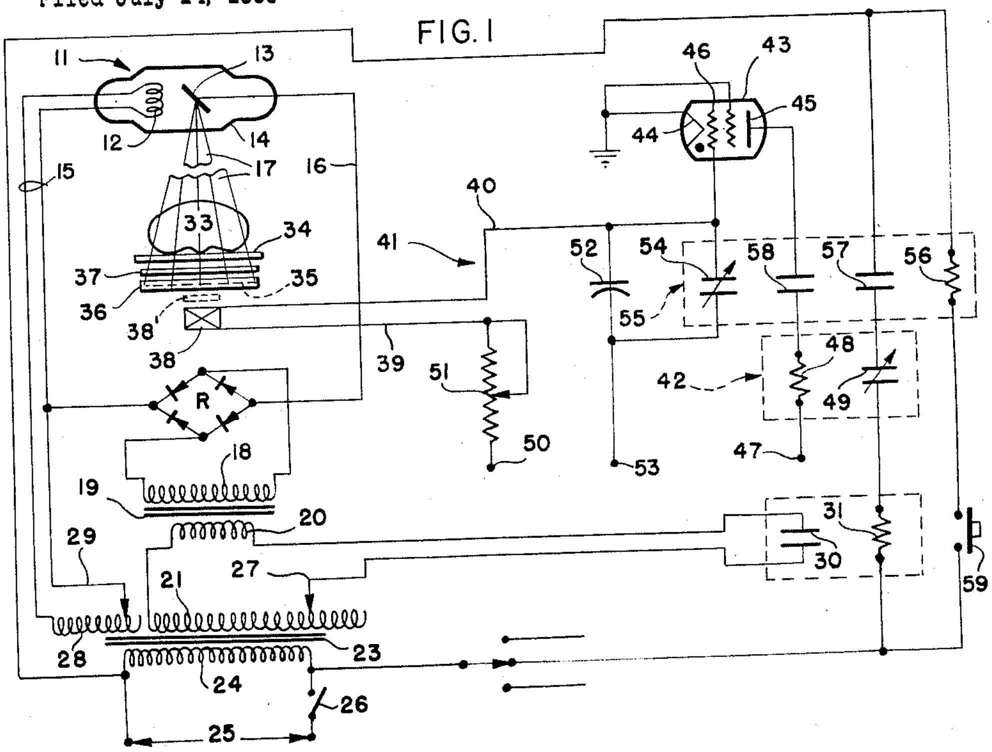
Oct. 20, 1959 R. GODBARSEN, JR 2,909,666

INTERVAL TIMING APPARATUS AND METHOD

Filed July 14, 1953 5 Sheets-Sheet 1

FIG. 1



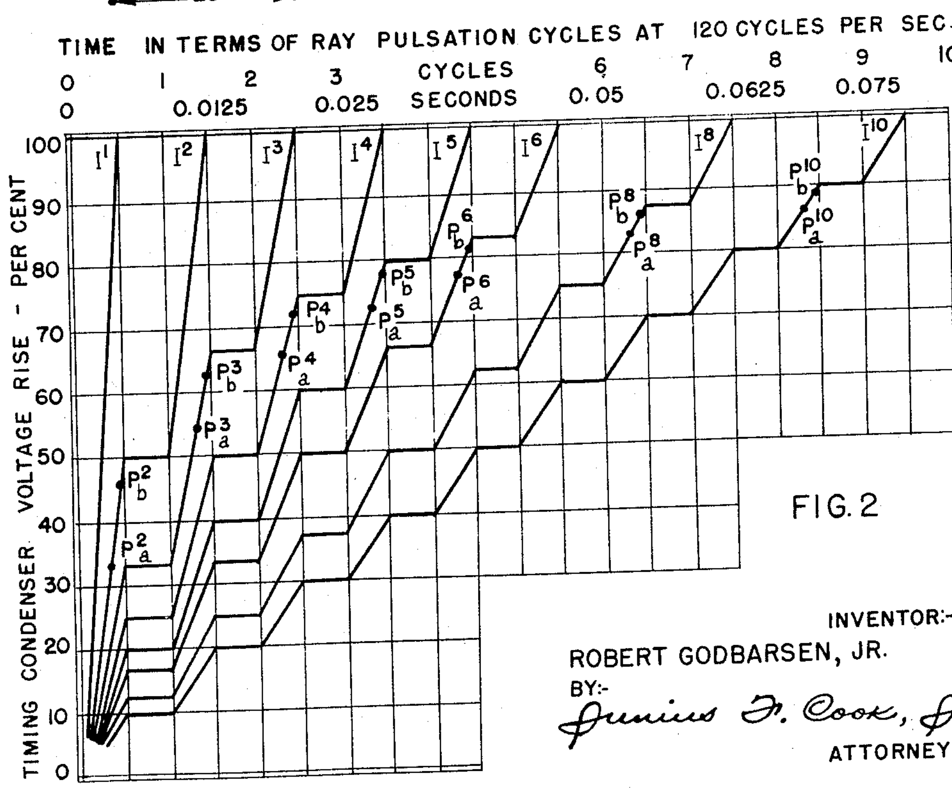


FIG. 2

INVENTOR:-
ROBERT GODBARSEN, JR.
BY:-
Junius F. Cook, Jr.
ATTORNEY

INTERVAL TIMING APPARATUS AND METHOD

Filed July 14, 1953 5 Sheets-Sheet 2

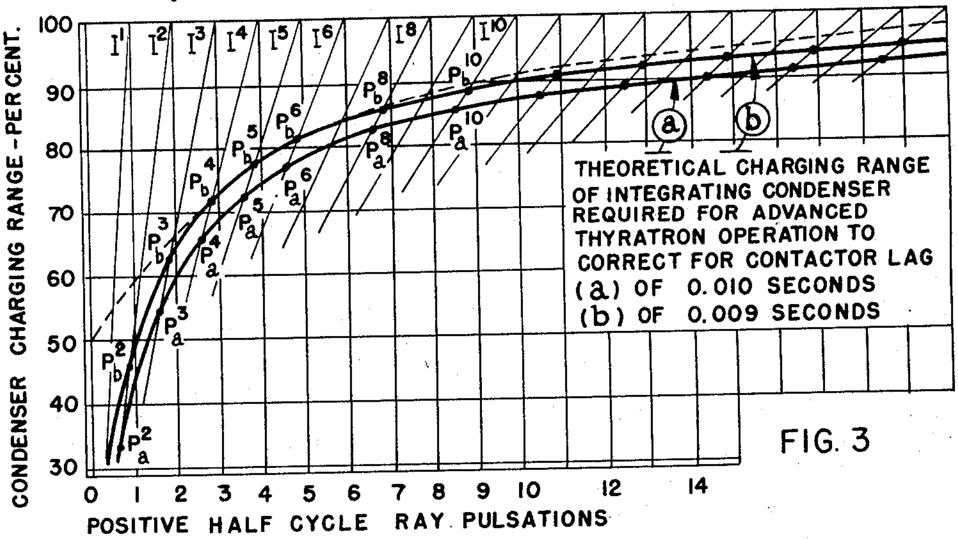


FIG. 3

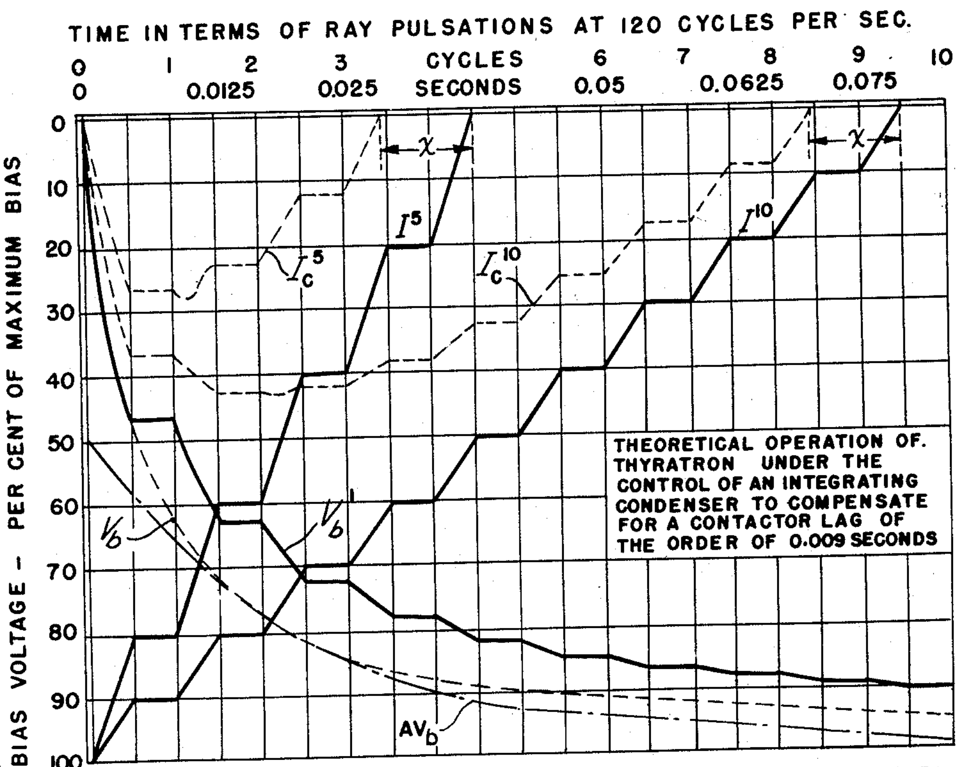


FIG. 4

INVENTOR:-
ROBERT GODBARSEN, JR.
BY:-
Junius F. Cook, Jr.
ATTORNEY

INTERVAL TIMING APPARATUS AND METHOD

Filed July 14, 1953 5 Sheets-Sheet 3

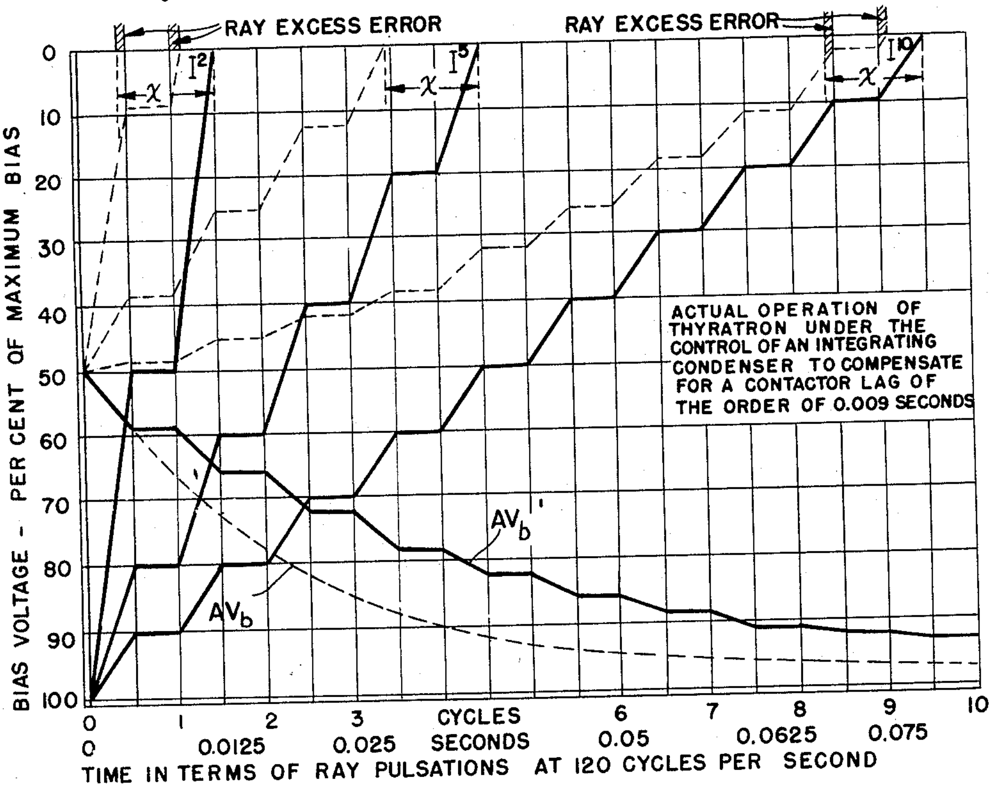


FIG. 5

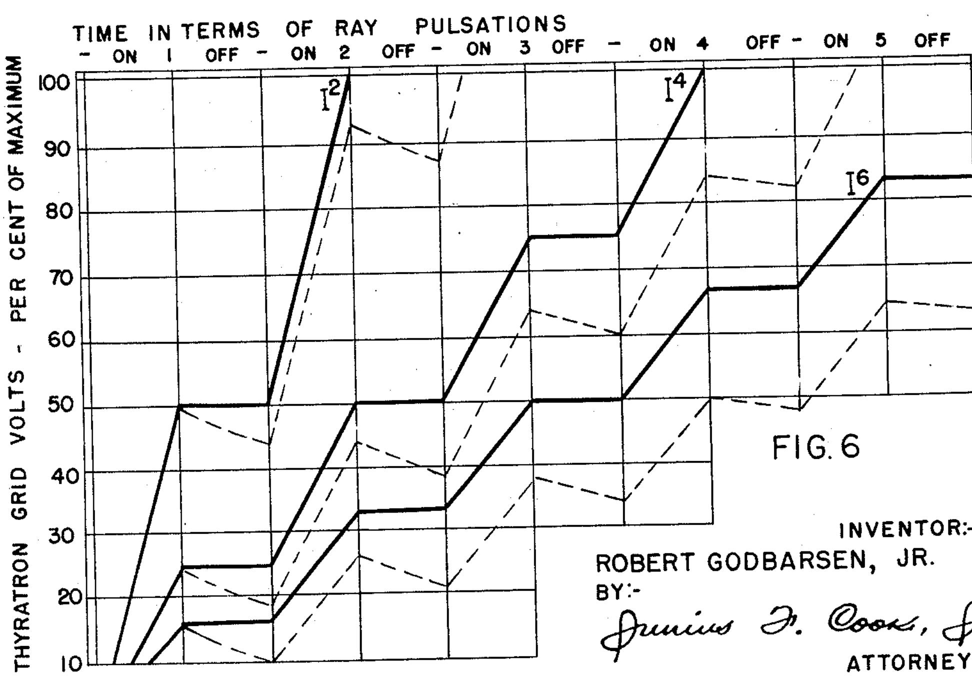


FIG. 6

INVENTOR:-
ROBERT GODBARSEN, JR.
BY:-
Junius F. Cook, Jr.
ATTORNEY

INTERVAL TIMING APPARATUS AND METHOD

Filed July 14, 1953 5 Sheets-Sheet 4

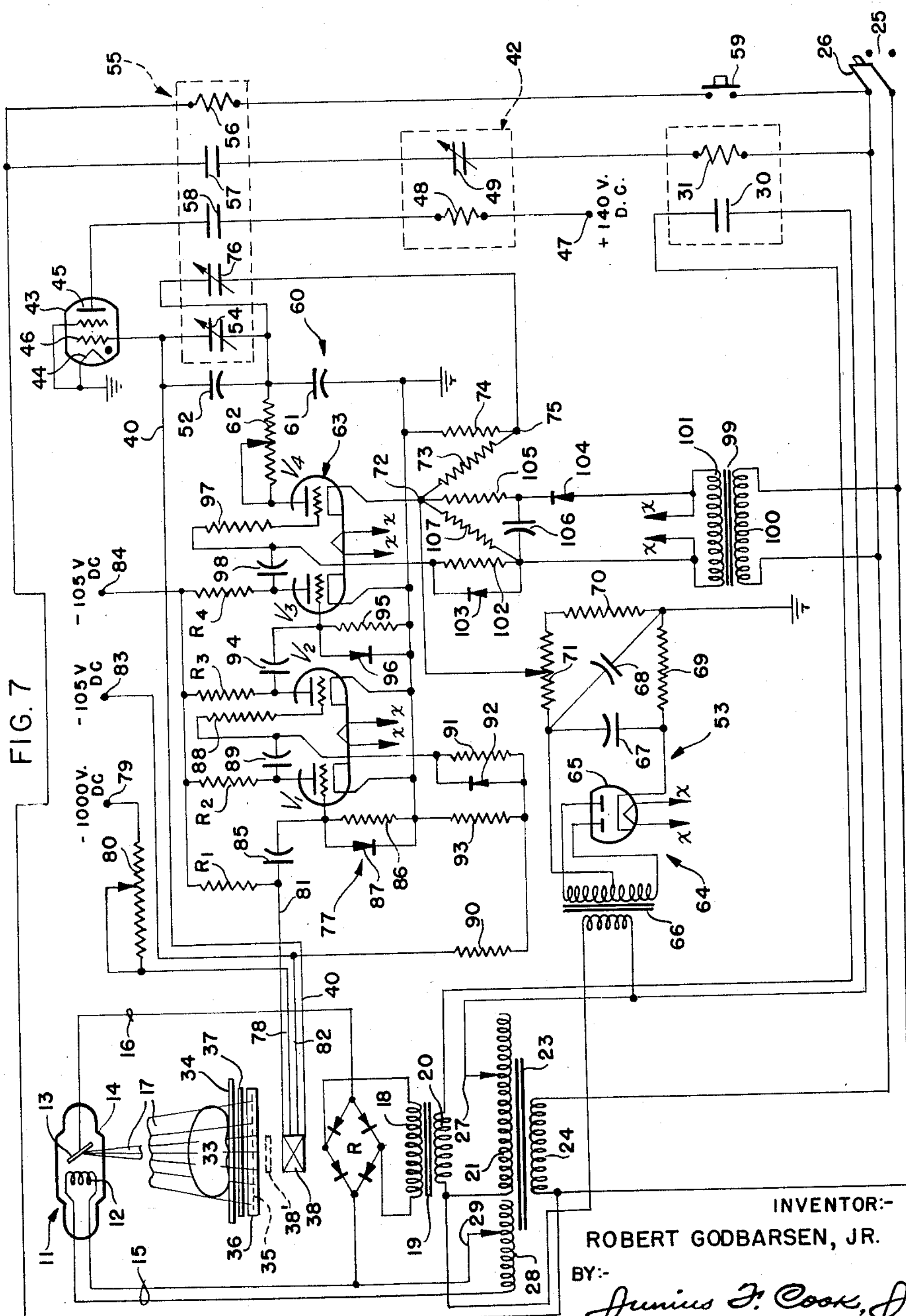


FIG. 7

INVENTOR:-
ROBERT GODBARSEN, JR.
BY:-
Junius F. Cook, Jr.
ATTORNEY

INTERVAL TIMING APPARATUS AND METHOD

Filed July 14, 1953 5 Sheets-Sheet 5

FIG. 8

VOLTAGE ON CONDUCTOR 81

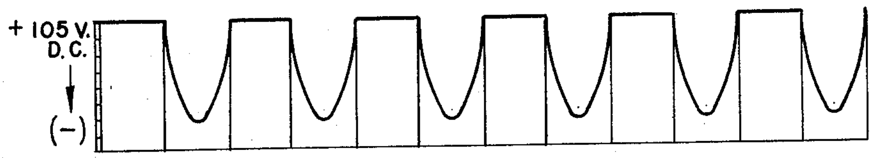


FIG. 9

GRID - CATHODE VOLTAGE - VALVE V_1

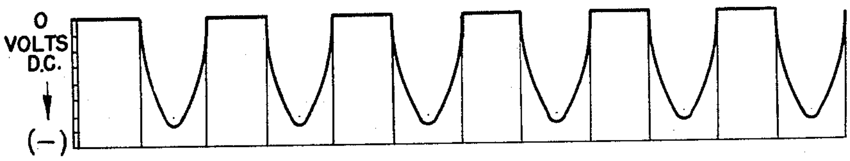


FIG. 10

GRID - CATHODE VOLTAGE - VALVE V_2

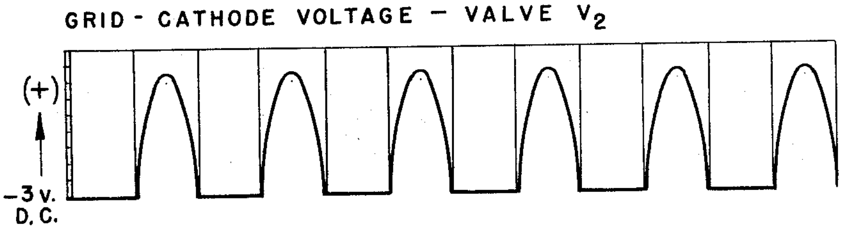


FIG. 11

GRID - CATHODE VOLTAGE - VALVE V_3

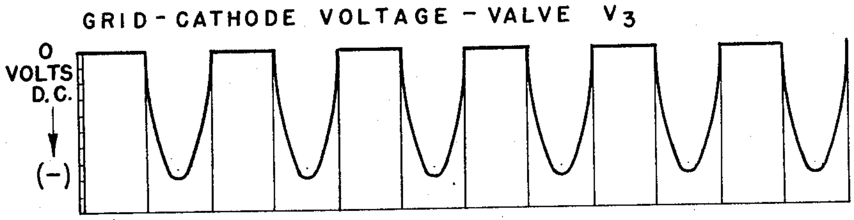
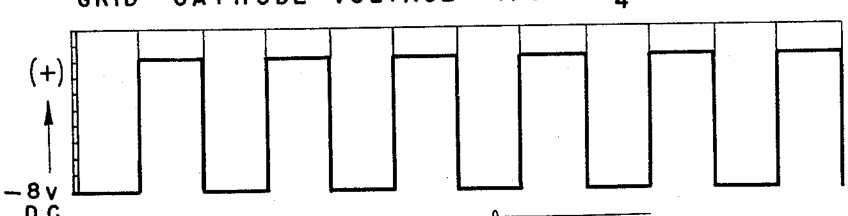


FIG. 12

GRID - CATHODE VOLTAGE - VALVE V_4



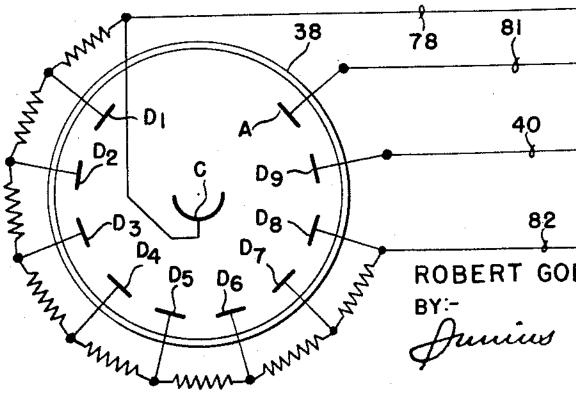


FIG. 13

INVENTOR:-
ROBERT GODBARSEN, JR.
BY:-
Junius F. Cook, Jr.
ATTORNEY

United States Patent Office 2,909,666
Patented Oct. 20, 1959

2,909,666

INTERVAL TIMING APPARATUS AND METHOD

Robert Godbarsen, Jr., Milwaukee, Wis., assignor to General Electric Company, a corporation of New York

Application July 14, 1953, Serial No. 367,937

8 Claims. (Cl. 250—95)

The present invention relates in general to the measurement of elapsed time intervals, and has more particular reference to the measurement of exposure intervals, the invention pertaining specifically to the provision of means for timing relatively short exposure intervals of the sort frequently employed in X-ray photography.

Timing apparatus of the character mentioned may comprise means operable to measure any elapsed time interval, within the range of the equipment and controllingly associated with translation circuitry for the actuation of relay switch means at the beginning and end of the measured interval, such relay switch means being connected with apparatus such as ray generating equipment to be operated during the measured time interval. An inherent characteristic of relay switches is that the same do not operate instantly. Because of inertia forces, there is always a time delay or lag interval between the instant at which a thyratron fires and the moment of effective response of the thyratron controlled relay switch means in disabling the associated ray generating apparatus, to thus terminate the exposure interval. While this time delay or operational lag may be relatively short, that is to say, of the order of 0.005 to 0.01 second, per switch, or 0.01 to 0.02 second where a pair of successively operating switch devices are involved, the delay, nevertheless, may represent a substantial and undesirable prolongation of an exposure interval, particularly where the exposure interval being measured is short. Where the exposure interval is of the order of one-fifth second, a prolongation of the interval by as much as 0.02 second will represent a 10 percent increase in the duration of the exposure interval. The prolongation, by 0.02 second, of an exposure interval of one-fiftieth second in duration, however, represents a 100 percent increase in the duration of the exposure interval.

An important object of the present invention is to provide an interval measuring or timing system of the character described having means for anticipating the end of a timed interval and for starting operable equipment, such as thyratron actuated relay switch means, in operation, sufficiently in advance of the end of the interval being timed, to offset the lag or delay in the effective operation of such operable equipment, whereby to accomplish a desired control function precisely at the end of the interval being timed.

Another important object is to provide for compensating an interval measuring system of the character described for operational time lag of relay means actuated by a thyratron valve under the control of an integrating condenser, by applying a varying negative bias in the system during the interval being timed, in order to cause the thyratron to fire sufficiently in advance of the end of the interval being timed to compensate for the operational lag of the switch means; a further object being to exponentially vary said compensating bias.

Another important object is to compensate for the operational lag time of mechanical elements in an interval measuring system embodying a thyratron valve for actuating said elements at the end of the measured interval, which consists in determining empirically or otherwise the operational lag interval of said elements and applying a variable negative bias in the system to cause the valve to operate, in advance of the end of the interval being measured, by an interval equal to the operational lag interval of said elements, regardless of the duration of the interval being measured.

Another important object is to employ a control circuit embodying resistance and capacity factors for applying a variable negative bias in a system of the character mentioned.

Apparatus for measuring ray exposure intervals by means of a thyratron valve operable under the control of an integrating condenser to de-limit the end of an interval being measured, may be operated by continuously charging the condenser, during the interval being measured, at a rate equal to the average ray quanta delivered during the interval, such arrangement being satisfactorily accurate where the rays are emitted continuously. It will be seen, however, that where the rays are emitted in pulses, the continuous delivery of charging current to an integrating condenser, during a period being measured, will result in the actuation of the connected thyratron sooner than the same would be actuated if the condenser were charged pulsatingly and precisely in accordance with the pulsations of the emitted rays.

Accordingly, it is an important object of the present invention to provide means in a system of the character mentioned for pulsatingly charging an integrating condenser in precise conformity with pulsating rays emitted during an exposure interval being measured.

Another important object is to provide means precisely responsive to the energy quanta of pulsating rays for measuring a ray exposure interval in terms of total ray quanta emitted pulsatingly during the interval and for actuating operating equipment, having inherent operational time lag characteristics, sufficiently in advance of the end of the interval being timed to permit the equipment to effectively complete its operational action precisely coincidentally with the end of the interval being measured.

Another important object is to include, in the integrating system, switch means operable to disable the integrating condenser during intervals between successive ray pulsations when no rays are delivered from the ray source; a still further object being to utilize electronic switching means for thus disabling the integrating condenser.

Another important object is to compensate for the operational time lag of mechanical equipment in an X-ray phototiming system embodying a thyratron valve, controlled by an integrating condenser, for actuating said equipment at the end of an exposure interval, which consists in determining said operational time lag, empirically or otherwise, and then providing for applying an exponentially variable bias on the integrating condenser to cause the same to actuate the thyratron to start the mechanical equipment in operation, in advance of the end of the interval being timed by a period equal to the lag interval of said equipment; a further object being to calibrate the equipment to bias the apparatus in accordance with the time constant of a resistance-capacity timing circuit approximating a selected exponential function, thereby providing the required bias conditions for causing precisely accurate operation of the equipment within a limited interval measuring range; a still further object being to provide equipment of the character mentioned embodying a plurality of resistance-capacity biasing systems, each adapted to bias the system in accordance with a corresponding time constant to accurately produce required bias conditions within successive limited timing ranges within the over-all timing range of the equipment.

The foregoing and numerous other important objects, advantages, and inherent functions of the invention will become apparent as the same is more fully understood from the following description, which, taken in connection with the accompanying drawings discloses a preferred embodiment of the invention.

Referring to the drawings:

Fig. 1 is a diagrammatic view of conventional interval measuring apparatus of the sort embodying a thyratron valve controlled by a ray responsive integrating condenser, the same providing an operational environment for the present invention;

Fig. 2 is a graphical representation of the performance of the integrating condenser in measuring ray quanta at various delivery rates in the conventional system shown in Fig. 1;

Figs. 3, 4, 5 and 6 are graphs illustrating the manner in which the integrating condenser is necessarily controlled, in accordance with the present invention, in order to correct for the operational lag times of operable means controllably associated with the thyratron valve;

Fig. 7 is a diagrammatic view of interval measuring apparatus embodying the present invention;

Figs. 8, 9, 10, 11 and 12 are graphs illustrating the operation of the system shown in Fig. 7; and

Fig. 13 is a diagrammatic showing of a preferred form of light sensitive detector which may be employed in systems embodying the invention.

To illustrate the invention, the drawings show a controllable source of X-rays comprising a conventional X-ray generating tube **11** having an electron emitting cathode **12** and an anode **13** forming an electron target disposed in position to receive the impact of electrons emitted by and at the cathode. The cathode and anode may be connected respectively with conductors **15** and **16** which extend outwardly of the envelope **14**, through suitable seals, for the purpose of applying tube energizing power to excite the cathode for electron emission, and to drive cathode emitted electrons at high speed toward the anode under the influence of electron driving potential applied between the anode and cathode. Impingement of electrons upon the cathode facing target surface of the anode **13** constitutes the target surface as an X-ray source from which the generated X-rays may be emitted outwardly of the envelope in the form of an X-ray beam **17**.

To operate the tube **11** as an X-ray generator, the anode conductor **16** and one of the cathode conductors **15** may be connected with the secondary winding **18** of a step-up transformer **19**, either directly, where the generator is to be operated as a self-rectified device, or through a suitable rectifier R if the device is to be operated by full wave rectified alternating current power.

To energize the transformer **19**, its primary winding **20** may be connected with the secondary winding **21** of a step-up transformer **23**. The primary winding **24** of this step-up transformer may be connected with a suitable power source **25**, preferably through a disconnecting switch **26**. Means, such as an adjustable connection **27** with the secondary winding **21**, may be and preferably is provided for varying the potential applied between the anode and cathode. To energize the cathode **12** for electron emission, the conductors **15** may be connected with a secondary winding **28** of the transformer **23**, preferably through an adjustable connection **29**.

In order to start and stop the generation of X-rays, a control switch **30** may be interposed at any convenient location in the anode-cathode power supply system, the switch **30**, as shown, being preferably connected in the power supply circuit to the primary winding of the transformer **19**. The switch **30** may comprise a normally open relay switch adapted to be closed, by an associated coil or solenoid **31**, when and so long as said coil is energized, as from the source **25**.

The X-ray beam **17** may be applied to any useful purpose, including the therapeutic irradiation of the body **33** of a patient, which may be supported for treatment in the path of the beam **17**, as on a treatment table **34**. The beam **17** may also be usefully employed for the production of X-ray shadow pictures of the body **33** or other object to be pictured, by mounting a sheet of X-ray sensitive film material **35**, preferably enclosed in a suitable light-tight cassette **36** in the path of the beam **17** on the side of the body **33** remote from the X-ray source, so that the film material **35** may be exposed to the action of the ray beam after it shall have passed through the body **33**, to thus impose, upon the film, an X-ray shadow picture of the body, in accordance with known X-ray photography procedures, which may include the arrangement of a Bucky diaphragm **37** between the body being pictured and the cassette enclosed film.

In thus applying X-rays to the bodies of patients for either therapeutic or radiographic purposes, it is highly desirable to determine accurately the total amount or quanta of X-rays applied to the body during the exposure interval, and to terminate the exposure precisely as and when a predetermined or selected X-ray quanta has been applied. Such accuracy is highly desirable for radiographic purposes in the interests of obtaining exposed films of optimum density. The accurate determination of ray quanta during X-ray therapy is likewise of importance, especially where the desired exposure is near the safe exposure limit for the subject being treated.

To this end, X-ray sensitive means may be disposed in any convenient location in the path of the X-ray beam **17**. As shown, the sensitive means may be mounted upon the side of the body **33** remote from the X-ray source, so that rays, in reaching the sensitive means, will first pass through the body **33**. Any suitable ray sensitive means may, of course, be employed for ray detecting purposes. To that end, the sensitive means may embody a detector element or cell **38** which may comprise crystalline, ray sensitive semi-conductor material, such as cadmium or mercury sulphide or cadmium selenide, of the sort disclosed in an application for United States Letters Patent Serial No. 250,141, filed October 6, 1951, on the invention of John E. Jacobs in Interval Timing Apparatus, which issued on May 22, 1956 as U.S. Patent No. 2,747,104. Such crystalline semi-conductor materials have impedance characteristics which vary precisely in proportion to the quanta of X-rays applied thereto, and, consequently, a unit **38** comprising such ray sensitive materials may be employed in a suitable electrical integrating system to precisely measure the X-ray quanta applied through the body **33** and upon the sensitive detector element **38**.

Alternately, the element **38** may comprise a photosensitive cell of the sort disclosed in United States Letters Patent No. 2,401,289 of May 28, 1946, covering a Photoelectric Timer System invented by Russel H. Morgan and Paul C. Hodges, such photoelectric unit serving to measure X-ray quanta applied upon a sheet of ray sensitive fluorescent material **38'** in terms of the amount of light emitted by the fluorescent sheet under the influence of X-rays impinging thereon.

The element **38**, whether the same be directly ray sensitive crystalline material, such as cadmium sulphide, or whether the same be a photo cell actuated by light rays emitted by an X-ray sensitive fluorescent screen **38'**, may be electrically connected in an electrical translation system **41** for the operation of the switch **30**, in order to open the same at the conclusion of a measured exposure interval. As shown, the translation system **41** may comprise means for integrating the response of the detector unit **38**, to thereby measure total X-ray quanta delivered during an exposure interval being measured, and for actuating a load device **42** for the disablement of the X-ray source **11** at the conclusion of the exposure interval. To these ends, the translation system **41** may embody a thyratron tube **43**, the same comprising a gas filled electron flow device having a cathode **44**, an anode **45**, and a control grid **46**. The cathode and anode **44** and **45** may be interconnected in an output circuit including a suitable power source **47** and the load device **42** which, in the illustrated embodiment, comprises the operating coil **48** of a normally closed relay switch **49**.

The control grid **46** of the thyratron may be connected in a control circuit in which the sensitive element **38** is also operatively connected; and means is provided for electrically energizing the grid **46** for the control of the tube **43** in accordance with total current caused to flow in the element **38** during an X-ray exposure interval to be timed. The sensitive element **38**, accordingly, may be electrically connected with the grid **46** of the thyratron through a conductor **40**. The grid control circuit may also include a preferably uni-directional power source **50** and a variable resistor **51** interconnected in series with the power source and with the sensitive element **38** through a conductor **39**. The control circuit also includes an integrating condenser **52** connected between the grid of the thyratron **43** and a suitable source **53** of negative grid biasing power for the thyratron.

The control circuit may also include a normally closed disabling switch **54**, interconnected in parallel across the integrating condenser **52**, and a normally open anode circuit switch **58**, connected between the anode **45** of the thyratron and ground in series with the power source **47** and the relay coil **48**, the cathode of the thyratron being grounded, as shown, and hence connected with the grounded side of the power source **47**. So long as the anode circuit switch **58** remains open, the valve **43** will continue to be inactive because its anode circuit will be open at the switch **58**. Furthermore, while and so long as the switch **54** remains in closed position, a negative bias, of potential substantially in excess of that at which the thyratron fires, will be applied upon the thyratron grid **46** from the source of biasing potential **53**. The condenser **52** also will remain inactive so long as the same is short-circuited by the closed switch **54**, both sides of the condenser **52** being at a potential with respect to the cathode **44** equal to the negative potential applied on the grid **46**.

Means is provided for opening the switch **54** coincidentally with the closure of the switch **30** for the actuation of the X-ray generator at the start of an exposure interval. Accordingly, when the switch **54** opens and switch **58** simultaneously closes, the thyratron will continue to be inactive because biased beyond cut-off. In this connection, the condenser **52** will have no charge in so far as the grid of the thyratron is concerned, but its grid connected side will be at the negative potential with respect to said cathode **44** as supplied by the power source **53**. As electrical current is delivered from the detector **38** through the conductor **40** to the grid **46** of the thyratron and the grid connected side of the condenser **52**, as the result of X-ray excitation of the detector **38**, the grid connected side of the condenser **52** will progressively lose negative electrons, thereby becoming more and more positively charged. After an interval determined by the current flow controlled by the detector, the capacity of the condenser **52**, and the bias voltage applied on the grid **46** while the switch **54** is closed, the difference of potential between the control grid and cathode of the thyratron will increase to the bias voltage level at which the thyratron may fire. When the thyratron is thus fired or placed in operation, it will energize the relay coil **48** and cause the switch **49** to open. After being triggered, the thyratron **43** will continue in operation until the switch **55** is reclosed and the switch **58** reopened.

Any preferred means may be employed for utilizing the foregoing operation of the thyratron for the control of the X-ray source **11**. As shown, such control may be accomplished by providing a relay **55** having an actuating coil **56**, a normally open switch **57**, the normally open switch **58**, and the normally closed switch **54**. By energizing the coil **56**, the normally closed switch **54** may be opened, and thereafter may remain open until the coil **56** is again de-energized. Conversely, the switches **57** and **58** may close when the coil **56** is energized, and thereafter may remain closed so long as said coil remains energized. The coil **56** may be connected with the power source **25** in series with, and hence under the control of a normally open control switch **59**, preferably of the manually operable, push button type. The normally open switch **57** may also be connected in series with the normally closed relay switch **49** and the operating coil **31** of the normally open switch **30**, to form a series circuit connected with the power source **25**. The normally open switch **58** may be interconnected in the plate circuit of the thyratron, in series with the power source **47** and the operating coil **48** of the load device **42**.

In order to place the X-ray generating tube **11** in operation for the application of the X-ray beam **17** to the body **33**, the sensitive picturing material **35**, and the detector means, the switch **59** may be closed, as by the action of the roentgenologist in operative charge of the equipment, thereby energizing the relay coil **56** to open the switch **54** and to close the switches **57** and **58**. Closure of the switch **57** will complete a relay energizing circuit through the switch **49**, which at such time is in closed condition, and the operating coil **31** to thereby cause closure of the normally open switch **30**, in order to start the X-ray generator **11** in operation. Thereafter, the X-ray generator will remain in operation until a predetermined X-ray exposure, measured in terms of X-ray quanta, shall have been applied to the body **33**. Thereupon, the thyratron tube **43** may be caused to fire as the result of the integrating action of the condenser **52**. When the thyratron thus is activated, it will complete an operating circuit through the switch **58**, which at such time is in closed condition, in order to energize the coil **48** and thus open the energizing circuit of the coil **31** at the switch **49**. The coil **31** being thus de-energized, the switch **30** will open, thereby removing the electron driving potential from the anode and cathode of the X-ray tube, thus disabling the same as an X-ray source, whereby the application of the X-ray beam upon the body **33** will be discontinued.

It will be seen from the foregoing that the integrating condenser **52** may be operated substantially exactly for the measurement of X-ray quanta applied to the body **33** during an exposure in order to fire the thyratron precisely when the body has received a preselected amount of X-ray irradiation. It will be obvious, also, that operation of the X-ray generator **11** will be discontinued as the result of the operation of the thyratron after a short time interval required for the successive operation of the switches **49** and **30**. Ordinarily, the operation of such relay switch means requires an interval of the order of one-fiftieth second. Such delayed switch operation, accordingly, is a factor which, if disregarded, will introduce errors in the determination of X-ray exposure intervals, such errors becoming proportionally greater as the measured exposure interval becomes smaller.

In order to compensate for operational lag of the control relay means, the present invention provides for anticipating the termination of the exposure interval and for firing the thyratron sufficiently in advance of the end of the exposure interval to cause discontinuation of the operation of the X-ray source **11** precisely at the end of the exposure interval as measured by the condenser **52**. The operation contemplated by the present invention is obtained by causing the bias voltage delivered from the source **53** to vary, during the course of the exposure interval being measured, whereby to affect the charging range of the condenser **52**, so that, regardless of the rate of flow of condenser charging current or the duration of the interval being measured, the thyratron will be caused to operate sufficiently in advance of the end of the measured interval to compensate for the operational lag of relay switching means driven by the thyratron.

The charging characteristics of the integrating condenser **52**, where the power source **53** supplies a bias potential of constant value, are shown in Fig. 2, in terms of elapsed time, between zero charge when both sides of the condenser are at the voltage supplied from the source **53**, upon the opening of switch **54**, and fully charged condition when the thyratron grid connected side of the condenser reaches the critical thyratron actuating voltage, the charging characteristics of the condenser being shown for various values of charging current supplied through the conductor **40** under the control of the sensitive detector **38**. The charging current thus supplied to the condenser **52** will, of course, vary with the quality or intensity of the X-rays comprising the beam **17**, the distance between the ray source **11** and the detector means, the thickness and texture of the object **33**, and the ray absorbing quality of its constituent material.

The several lines I^1–I^{10}, shown in Fig. 2 of the drawings, represent the charging characteristics of the condenser **52** in response to emitted rays of various intensity values. Line I^1 represents the action of the condenser when rays are emitted at relatively high intensity such that the detector **38** releases condenser charging current at a rate such that the condenser is charged to thyratron firing condition during a single X-ray pulse interval. The lines I^2–I^{10} show condenser action where emitted ray intensities are such that the condenser is charged at rates respectively requiring the delivery of two–ten ray pulses to charge the condenser to thyratron firing condition. It will be noted that the lines I^2–I^{10} each include one or more portions representing inter-pulse intervals during which rays are suppressed and the condenser consequently is not charged.

The operational lag time of the relay switches **30** and **49** may be empirically determined for any particular installation, the same ordinarily being of the order of 0.01–0.02 second, where a pair of sequentially operating devices are involved. By measuring from the point on each of the lines I^1–I^{10} which represents thyratron firing condition, that is to say, when the condenser is fully charged, a graphical distance corresponding with, say, 0.01 second, a series of points P_a^2–P_a^{10} may be determined, such points representing the voltage transitorily applied on the thyratron grid 0.01 second before the condenser **52** becomes charged to the normal firing potential. In like fashion, by measuring a graphical distance corresponding with 0.009 second from the normal thyratron firing positions on the lines I^1–I^{10}, a series of points P_b^2–P_b^{10} can be determined. In fact, points representing any empirically determined lag time interval may be picked off on the lines I^1–I^{10}.

In a thyratron valve operated relay system embodying relays having operational lag time of 0.009 second, the lag interval would be compensated if the thyratron were caused to fire at the voltages represented by the points P_b^2–P_b^{10}. The locus of the points P_b^2–P_b^{10} is a function of time only. Hence, if the thyratron firing grid potential could be controlled in accordance with such locus, satisfactory switch operating lag time compensation would result. It is possible to accomplish such control by suitably varying the voltage applied upon the second control grid of a four element thyratron valve. It is, however, preferable to accomplish the desired advance operation of the thyratron by continuously varying the bias voltage delivered from the source **53**, upon the grid remote side of the integrating condenser **52**, during the interval being measured or timed.

In order to determine the nature of such required variable bias voltage, the inter-pulse periods, during which ray emission is suppressed, may be eliminated from the graph illustrated in Fig. 2, in order to produce the graph comprising Fig. 3 showing the lines I^1–I^{10} with dead intervals removed and showing as curved lines *a* and *b* the loci of the points P_a^2–P_a^{10} and the points P_b^2–P_b^{10}. In like fashion the locus of thyratron grid voltages theoretically required to anticipate and compensate for any operational lag interval can be determined.

The variable voltage required to be applied, upon the grid remote side of the condenser **52** during the timing of an exposure interval, in order to control the thyratron in accordance with firing conditions indicated by the locus of the points P_b^2–P_b^{10}, is shown in Fig. 4 as a line V_b. The equation for this function is

$$V_b = V_{b\,\max}\left(1-\frac{K}{T+K}\right)$$

in which $V_{b\,\max}$ is the steady value of maximum voltage delivered from the source **53**, T is elapsed pulse-on time, and K is the operational time lag to be compensated for by substracting the same from each exposure interval measurement, the same commonly comprising a time interval of the order of 0.01–0.02 second.

Since the condenser **52** receives charging current intermittently under the control of the detector means **38**, where the ray beam **17** comprises intermittent ray pulses, the present invention contemplates the application of the bias voltage V_b upon the grid remote end of the condenser **52** in intermittent fashion so that the voltage V_b as applied to the condenser will alter only during ray pulse emission periods and will remain constant during inter-pulse intervals, such condition being illustrated, in Fig. 4, by the stepped line V'_b, the same comprising successive sections of the function V_b and intervening steps illustrating time intervals during which the voltage remains constant.

It will be seen that Fig. 4 also reproduces the stepped lines I^5 and I^{10}, which illustrate two of the several condenser charging rates shown in Fig. 2, said condenser charging rates being illustrated in terms of negative voltage at the grid connected side of the condenser. By subtracting the values of the lines I^5 and I^{10} from the values of the line V'_b, combined lines I_c^5 and I_c^{10} may be developed which illustrate the variant voltage, with respect to the grounded cathode of the thyratron which is made to appear at the grid connected end of the condenser, and hence upon the grid of the thyratron, as the combined result of the delivery of charging current to the condenser, under the control of the detector means **38**, and the application of the variant voltage V_b at the grid remote side of the integrating condenser **52**.

The desired variable bias voltage conditions represented by the locus of the points P_b^2–P_b^{10}, in Fig. 3, and by the function V_b in Fig. 4 may be substantially produced by means of a network **60** comprising a condenser **61** and a resistor **62** in conjunction with the power source **53**, switching means **63** being provided for disconnecting the condenser from the charging and biasing means during inter-ray pulse intervals when no rays are being emitted from the ray source.

The values of resistance and capacity required for the elements of the network **60** may be chosen so that the actual bias voltage delivered from the source **53** upon the thyratron grid remote side of the integrating condenser **52** will vary as closely as possible in conformity with the theoretically required voltage function V_b shown in Fig. 4. In that conneciton, the equation of an exponential curve of simplest form and embodying resistance and capacity values is

$$V_b(T) = V_0 + V_{b\,\max}(1 - e^{-T/RC})$$

where R and C, respectively, are the resistance and capacity values of the resistor **62** and the condenser **61**, and V_o is a factor depending upon the starting point of the exponential curve. The above exponential function can be made to correspond closely with the theoretically required variable bias voltage function V_b, as shown by the line AV_b, in Figs. 4 and 5, by selecting appropriate values for the factors R, C, $V_{b\,max}$ and V_o. In Fig. 5 the stepped line AV'_b illustrates the actual voltage applied upon the thyratron grid remote side of the condenser **52** from the power source **53** in accordance with the present invention, as shown in Fig. 7 of the drawings.

It will be seen that the function AV_b does not exactly match the theoretically desired function V_b. It is, however, possible, by properly selecting the values of R, C, V_0 and $V_{b\,max}$, to obtain exact coincidence of the functions AV_b and V_b throughout substantial intervals of time within the over-all operating range of the equipment. As shown more particularly in Fig. 4, exact coincidence occurs within the elapsed time range from 0.0125 to 0.025 second. It is, however, possible to select values of R, C, V_0 and $V_{b\,max}$ which will afford an exact match of the functions V_b and AV_b in any desired zonal position within the elapsed time measuring range of the apparatus.

As shown in Fig. 7, the power source **53** may comprise a full wave rectifying system **64** embodying an electron flow device **65** and a transformer **66** having a center tapped secondary winding and a primary winding interconnected in parallel with the winding **20** of the transformer **19** and hence powered from the same power source which energizes the X-ray generator. Full wave rectified power thus may be delivered through a filtering network comprising interconnected condensers **67** and **68**, resistors **69** and **70** and an adjustable potentiometer **71**, between ground and a supply terminal **72**, whence maximum bias potential may be delivered through the switch means **63** and the resistor **62** to the grid remote side of the condenser **52**. Bias potential may also be delivered from the supply terminal **72** through a resistor **73** to one side of a ballast resistance **74**, the other side of which is grounded, whereby to provide a secondary bias supply terminal **75** adapted to deliver bias potential at a level substantially lower than that at which bias potential is supplied from the terminal **72**, said auxiliary supply terminal **75** being interconnected with the grid remote side of the condenser **52** through a normally closed switch **76** operable with the short circuiting switch **54**.

It will be seen from the foregoing that, when the equipment is in stand-by condition, the switches **54** and **76** being closed, a negative bias voltage will be applied from the supply terminal **75** through the normally closed switches **54** and **76** to the grid of the thyratron valve and to both of the opposite sides of the condenser **52**. Upon closure of the switch **59** to initiate an exposure interval, the switches **54** and **76** will open to disconnect the bias supply terminal **75** from the condenser and to free the condenser for integrating action. Bias voltage of a substantially higher order, as supplied from the terminal **72**, however, will be applied to the grid remote side of the condenser **52** in response to closure of the switch **63**. This voltage, because of the time constant characteristics of the resistor-condenser network **60**, will not immediately reach its full value upon the grid remote side of the condenser **52**, but the voltage applied on said grid remote side of the condenser will follow the exponential curve of actual bias voltage as shown in Fig. 5, as the interval being timed progresses. As a consequence, the application of charging current upon the condenser **52** through the conductor **40** from the detector means **38** will result in the operation of the thyratron valve **43** in the manner desired.

It should be noted, however, that, since the charging current, as shown in Fig. 2, is delivered to the condenser **52** in successive pulses and alternate inter-pulse intervals during which no current is delivered to the condenser, it is necessary to provide means for applying the compensating bias AV_b in the manner indicated at AV_b' in Fig. 5. It is also necessary to arrange to disconnect the correctional bias from the condenser during inter-pulse intervals in order to avoid the exponential alteration of the charged condition of the condenser during such inter-pulse intervals and hence introducing operational inaccuracies in the system. If no provision were to be made for disconnecting the exponentially varying bias during inter-pulse intervals, voltage would be supplied to the thyratron grid in the manner indicated in dotted lines in Fig. 6 due to the continuation of the time variable biasing action on the thyratron grid remote side of the integrating condenser, during inter-pulse intervals. If the exponential lag anticipating and correcting bias potential were to be in operation continuously during the interval being measured, the voltage range, through which the timing capacitor would be charged, would be effectively increased, as indicated in Fig. 6, so that thyratron actuating voltage would not be attained until substantially more than the desired total X-ray quanta had been emitted. Accordingly, the present invention, as shown more especially in Fig. 7, provides a control system **77** for actuating the switch **63** to switch the anticipator circuit comprising the exponential biasing means into and out of operation in concert with the ray pulsations emitted during the period being measured.

To these ends the detector **38** may conveniently comprise a photoelectric tube of the sort disclosed in Letters Patent of the United States No. 2,231,697 of February 11, 1941, covering the joint invention of Vladimir K. Zworykin and Richard L. Snyder, Jr., such tube having an anode A, a light sensitive cathode C and a plurality of dynode electrodes, D_1–D_9, including an end dynode D_9. The several dynodes D_1–D_8 are interconnected by resistors, and the dynode D_1 is connected with the cathode C through a resistor. The cathode of the phototube, as by means of a conductor **78**, may be connected with a suitable source **79** of relatively high voltage negative potential, preferably through an adjustable resistance **80**. The anode of the detector tube, by means of a conductor **81**, may be connected with the translation system **77** to operate and control the same in accordance with the pulsations of the ray beam **17**. The end dynode D_9 may be connected with the grid connected side of the integrating condenser **52** through the conductor **40**, while the dynode D_8 may be connected, as by means of a conductor **82**, with a source **83** of relatively low voltage negative potential.

The system **77** may comprise a series of triode electron flow valves V_1, V_2, V_3, and V_4, the valve V_4 forming the switch means **63**. The anodes of the valves V_1, V_2 and V_3 and of the phototube **38** are connected with a source **84** of relatively low voltage positive potential through resistors R_1, R_2, R_3 and R_4. The anode of the valve V_4 is connected with the interconnected sides of the condensers **52** and **61** through the adjustable resistor **62**. The cathodes of the valves V_1, V_2, V_3 and V_4 may be connected to ground.

The control grid of the valve V_1 may be connected with the anode of the phototube **38** through a condenser **85** and with ground through a resistor **86** and a one-way current flow diode device **87** connected in parallel with respect to the resistor **86**. The grid of the valve V_2 may be connected with the anode of the valve V_1 through a resistor **88** and a condenser **89**, the negative low voltage power source **83** being connected through resistors **90** and **91**, in series, with the interconnected sides of the resistance **88** and the condenser **89**, a one-way current flow diode **92** being connected in parallel with the resistor **91** and the interconnected ends of the resistors **90** and **91** being connected to ground through a resistor **93**.

The control grid of the valve V_3 may be connected with the anode of the valve V_2 through a condenser **94**. The control grid of the valve V_3 may also be connected to ground through a resistor **95** and a one-way current flow diode **96** connected in parallel with the resistor **95**. The control grid of the switch valve V_4 may be connected with the anode of the valve V_3 through a resistor **97** and a condenser **98**. Power may be delivered, between the cathode of the switch valve V_4 and the interconnected sides of the grid connected resistor **97** and the condenser **98**, by means of a transformer **99** having a primary winding **100** energized from the power source **25**. The secondary winding **101** of the transformer may supply power for energizing the cathode filaments of the valves V_1, V_2 V_3 and V_4. One end of the secondary winding **101** may be connected through a resistor **102** with the interconnected sides of the resistance **97** and the condenser **98**, a one-way current flow diode **103** being connected in parallel with the resistor **102**. The other end of the winding **101** may be connected through a one-way current flow diode **104** and a resistor **105** with the cathode of the switching valve V_4, a condenser **106** being interconnected between the transformer connected ends of the resistors **102** and **105**. A resistor **107** also may be connected between the transformer connected end of the resistor **102** and the transformer remote end of the resistor **105**.

When ray pulses impinge upon the detector tube **38**, corresponding current pulses which pass from the end dynode to the anode of the phototube will traverse the resistor R_1 to the source **84**, thus developing corresponding voltage pulses across the resistor R_1. Accordingly, the voltage at the source remote end of the resistor R_1 will periodically fall below the voltage value supplied from the source **84**, as shown in Fig. 8 of the drawings. This voltage fluctuation is reflected through the condenser **85** to the grid of the tube V_1, as shown in Fig. 9 of the drawings. The valve V_1 is in conductive condition prior to the occurrence of an X-ray pulsation and is held conductive by the diode **87** and by virtue of the fact that there is no voltage drop across the resistor **86**, the grid of the valve V_1 being thus effectively tied to its cathode so that the tube remains in conductive condition.

As the voltage established across the resistor R_1 in response to the application of an X-ray pulsation upon the detector tube is reflected on the grid of the valve V_1 by the condenser **85**, a voltage is developed across the resistor **86** which causes a reduction below zero value in the voltage on the grid of the valve V_1, thereby reducing the conductivity of said valve. The magnitude of the voltage pulsation, however, is not great enough to make the tube V_1 completely non-conducting, and it is for that reason that the tubes V_2 and V_3 are operated as amplifiers to increase the signal gain so that the end valve V_4 will become conductive at the start of an X-ray impulse and non-conductive at the conclusion of a ray pulsation. Figs. 10, 11 and 12 respectively illustrate the operation of the valves V_2, V_3 and V_4. It will be seen that while the valves V_2 and V_3 produce an amplification gain, they nevertheless do not become sharply conducting and non-conducting with the commencement and termination of a ray pulsation.

In this connection, the plate voltage pattern developed in the valve V_1 is fed through the condenser **89** upon the grid of the valve V_2. Accordingly, when the X-ray pulse is a maximum, the valve V_2 is in its maximum conducting condition, the voltage at the anode of the valve V_2 being a minimum when the X-ray pulse is at its maximum value. Such minimum voltage is then applied through the condenser **94** to the grid of the valve V_3 in order to decrease the conductivity thereof when the X-ray impulse is at maximum value. Accordingly the voltage developed at the anode of the valve V_3 is a maximum when the ray impulse is at its maximum value. The anode voltage thus developed in the valve V_3 is applied through the condenser **98** upon the grid of the switching valve V_4 to render the same conductive during X-ray pulse intervals and non-conducting during inter-pulse intervals.

It will be understood from the foregoing that the valve V_2 should be relatively non-conductive during ray inter-pulse intervals. Its grid voltage consequently must be negative with respect to its cathode during such intervals. The necessary negative voltage may be derived from the source **83** through the voltage divider comprising the resistors **90**, **91** and **93** and the diode **92**. The diode **92** as well as the other diodes **87**, **96** and **103** serve as direct current restorers, that is to say, they permit the voltage change, which occurs when the pulse enters and leaves, to have a full effect upon the grid of the valve with which connected, and they prevent the same from assuming opposite polarity due to the one-way conductivity of the diode.

In order to assure the negativity of grid voltage on the valve V_4 and the non-conducting condition thereof during inter-pulse intervals, its grid is connected through the resistors **97** and **102** and the diode **103** to the point of connection of the resistor **102** and its diode **103** with the condenser **106** and the resistor **107**. This connection point is negative with respect to the cathode of the valve V_4 by the voltage which is developed across the resistor **107** through the operation of the power input circuit means comprising the transformer **99** and the diode rectifier **104**, power delivered through the transformer being rectified by the diode **104** and applied to the condenser **106** and network of resistors **105** and **107** which operate as a voltage divider.

Where the ray detecting means comprises a sensitive panel, screen or layer of fluorescent material **38** for the operation of a phototube, the possibility exists of introducing errors in the measurement of elapsed time intervals due to slow image decay time constant characteristics of the fluorescent material constituting the element **38′**. Ordinary fluorescent materials have image decay time constant characteristics such that the same may be employed for measuring intervals of duration of the order of 0.1 second or more, but have image persistence of such duration after the extinction or termination of exciting rays as to cause erroneous operation of an integrating system in which employed, where the interval being measured is short.

Due to image persisting characteristics of fluorescent material, excitation thereof and consequent light production and emission by the element **38′** may result in the application of light upon the detector tube **38** during the initial portions of inter-pulse intervals. The relatively slow decay time constant of ordinary fluorescent materials thus will result in the delivery of more current from the detector tube **38** than would occur if light emission from the material of the element **38′** were to be precisely responsive to X-ray incidence thereon. Where the interval being measured comprises an extended period of sufficient length to include several successive ray pulsations, the integrating errors caused by image persistence can be compensated for by adjusting the bias supplied upon the thyratron from the power source **53**, since the error, measured over several pulsations tends to become directly proportional to the length of the measured interval.

Where, however, the exposure interval is of duration of the order of less than 0.1 second, equivalent to less than twelve ray pulsations, where the rays are produced in a tube energized by full wave rectified sixty cycle alternating current power, the error introduced as the result of slow image decay characteristics in the element **38′** becomes appreciable. The error, furthermore, increases as the exposure time interval diminishes, the extent of error being somewhat erratic and dependent to some extent upon the relative position of the instant of exposure interval termination in or with respect to the ray source energizing power cycle. Accordingly, where the ray sensitive unit is to be used in conjunction with equipment for measuring exposure intervals of duration of the order of 0.1 second or less, and particularly for ultra short exposure intervals of the order of one-thirtieth second, and less, the element **38′** should comprise ray sensitive fluorescent material, such as calcium tungstate, having substantially instantaneous image decay characteristics, that is to say, material in which ray induced luminosity becomes extinguished as during an interval of the order of one-thousandth of a second, after the termination of ray impingement thereon.

Where such sensitive screen elements having high speed image decay characteristics, as differentiated from standard or slow speed screens, are used, it is desirable to compensate the interval measuring equipment for changes in the anode-cathode voltage at which the X-ray generating tube is operated. It is to this end that the transformer **66** is energized by power derived from the adjustable secondary winding **21** of the transformer which supplies energy at desired adjustable voltage for application between the anode and cathode of the generator tube.

The output of the transformer **66** is subjected to full wave rectification and applied to the filter network comprising the condensers **67** and **68** and the resistor **69**. The voltage thus produced across the condenser **68** is applied across the resistor **70** and potentiometer **71**, the positive end of the resistor **70** being grounded so that the voltage derived from the adjustable potentiometer **71** is negative with respect to ground. This voltage is used as the full bias voltage, that is to say, the voltage labeled 100 percent in the graphical illustrations comprising Figs. 2–6. This full bias voltage is connected to ground across resistors **73** and **74**, which are preferably of identical value so that their interconnected ends at the terminal 75 provide a 50 percent voltage value as the bias voltage initially applied upon the thyratron grid at the commencement of interval measurement. It will be obvious, of course, that an adjustable potentiometer could be substituted for the resistors **73** and **74** in order to permit adjustment of the bias voltage obtainable at the delivery terminal **75**.

It is thought that the invention and its numerous attendant advantages will be fully understood from the foregoing description, and it is obvious that numerous changes may be made in the form, construction and arrangement of the several parts without departing from the spirit or scope of the invention, or sacrificing any of its attendant advantages, the form herein disclosed being a preferred embodiment for the purpose of demonstrating the invention.

The invention is hereby claimed as follows:

1. Apparatus for actuating operable devices at the conclusion of a measured time interval comprising a gaseous conduction electron flow valve having an anode, a cathode and a control grid, an integrating condenser connected on one side with said grid, a switch for initially biasing said grid and both sides of said condenser at selected negative voltage values with respect to the cathode of the flow valve to hold the same normally in non-conducting, inoperative condition, means for applying current pulses during successive intervals to charge the condenser and thus decrease the negativity of the voltage applied on the grid in accordance with the charging rate of said condenser, a circuit embodying a condenser operable to provide a progressively varying bias voltage, and a switch operable in synchronism with said current pulses for applying said bias voltage of progressively increasing negativity upon the grid remote side of the condenser during said pulse intervals only, to alter the condenser charging rate in accordance with said bias voltage for the operation of said operable devices in advance of the end of the interval being measured to thereby compensate for the operational lag interval of said devices.

2. Control apparatus comprising a gaseous conduction valve having a control grid, an integrating condenser connected with said control grid, means to apply successive current pulsations upon the condenser to charge the same progressively and thus to alter the voltage applied upon said grid, a circuit including a condenser operable to provide a bias voltage of progressively changing value, and intermittently operable switch means for applying said progressively varying bias voltage upon the grid remote side of said condenser to thereby alter the condenser charging rate in accordance with said bias voltage.

3. Control apparatus comprising a gaseous conduction valve having a control grid, an integrating condenser connected with said control grid, means to apply successive current pulsations upon the condenser to charge the same progressively and thus to alter the voltage applied upon said grid, a circuit including a condenser operable to provide a bias voltage of progressively changing value, an electron flow switching valve operable in synchronism with the pulsations of charging current for applying said progressively varying bias voltage upon the grid remote side of said condenser to thereby alter the condenser charging rate in accordance with said bias voltage.

4. Control apparatus comprising the combination with a penertating ray source, means including a control switch for controlling the emission of ray energy pulsations from said source, and a ray responsive detector, of a gaseous conduction valve having a control grid, an integrating condenser connected with said control grid, means operable under the control of said detector for producing successive current pulsations, corresponding with ray quanta emitted by said source, and for applying such pulsations upon the condenser to charge the same progressively and thus to alter the voltage applied upon said grid progressively in accordance with emitted ray quanta, a circuit including a condenser operable to provide a bias voltage of progressively changing value, and an electron flow switch device operable in synchronism with said current pulsations for applying said progressively varying bias voltage upon the grid remote side of said condenser, at intervals corresponding with said current pulsations, to thereby alter the condenser charging rate in accordance with said bias voltage.

5. Control apparatus comprising the combination with a penetrating ray source, means including a control switch for controlling the emission of ray energy pulsations from said source, and a ray responsive detector, of a gaseous conduction valve having a control grid, an integrating condenser connected with said control grid, means operable under the control of said detector for producing successive current pulsations, corresponding with ray quanta emitted by said source, and for applying such pulsations upon the condenser to charge the same progressively and thus to alter the voltage applied upon said grid progressively in accordance with emitted ray quanta, an electron flow switch, amplifier means driven in synchronism with said pulsation producing means, under the control of said ray detector, for applying a progressively varying bias voltage upon the grid remote side of said condenser, at intervals corresponding with said current pulsations, to thereby alter the condenser charging rate in accordance with said bias voltage, and means, operable by said gaseous conduction valve, to actuate said control switch after emission of predetermined ray quanta from said source, including means for varying said bias voltage with and in proportion to variations in the average intensity of emitted rays.

6. In a system for generating X-rays of pulsating intensity, apparatus for limiting an exposure to a predetermined quanta of X-ray energy, said apparatus comprising a ray sensitive device positioned to receive X-rays from said generating system, a biasing circuit for producing a varying bias voltage, an integrating condenser connected between the ray sensitive device and the biasing circuit, a relay switch connected across said integrating condenser for establishing an initial condition wherein said integrating condenser has no charge and wherein an initial bias voltage is applied thereto, said integrating condenser being operable to accumulate charge from the ray sensitive device in accordance with the X-ray intensity, a gaseous conduction device having a control grid coupled to the integrating condenser, said gaseous conduction device being responsive to the appearance of a grid voltage upon its control grid, said grid voltage being an addition

of the varying bias voltage and a voltage appearing across the integrating condenser corresponding to the charge accumulated from the ray sensitive device, said gaseous conduction device being operable to cause relay action to terminate the X-ray exposure.

7. The apparatus according to claim 6 wherein the circuit for producing the bias voltage is coupled to a switching circuit for disabling the biasing circuit and holding the bias voltage constant during intervals between the pulsations of the X-rays, and thereby allowing the bias voltage to vary only during times of ray impingement upon the ray sensitive device.

8. The apparatus according to claim 6 wherein the biasing circuit comprises a condenser resistively coupled across a source of unidirectional voltage by an electron tube, said electron tube being conductive during intervals

of X-ray impingement upon said ray sensitive device and being nonconductive between the intervals of X-ray impingement, thereby allowing the condenser to charge only during the intervals of ray impingement.

References Cited in the file of this patent

UNITED STATES PATENTS

2,401,289	Morgan et al.	May 28, 1946
2,438,303	Simmon	Mar. 23, 1948
2,453,486	Ball	Nov. 9, 1948
2,494,218	Weisglass	Jan. 10, 1950
2,679,598	Wright et al.	May 25, 1954
2,747,104	Jacobs	May 22, 1956

FOREIGN PATENTS

904,916	Germany	July 8, 1949