the X-ray tube 11 at a desired point of zero or near zero line current.

The firing of thyratron 66 establishes current flow in resistor 67 which serves as a load resistor for tube 66. The resulting voltage drop across 67 is employed to trigger triode 61, its cathode being connected to the negative end and its grid to the positive end of resistor 67 to swing the grid sufficiently positive to render tube 61 fully conductive. The resulting D. C. current flow through tube 61 is applied to coil 31 through closed contactors 54 to switch on tube 11 at a point phase locked in respect to the line current wave to complete operation of that portion of the circuit. The magnetic field status of coil 31 is improved by the application of D. C. to effect a more uniform pickup time than is possible with A. C., thus insuring phase locking of the contacts and consequent circuit closure.

Switching the device off with a measured drop-out interval

Since the purpose of system 40 is accurately to measure time as a function of a device initiated effect, such as a quanta of X-radiation, system 40 produces, at the end of that time interval, its output signal to fire thyratron 42 to open contactors 48 of switch 41, which will result, after a drop-out time delay, in the opening of switch 30 to terminate operation of X-ray tube 11. As is well understood, however, cut-off of a device controlled by electro-magnetic switches cannot be instantaneous due to the drop-out time intervals of the switches such as 41 and 30. Hence without further correction for those intervals, tube 11 would operate for a period of time after the firing of thyratron 42, and since the extent of that interval, if left to chance, would not be accurately determinable, the total operating time of X-ray tube 11 or any function of that operating time such as detected X-ray quanta would be the sum of an accurate indication from system 40 plus the drop-out interval. With short exposure intervals commonly used in radiography, the drop-out interval may equal a substantial portion of the exposure interval.

The circuit provides for an adjustable total drop-out interval which includes cumulatively the drop-out intervals of switches 41 and 30 plus the bias controlled cut-off time of triode 61, in the following manner. Capacitor 64 is of a pre-selected value and charges upon firing of tube 66 and the establishment of a voltage drop across resistor 67. Opening of contactors 48 with the firing of tube 42 removes the positive grid bias from tube 61 by opening the circuit to resistor 67, but sufficient charge has been stored in capacitor 64 to hold tube 61 conducting until that charge leaks off to the cut-off point through adjustable resistor 65, resulting in the opening of switch 30. In a practical application of the circuit, the drop-out intervals of electromagnetic switches 30 and 41 give a total drop-out interval of less than one-half cycle of line current fluctuation. Therefor, the time constant of capacitor 64 and resistor 65 is adjusted to a value that when added to the drop-out intervals of switches 41 and 30 insure a total drop-out interval equal to one-half cycle of current wave. Drop-out intervals equal to one-half cycle or a multiple thereof are employed because the radiation resulting from a half cycle of operation is a constant for any given exposure condition hence the interval timer may include an anticipator circuit taking this constant into consideration to measure total exposure. Any desired multiple of this total drop-out time may be selected to compensate for longer switch drop-out intervals, the important point being that the device, such as X-ray tube 11, is cut-off at a known time interval after system 40 performs its function, hence the actual operating time of the device is obtainable from the sum of two accurately measured intervals.

Fig. 3 shows alternate circuitry for actuation of switch 41 in response to the firing of thyratron 42. Contactors 53 are open, as in Fig. 1, but when closed by switch 58 coil 47 is energized through fixed and adjustable resistors 88 and 89 respectively to close contactors 48^1. When tube 42 fires, source 46 is shorted to ground through load resistor 87 with D. C. energization time of coil 47^1 controlled by series resistors 88 and 89. Since the drop-out constant

$$\frac{L}{R}$$

of switch 41 is controllable by resistor 89, permitting adjustment of total drop-out time for the circuit, a variable is not required in the grid circuit of tube 61, hence that tube can be operated at a shorter cut-off time constant.

It will be readily apparent that the above described inventive concepts are applicable to numerous other circuit arrangements which may control devices of widely differing characteristics. The appended claims establish the parameters of those concepts.

The invention is hereby claimed as follows:

1. The combination with a work device operable by pulsating current and a source of such current, of triggerable switch means for current control between said device and source, said means being operably associated with said source and triggerable in locked phase relation to current pulsations, whereby to connect said device to said source only at or near zero value of current pulsations.

2. In a switching circuit, an alternating current work device, a triggerable switch for the control of said device, means for triggering said switch including phase shifting

means, a source of alternating current common to both said device and phase shifting means, and circuit means cooperatively associated with said triggering means, said phase shifting means, and said switch, whereby to effect actuation of said triggering means and resulting actuation of said switch only at or near a zero point in the current wave of said source.

3. The combination with an alternating current source, an energy emitting device drawing current from said source, and a measuring device responsive to said emitted energy, said measuring device having associated therewith instantaneously triggerable means adapted to be energized by said measuring device; of a switch phase locked to the current of said source for connecting said emitting device to said source, and a second switch operatively associated with said phase locked switch and responsive to the triggering of said discharge device to inactivate the first switch and disconnect said emitting device from said source.

4. The circuit of claim 3 including time delay means operable in response to the triggering of said second switch to actuate said first switch at a predetermined time interval after the triggering of said first mentioned triggerable means.

5. In a switching circuit adapted for timed energization of a device from an alternating current source, a switch for energizing said device, means for the timed termination of an energizing period, a second switch responsive to the actuation of said timing means for disconnecting said source, said switches having inherent drop-out delay characteristics, and a time delay circuit associated with said second switch to add an interval, which, together with the drop-out intervals of both switches, equals a half cycle of line current or a multiple thereof.

6. The combination of a device operable from an alternating current source, timing means for terminating operation of said device, an electro-magnetic switch between said device and said source, means adapted to be phase locked to said source to energize said device through actuation of said switch at a point of low current, a second electro-magnetic switch, an instantaneously triggerable electron discharge device in circuit with said timing means and said second switch to be triggered by an output signal from said timing means for actuation of said second switch, and time delay means associated with said second switch to add an interval which, together with the drop-out intervals of the electro-magnetic switches equals a half cycle of line current or any multiple thereof.

7. In a device of the character described, the sub-combination including a thyratron adapted to be fired at the end of a timed interval, an electro-magnetic switch including a coil, and a circuit for actuation of said switch in response to said firing, said circuit including a variable resistance series connected to one end of said coil and to the thyratron anode, a D. C. source with the positive side connected to said anode; the opposite end of said coil, the negative end of said source, and the cathode of said thyratron being interconnected to energize said coil with the thyratron cut-off, whereby firing of the thyratron shorts the anode potential to deenergize said coil and inactivate said switch, the drop-out period of said switch being adjustable through said variable resistance.

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