

July 18, 1944.

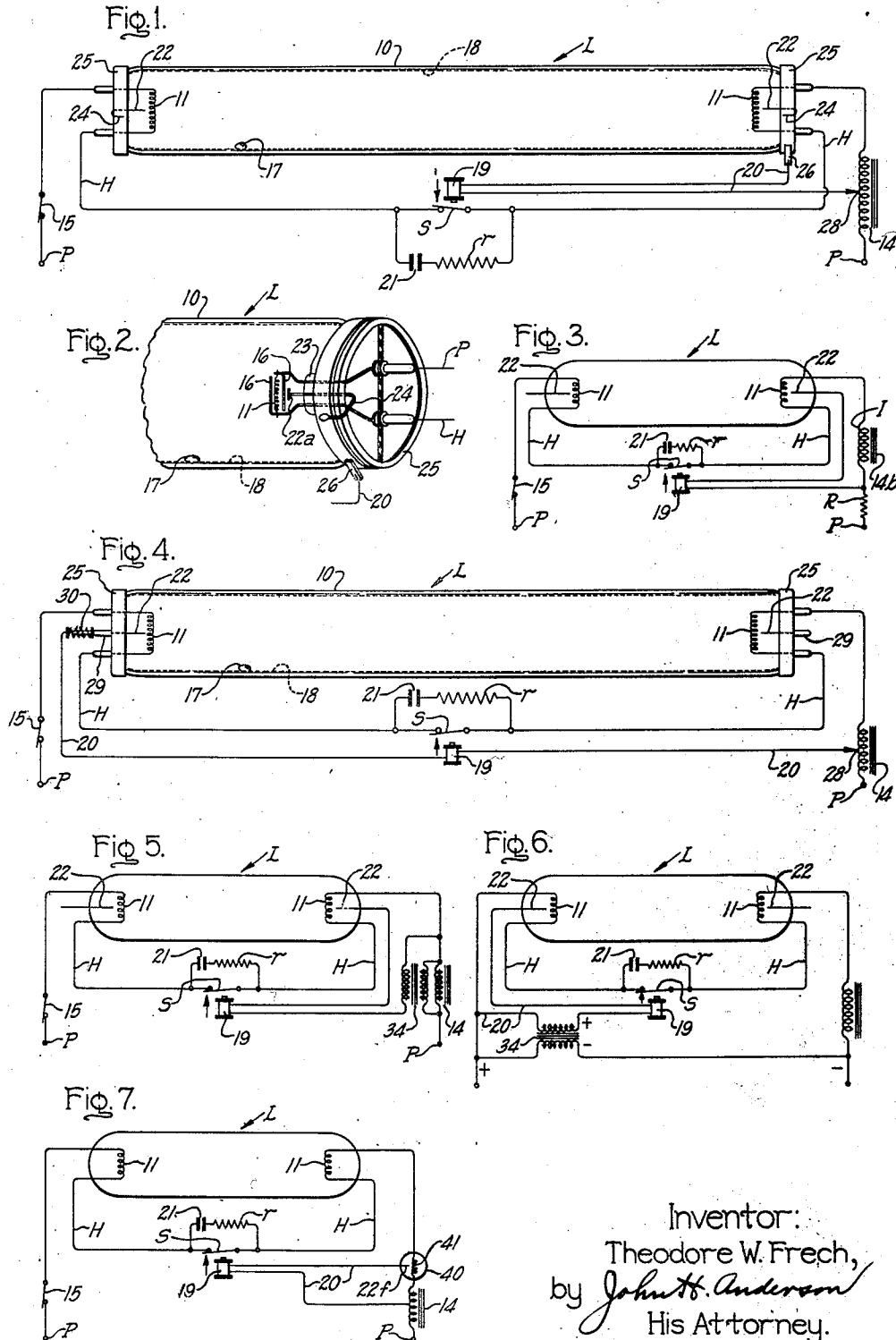
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2,353,660

STARTING CONTROL FOR ELECTRIC DISCHARGE DEVICES

Filed Dec. 17, 1942

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 8.

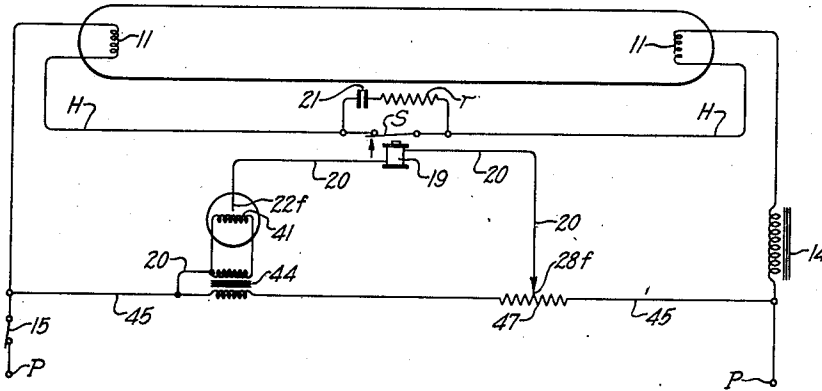


Fig. 9.

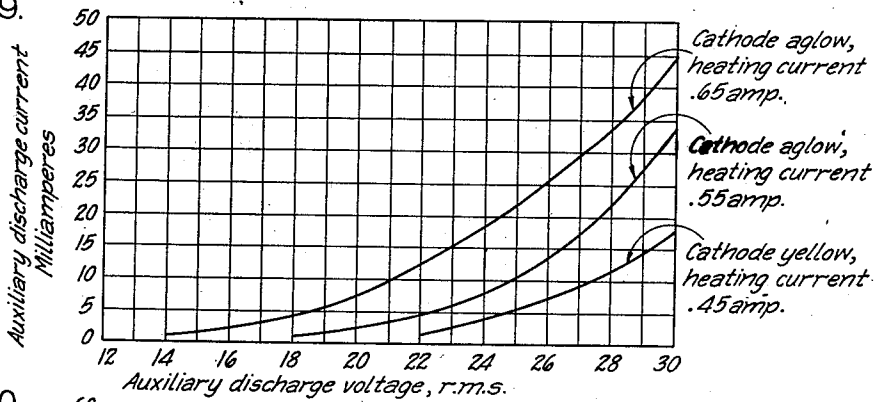
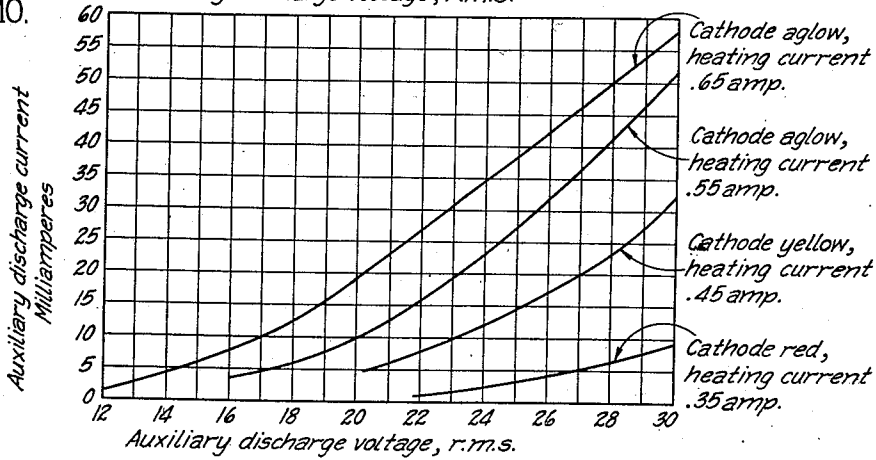


Fig. 10.



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UNITED STATES PATENT OFFICE

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STARTING CONTROL FOR ELECTRIC
DISCHARGE DEVICESTheodore W. Frech, Cleveland, Ohio, assignor to
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10 Claims. (Cl. 315—99)

This invention relates to the control of electric discharge devices, and is especially concerned with the starting of devices having an operating atmosphere of gas or vapor, or both, and employing cathodes which are electron-emissive. Very commonly, thermionic cathodes of such devices are especially heated to produce ample emission, and particularly as a preliminary to starting the discharge—for after starting, many types of cathodes are so effectively heated by the discharge itself that special heating becomes unnecessary. The invention is particularly useful for fluorescent tubes or lamps of the usual positive column discharge type, as well as for other discharge devices operating at relatively low internal pressure.

The ordinary type of low pressure discharge lamp has a thermionic type of cathode that is rendered freely emissive at relatively low temperatures by being coated with activating oxides—such as a mixture including barium and strontium oxides—and is heated for starting by passing electric current through heating means or resistance incorporated or embodied in the cathode(s). To permit of fully effective operation on alternating current, as well as to make the device operable on direct current circuits without regard to which end of the device is connected to which side of the circuit, such thermionic cathodes are provided at both ends of the discharge device, and are connected to opposite sides of the main current supply or discharge circuit of the device. In fluorescent lamps, the cathodes commonly consist of coiled coil tungsten filaments which carry the activating material and also embody and constitute the cathode-heating resistance means. A current-limiting choke or ballast having inductance is commonly included in the discharge circuit. For starting purposes, a circuit including a switch is connected across the supply circuit through the cathode-heating means, so that while this starting switch is closed, current flows through the several cathode heating means in series. When the cathodes have thus been heated to adequate emissive temperature, the starting switch is suddenly opened, and the resulting voltage kick between the cathodes (due to the inductance in the supply circuit) suffices to initiate discharge.

The usual switch for the starting circuit is an automatic thermal or glow switch that heats and opens in a length of time which is determined and fixed, by design and adjustment, to assure that the cathode(s) of any lamps of the type for which the switch is designed shall have a chance to heat

to adequate emissive temperature. Not only, however, may individual lamps of any particular type (wattage and voltage) differ somewhat in their heating and starting characteristics, but in practice the preheating current through the cathodes and the time required for proper preheat vary considerably with variations of supply voltage above and below rated normal, as well as with seasonal and day to day variations in the temperature of the surrounding atmosphere. Differences in required preheating current and time for different lamps also arise from differences in their associated ballasts. Thermal and glow-switch starters, therefore, must be calibrated to allow adequate preheat time under the most unfavorable conditions of voltage regulation and ballast performance. Besides all this, thermal and glow switches are rather difficult to calibrate exactly alike, so that differences in the actual starting of identical lamps may arise from differences in the performance of such switches under identical conditions.

On A. C. supply circuits, furthermore, irregularities and delays in starting, after the discharge circuit is energized, may arise because the starting switch happens to open at an instant when the preheating current is zero, or nearly so, so that there is no resulting voltage kick that will start the discharge; and so the starting switch may recycle several times before it opens in such relation to the supply voltage cycle that the lamp is successfully started.

Owing to such causes as these, the differences and irregularities in the starting of discharge lamps in a group installation may be rather conspicuous and objectionable; and there may be considerable differences of starting time on different occasions, and annoying delays in starting.

It is an aim of this invention to overcome such drawbacks by making the time consumed in each start of a discharge device correspond substantially to the development of emission from its cathode(s) on that occasion, under the conditions affecting the emission, so that the invention may aptly be characterized as an electron-emission start-timing system. Preferably, the starting is actually controlled by the emission from the cathode(s) in question. Thus the starting need never be retarded by any general standard of starter calibration, based on requirements under unfavorable conditions; irregularities of starter calibration can be minimized or avoided; starter action on A. C. can be tied into proper relation to the supply voltage cycle; lamps can all ways be started as quickly as conditions permit,

with little or no injury to their cathodes; and differences in starting amongst lamps of an installation can be greatly reduced, or even abolished. Moreover, relatively longer lamps can be started on a given supply voltage than with starters now in general use.

The control may be effected by taking current to operate a starting switch from an auxiliary discharge between a cathode and an associated auxiliary electrode—either in the lamp or in a separate envelope—this auxiliary discharge being itself controlled in correspondence with the emission from the lamp cathode. By making the auxiliary electrode thus employed unemissive, a rectified current may be obtained to operate the starting switch, which may thus be a D. C. relay switch that is relatively noiseless. As compared with a glow-switch or a thermal switch, an electromagnetic relay switch has the advantage that if it fails to start the discharge when it opens, it recloses and repeats immediately, instead of after the delay required to allow cooling of heated parts; so that starting tends to be achieved on a second, third, or subsequent attempt much sooner than by a glow switch or a thermal switch.

Under normal conditions, when lamps have not been in operation during an immediately preceding interval of five minutes or more, they can be started by my starting system in about 1 second, and with very little more injury, if any, than in starting with the glow switches and thermal starters now in use. Even quicker starting is possible if the lamp cathodes retain some heat from previous operation when the lamp is turned on. In general, the starting system is applicable to lamps operated on direct current, as well as to lamps operated on alternating current.

Various other features and advantages of the invention will appear from the description of species or forms of embodiment, and from the drawings.

In the drawings, Fig. 1 is a diagrammatic view of a fluorescent tube or lamp, with circuit connections such as described above, and shows a starting system in accordance with the present invention; and Fig. 2 is a perspective or tilted skeleton view of parts at one end of such a lamp, illustrating one suitable way of connecting auxiliary electrodes in the lamp to terminals embodied in its bases, and omitting the usual insulative base disc for the sake of clearness of illustration.

Fig. 3 is a circuit diagram illustrating a modification of the Fig. 1 system.

Fig. 4 is a view similar to Fig. 1 illustrating a somewhat different starting system arrangement, and also different base terminal arrangements and connections for auxiliary electrodes.

Figs. 5, 6, 7, and 8 are circuit diagrams illustrating various other modified starting arrangements.

Figs. 9 and 10 are diagrams illustrating characteristics of auxiliary starting discharges for the purposes of the invention.

In various figures of the drawings, the arrow associated with the starting relay switch indicates its direction of self-closing movement when the relay is not energized.

Fig. 1 shows an ordinary fluorescent lamp L, of the positive column electric discharge type, consisting of a tubular envelope 10 having spaced apart thermionic cathodes 11, 11 in its ends, which may be the specially heated activated cathodes of usual coiled filament type, and are

shown connected across a power-supply circuit P including the usual inductive ballast 14, which also serves as a starting inductance, and the make-and-break power supply switch 15. With each cathode 11 may be associated the usual unemissive electrode(s) 16, Fig. 2, to function as anode(s) when the cathode 11 in question is positive. The envelope 10 may contain a low-pressure atmosphere of starting gas, such as argon at a pressure of 2 to 4 mm. of mercury, and also a vaporizable and ionizable working substance such as mercury. A supply of mercury, which may exceed the amount that will vaporize during operation of the lamp L, is indicated by a drop 17 inside the envelope 10, and an internal coating of fluorescent material or phosphor 18 on the envelope walls is also indicated. A starting and electrode-heating circuit H is shown connected across the circuit P through the filamentary cathodes 11, 11, with a starting relay-switch S included therein. This switch S is shown as having an operating coil or winding 19 connected in a control circuit 20 from which it is energized. A capacitor or condenser 21 of suitable capacity may be connected across the switch S, to minimize radio interference, as well as to prevent objectionable arcing when the switch S opens and breaks the circuit H. A resistance r of a few ohms (e. g., 7 to 10) is shown connected in series with the condenser 21 across the switch S, to prevent any welding tendency between the switch contacts, which might otherwise delay opening or even prevent switch S from opening at all. By means of switch S, when it opens, a high starting voltage (exceeding that of the main discharge circuit P) is impressed across the electrodes 11, 11, to initiate the main discharge between them.

As shown in Fig. 1, an auxiliary starting anode 22 for the purposes of my invention is associated with one or both of the cathodes 11, 11 (in addition to any electrode(s) 16 that may be used), and may be provided with circuit connections in any suitable way. While only one of the starting anodes 22 is shown as actually connected, it is desirable to provide such an anode for each cathode 11, to insure operation of the starting system regardless of which end of the lamp L is connected to which side of the discharge circuit P. The anode(s) 22 may in practice consist of a straight length of 30 mil wire, nickel for example, sealed through the stem 23 of the filament mount at each end of the lamp, and may extend to within about $2\frac{1}{2}$ mm. of the corresponding cathode 11. A smaller surface area of electrode 22 or a greater distance thereof from the cathode 11 results in a higher internal resistance for the discharge between these electrodes 11, 22, and this requires a more sensitive relay C. As shown in Fig. 2, the connection to each anode 22a includes a lead-wire 24 connected to the usual metal shell or band 25 of the corresponding lamp base, and a spring contact 26 that engages the base shell 25 and is connected to one lead of the circuit 20.

Fig. 2 also shows a variant T-type of anode 22a, consisting of a straight wire sealed through the stem 23 and a cross bar of similar wire welded across its end. Both these wires may be of 22 mil nickel, the cross bar about $7\frac{1}{2}$ mm. long and distant about $2\frac{1}{2}$ mm. from the nearest point on the cathode coil 11.

As shown in Fig. 1, the starting control circuit 20 connects the operative anode 22 to its associated cathode 11 through the relay switch wind-

ing 19 and the side of the discharge circuit P that includes the ballast 14, being itself connected to a variable tap 28 adjustable along the winding of the ballast to vary and regulate the effective voltage between the associated electrodes 11, 22, before the auxiliary discharge starts as well as afterward. In other words, the control circuit 20 is shown connected through only part of the ballast 14. The effective voltage between these cooperating electrodes 11, 22 should of course exceed the ionizing potential of the discharge atmosphere in the envelope 10, but may preferably be below what may be termed its cathode-disintegration voltage: that is to say, below the voltage under which ions of the discharge atmosphere would bombard the cathode with sufficient velocity to disintegrate and sputter the cathode material, and especially the activating material. Mercury and argon have ionizing potentials of 10.4 and 15.8 volts, respectively, and cathode-disintegration voltages of 22 and 25 volts; and for discharge devices operating with these particular substances, I have found that an adjustment of tap 28 to give about 10½ volts R. M. S. between the co-operating electrodes 11 and 22 when the main supply voltage in circuit P is at the lower limit of the range in which the lamp L is expected to be operable produces satisfactory starting performance. Higher voltages up to 30 or even some 45 volts or more can be used without serious resulting cathode disintegration as compared with what occurs when this limit is substantially exceeded—to say nothing of the effects of a full supply voltage of the order of some 115 volts applied between the electrodes 11, 22. As a whole, the matter may be summed up by saying that with the effective degree of protective preheat of cathode 11 which is attained when the relay switch S opens under an auxiliary discharge current corresponding to an auxiliary discharge voltage not too greatly (if at all) exceeding the cathode disintegration voltage of the discharge atmosphere—and thus considerably lower than the main discharge voltage—both positive ion cathode bombardment at the starting of the auxiliary discharge and such bombardment at the starting of the main discharge can be very successfully minimized, and all serious injury to the cathode 11 thus avoided. In other words, the voltage of the order of some 10½ volts (the ionizing potential of the discharge atmosphere) to 45 volts by which the control circuit 20 is energized does not deleteriously exceed the cathode disintegration voltage and is so low that the resulting current in said circuit 20 cannot open the relay switch S until the cathode 11 has been preheated by the current flowing in the starting circuit H to a self-protective temperature, at which its thermionic emission of electrons suffices to obviate destructive disintegration of said cathode by ion bombardment. Thus by means of the control circuit 20 and the limited auxiliary discharge voltage in it, the application of the high voltage that initiates the main discharge is delayed while the cathode 11 is being preheated to provide for an auxiliary discharge current that can open the relay switch S. In this connection, it may be remarked that the auxiliary discharge between electrodes 11, 22 shows a positive voltage and current characteristic, as is more fully set forth hereinafter.

Of course the actual auxiliary discharge voltages at the peaks of A. C. voltage cycles are higher than the R. M. S. values of 10½, 30, 45 here mentioned

The relay switch S may be of an electromagnetic type having a switch-opening coil 19, and may be biased to close when its control circuit 20 and the coil 19 are not energized. An ordinary type of relay switch S for this purpose may operate on a current as low as 15 to 30 milliamperes, with a total loss of energy in the starter of less than 1 watt; and suitably designed relays can be made to operate on much lower current and consumption of energy. The low power requirement is of consequence when energy is taken by the relay-switch S as long as the lamp L is in operation, as is the case with the simple type of switch here shown. In general, it is desirable for the relay coil 19 to be so wound that its resistance in the circuit 20 equals or approximates the internal resistance for the discharge between the electrodes 11 and 22.

The following is a mode of operation of the starting system shown in Fig. 1 when energized from an A. C. supply circuit:

When the power switch 15 is closed, the already closed starter switch S permits A. C. current flow through the circuit H and the cathode filaments 11, 11 therein until the latter have preheated to a temperature of adequate electron emission for a discharge between the cooperating electrodes 11, 22 at the right of Fig. 1, under the "open-circuit" voltage of some 10½ volts R. M. S. or more between these electrodes. With cathodes 11, 11 designed as is now usual for fluorescent lamps, the voltage drop in each of these cathodes due to its resistance exceeds the ionizing potential of the discharge atmosphere, so that an ionizing discharge along or "across" each cathode 11, 11 takes place, and assists in heating the cathode. The ionization of the atmosphere by these shunting discharges facilitates the initiation of an auxiliary uni-directional discharge between the co-operating electrodes 11, 22 at the right of Fig. 1, with a corresponding flow of half-wave rectified current in the control circuit 20. This discharge between the electrodes 11, 22 is ballasted by the relay winding 19, as well as by part of the ballast 14. As soon as the cathode 11 becomes sufficiently heated to permit a current flow of adequate value in the circuit 20, the relay switch S suddenly opens the circuit H, and the resulting voltage kick initiates the main A. C. discharge between the cathodes 11, 11. Under normally favorable conditions, all this may take place in about 1 second, more or less, for a 30 or 40 watt fluorescent lamp whose cathodes 11, 11 are cold when the switch 15 closes, so that an interval of darkness after the switch 15 closes may be scarcely observable. If the cathodes 11, 11 retain some heat from previous operation when the switch 15 is closed, the start is even quicker. In general, the reactance of the coil 19 may be so correlated with the other conditions affecting the operation of the relay S that the circuit H is opened when the instantaneous value of the current in this circuit is at its maximum (or nearly so), since this gives the maximum voltage kick for starting the lamp L.

The ionization of the atmosphere in the tube 10 by the shunt discharges along the electrodes 11, 11 plays the same part with respect to the main discharge as in fluorescent lamps started by the present thermal or glow-switch starters. While the ionization of this atmosphere by the auxiliary discharge between the electrodes 11, 22 at the right of Fig. 1 does not play any such part with respect to the main discharge, because the polarity relations between these electrodes 11,

22 do not permit, this auxiliary discharge does time the main discharge by energizing the relay switch S to break the starting circuit H, as already explained.

The cathode 11 that is associated with the operative auxiliary electrode 22 has to sustain the auxiliary discharge as well as the main discharge, and may therefore be expected to lose its activation and emission ahead of the other cathode 11, unless this is offset by a smaller amount of activator on the other cathode, or in some other way. To the extent that such an expectation is realized in practice—whether accidentally, or by purposely providing the cathode 11 associated with the operative electrode 22 with less activation—the system affords an automatic no-blink action to prevent flashing of a defective or worn-out lamp L whose cathode 11 associated with the operative starting anode 22 has lost its emission; for without emission from this cathode 11, there can be no current flow in the circuit 20, and hence no futile attempts to start such a failed lamp.

The system illustrated in Fig. 3 closely resembles that in Fig. 1, but is distinguished by the fact that the ballast 14b includes a resistance R in series with the inductance I, and that the connection of the circuit 20 to this side of the circuit P is made between ballast resistor R and ballast inductance I. Thus the voltage between the adjacent electrodes 11, 22 is that through the part I of the ballast, while the part R assists in ballasting the discharge between the electrodes 11, 22, as well as the main discharge.

In the system shown in Fig. 4, the ionization of the atmosphere in the tube 10 by the auxiliary discharge between co-acting electrodes 11, 22 assists in starting the main discharge in about the same way as shunt discharges along the electrodes 11, 11, the polarity relations amongst the electrodes being suitable for this. Accordingly, this system differs from that of Fig. 1 in that its starting anode 22 that is operative is the one associated with the cathode 11 pertaining to the side of the circuit P that does not include the ballast 14. In other words, the control circuit 20 extends from the ballast tap 28 through the relay coil 19 to the anode 22 at the opposite end of the lamp from the cathode 11 which is connected to the ballast side of the circuit P. Instead of being connected to the base shells 25, 25 as in Figs. 1 and 2, the anodes 22 are here shown as connected to central contact pins or posts 29 on the lamp bases, which may be of the three-post type illustrated in Reissue Patent No. 21,545 to Marshaus. The external circuit connection to the center pin 29 of the operative anode 22 may be made by any suitable contact means connected to the corresponding side of the circuit 20, here indicated by the head of a spring-pressed contact pin 30.

All of the systems illustrated in Figs. 1-4 are suitable for both A. C. and D. C. operation.

The use of a variable tap 28 on the winding of the ballast 14 as in Figs 1 and 4 (or of a fixed connection to an intermediate point of the ballast, as in Fig. 3), is only one of a number of ways of securing the desired auxiliary voltage between coacting electrodes 11, 22. On the other hand, the types of control circuit connection represented in Figs. 1-3 and in Fig. 4, respectively, are generic, and can both be used with many different methods of deriving the desired auxiliary voltage from the main discharge circuit P and applying it between the electrodes 11, 22 through the control circuit 20. It has therefore been

deemed superfluous, in order to make it evident that both types of control circuit connection are applicable to each illustrated method of voltage derivation, to illustrate both these types of control circuit connection with each of the ways of deriving the desired auxiliary voltage which are shown in the drawings.

Fig. 5 illustrates a method of securing the desired auxiliary voltage between electrodes 11, 22 by means of a transformer 34, which also serves to ballast the auxiliary discharge. As shown in Fig. 5, the transformer 34 has its primary connected into the same side of circuit P as the ballast 14, in parallel with the ballast. Superficially, the starting system in Fig. 5 seems to correspond to that of Figs. 1 and 3, since one end of the control circuit 20 is connected to the anode 22 at the same end of the lamp L as the cathode 11 which is connected to the ballast side of the circuit P, while the other end of the control circuit, which includes the transformer secondary, is connected to this same side of circuit P, though at a point between ballast 14 and the corresponding cathode 11. However, the interposition of transformer 34 brings the voltage between the coacting electrodes 11, 22 and the resulting ionization of the discharge atmosphere into such relation with the main discharge between the electrodes 11, 11 that it assists the main discharge. In this respect, therefore, the Fig. 5 system corresponds to that shown in Fig. 4.

The system illustrated in Fig. 6 somewhat resembles that of Fig. 4, but has its control circuit 20 connected from anode 22 through relay coil 19 to the side of the circuit P that does not include the ballast 14. In the circuit 20 is connected the secondary of a transformer 34 whose primary is connected across the circuit P. For a supply circuit P of the order of 115 volts, the transformer 34 may be of the ordinary bell-ringing type. Besides producing the desired voltage between the adjacent electrodes 11, 22, the transformer 34 also serves to ballast the discharge between them. Owing to the interposition of the transformer 34, the ionization of the discharge atmosphere by the voltage between the electrodes 11, 22 is out of phase with the main discharge between the electrodes 11, 11, so that in this respect the system corresponds to Fig. 1.

The system illustrated in Fig. 7 resembles that of Fig. 1, but differs in having its auxiliary anode 22' in a separate envelope 40 that contains a co-acting auxiliary cathode 41 which is connected into the circuit P in series with one of the main cathodes 11 and between this cathode 11 and the ballast 14, so that the heating current flowing through it when the switch S is closed is the same as that through the main cathodes 11, 11. The envelope 40 may contain an atmosphere of the identical starting gas used in the lamp L, at the very same pressure. If the cathode 41 is made an exact counterpart of the main lamp cathodes 11, 11 in all essential respects, including activation, the auxiliary cathode 41 will reach various degrees of temperature and emission pari passu with the main cathodes 11, 11, so that the operation will be essentially just the same as already described in connection with Fig. 1. Preferably, however, the resistance and emissive properties of the auxiliary cathode 41 may bear such a proportion to those of the main cathodes 11, 11 that the cathode 41 will reach emission sufficient for the auxiliary discharge current required to operate the starting relay switch S at

the same time that the main cathodes 11, 11 reach emission sufficient for the full rated current of the main discharge. In either case, the heating time characteristics of the auxiliary cathode 41 may be substantially like those of the main cathodes 11, 11. Such a correlation of the auxiliary cathode 41 with the main cathodes 11, 11 may afford them even better protection against destructive ion bombardment than is possible when the auxiliary discharge current is taken from a main electrode 11 as already described. It is found that by using an unactivated thermoemissive auxiliary cathode 41 (e. g., a bare refractory metal heating wire filament coil, such as tungsten) instead of an activated cathode, it is possible to obviate irregularity of starter action due to irregularity of activating cathode coatings, which is exceedingly difficult to avoid in commercial manufacture of activated cathodes. This Fig. 7 system is suitable for both D. C. and A. C. operation.

Fig. 8 illustrates a system resembling that of Figs. 6 and 7, with a transformer 44 interposed in the heating connections for the auxiliary cathode 41. The thermionic devices 40 in Figs. 7 and 8 are of course alike in that their thermionic cathodes 41 do not participate in the main discharge, though they do coact with their auxiliary anodes 21f in the auxiliary discharge. In each of these figures, likewise, the cathode 41 is preheated from the main discharge circuit P in definite relation to the heating of the main cathodes 11, 11 therefrom; and the initiation of the main discharge in the device L by the opening of relay switch S in starting circuit H is effected and timed in response to emission from cathode 41, by means of control circuit 20 and switch-actuating coil 19. As here shown, the primary of the transformer 44 is connected in a circuit 45 across the main discharge circuit P, while its secondary is connected in series with the auxiliary cathode 41. The control circuit 20, which includes the auxiliary electrodes 41, 22f in the separate envelope 40, is shown connected to the circuit 45 in parallel with the transformer primary, through a variable tap 28f to a resistor 47 in said circuit 45, whereby the voltage between the electrodes 41, 22f can be adjusted as desired. Like the Fig. 5 and Fig. 6 systems, the Fig. 8 system is only suitable for A. C. operation.

To dispense with repetitive description, various parts and features in Figs 3-8 are marked with the same reference numerals as the corresponding ones in Figs. 1 and 2, a distinctive letter being added where such distinction appears necessary.

One of the requirements for the operation of the starter (in all forms of the system described above) is a sufficient preheat of the cathode 11 (or 41) to produce ionization of the starting gas and allow the auxiliary discharge between the electrodes 11, 22 (or 41, 22a) to take place. If the preheat current is very much reduced, as in a lead circuit with too small a condenser, it may be possible to heat the cathode 11 to a dull red without reaching ionization in the lamp that will allow discharge to occur. However, the ionization is not solely due to cathode temperature, but depends also on the potential difference between the electrode 22 and the cathode 11. For a lag circuit with a tap on the reactor 14, Fig. 4, intended to give 22 volts with normal supply voltage in the circuit P, the R. M. S. voltage available to start the auxiliary discharge may be of the order of 29 volts.

Figs. 9 and 10 show "families" of volt-ampere characteristics for the auxiliary discharge between the electrodes 11, 22 in Figs. 1 and 2 at steady-state temperatures corresponding to various values of heating current through the cathode 11. It is of practical significance that these characteristics are positive in every instance, instead of negative—as discharge characteristics very usually are. Fig. 9 shows the results of tests with straight auxiliary anodes 22 such as shown in Fig. 1, while Fig. 10 shows the results of tests with T-shaped auxiliary anodes 22a such as shown in Fig. 2. It is to be remarked that with preheating currents of 0.65 and 0.55 ampere, the cathodes 11 of the devices tested took voltages sufficient to produce shunt discharges along these cathodes, as mentioned above and indicated on the diagrams by the word "aglow"; while at lower currents, the cathodes showed yellow and red, as marked on the diagrams.

Referring especially to Figs. 2 and 10, it will be seen that with the system and lamp here represented, and with a cathode temperature corresponding to a heating current of 0.35 ampere, starting is impossible at any auxiliary discharge voltage under 31 volts R. M. S. if the relay switch S requires a current of 30 milliamperes to operate it, or even a current of as much as 12 milliamperes. With a cathode temperature corresponding to 0.45 ampere and a relay switch S requiring 30 milliamperes, starting would be possible only at an auxiliary discharge voltage of nearly 30 volts R. M. S. With this same relay switch S, starting would be possible at an auxiliary voltage of about 26 volts R. M. S. for a temperature corresponding to 0.55 ampere, and at an auxiliary voltage of about 23 volts R. M. S. for a temperature corresponding to 0.65 ampere. On the other hand, a relay switch S requiring only 20 milliamperes for its operation would give starting at an auxiliary voltage of about 27 volts R. M. S. for a temperature corresponding to 0.45 ampere, at about 23 volts R. M. S. for a temperature corresponding to 0.55 ampere, and at about 20 volts R. M. S. for a temperature corresponding to 0.65 ampere. Thus it is seen how the operating current requirements of the relay switch S and the auxiliary discharge voltage for starting are related to cathode temperature. The auxiliary discharge current is a function of the voltage between anode 22 and cathode 11, as well as a function of the cathode temperature.

It will be seen, finally, that considerable control is possible over the time required to start lamps. One means of such control is the relation of the preheat current to the normal current. A saturating reactor 14 will increase the ratio of these currents and shorten the lamp-starting time, while at the same time the cathode is automatically protected from the danger of overheating. On lead circuits, similar results can be obtained by using compensator reactors 14. Since this control is based on heating up the cathode rapidly, it is not likely to result in injury to the lamp. Another means of control over the starting time lies in the potential difference between the electrode 22 and the cathode 11. Increasing this potential difference decreases the time of ionization without a corresponding increase in cathode temperature, so that it tends to result in comparatively cold cathode starting, and must be used with caution.

The starting system can be so correlated with the ballast 14 that lamps will start in the same length of time on lead and lag circuits.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a start-timing system for a gaseous electric discharge device having thermionic electron-emissive cathode means embodying heating resistance, the combination of a main discharge circuit connected to said cathode means; means for preheating said cathode means comprising a starting circuit connected across said main discharge circuit through said resistance, and means for impressing across said discharge device a high starting voltage exceeding that of said main discharge circuit, including a relay switch in said starting circuit; another thermionic cathode energized and heated from said main discharge circuit; an auxiliary electrode for coacting with one of said cathodes; and means for delaying application of said high starting voltage including a control circuit for said relay switch connected between said coacting auxiliary electrode and cathode and energized by a voltage not deleteriously exceeding the cathode-disintegration voltage and so low that the current in said control circuit cannot open the relay switch until said cathode means of the discharge device has been preheated by the aforesaid heating current to a temperature at which its thermionic emission of electrons suffices to obviate destructive disintegration.

2. The invention as set forth in claim 1 further characterized in that while one of the cathodes there referred to is a main cathode of the discharge device, the other is an auxiliary cathode which does not participate in the main discharge but coacts with the auxiliary electrode in the auxiliary discharge, and is correlated with said main cathode to reach emission corresponding to discharge current that opens the relay switch when said main cathode reaches emission substantially corresponding to the rated main discharge current.

3. A start-timing system as set forth in claim 1 further characterized in that while one of the cathodes there referred to is a heating conductor activated with activating oxide and serves as a main cathode of the discharge device, the other is an unactivated thermoemissive refractory metal filament which does not participate in the main discharge, but coacts with the auxiliary electrode in the auxiliary discharge, and is correlated with said main cathode to reach emission corresponding to discharge current that opens the relay switch when said main cathode reaches emission substantially corresponding to the rated main discharge current.

4. The invention as set forth in claim 1 wherein the auxiliary electrode and its coacting cathode aforesaid are in an envelope separate from that of said discharge device.

5. The invention as set forth in claim 1 wherein the auxiliary electrode and its coacting cathode are in a separate envelope, and the heating means of said cathode is connected in circuit in series with the heating means of the discharge device cathode set forth in claim 1.

6. In a start-timing system for a discharge device having an ionizable discharge atmosphere and a thermionic cathode, the combination with a main discharge circuit for said discharge device, of a separate thermionic discharge device comprising an envelope separate from that of the first-mentioned discharge device, with a thermionic cathode in said separate envelope, and means for heating both of said thermionic cathodes from said main discharge circuit in definite

relation to one another, with means responsive to thermionic emission from the thermionic cathode in said separate envelope for timing the initiation of discharge in the first-mentioned discharge device.

7. In a start-timing system for a discharge device having an ionizable discharge atmosphere and a thermionic cathode comprising heating means, the combination with a ballasted main discharge circuit connected to said cathode, and a starting circuit connected across said main discharge circuit through said cathode heating means and having an interrupting switch therein, of a separate thermionic discharge device having a thermionic cathode, with means for energizing said last-mentioned cathode and heating the same to thermionic emission in definite relation to the heating of the first-mentioned cathode, and means responsive to thermionic emission from said last-mentioned cathode for timing the opening of said starting circuit by said interrupting switch, and the resulting initiation of the main discharge.

8. In a start-timing system for a gaseous electric discharge device having thermionic electron-emissive cathode means embodying heating resistance, and coacting main electrode means, the combination of a main discharge circuit connected across said cathode means and said coacting main electrode means; means for preheating said cathode means comprising a starting circuit connected across said main discharge circuit through said resistance, and means for impressing across said discharge device a high starting voltage exceeding that of said main discharge circuit, including a relay switch in said starting circuit; an auxiliary electrode for coacting with said cathode; and means for delaying application of said high starting voltage including a control circuit for said relay switch connected between said coacting auxiliary electrode and cathode and energized by a voltage of the order of $10\frac{1}{2}$ to 45 volts.

9. In a start-timing system for a gaseous electric discharge device having thermionic electron-emissive cathode means embodying heating resistance, and coacting main electrode means, the combination of a ballasted main discharge circuit connected across said cathode means and said coacting main electrode means; means for preheating said cathode means comprising a starting circuit connected across said main discharge circuit through said resistance, and means for impressing across said discharge device a high starting voltage exceeding that of said main discharge circuit, including a relay switch in said starting circuit; an auxiliary electrode for coacting with said cathode; and means for delaying application of said high starting voltage including a control circuit for said relay switch connected between said coacting auxiliary electrode and cathode through such part only of the main discharge circuit ballast that the voltage energizing the control circuit does not deleteriously exceed the cathode-disintegration voltage and is so low that the current in said control circuit cannot open the relay switch until the cathode means of the discharge device has been preheated by the aforesaid heating current to a temperature at which its thermionic emission of electrons suffices to obviate destructive disintegration.

10. In a start-timing system for a gaseous electric discharge device having thermionic electron-emissive cathode means embodying heating re-

sistance, and coating main electrode means, the combination of a main discharge circuit connected across said cathode means and said coating main electrode means; means for preheating said cathode means comprising a starting circuit connected across said main discharge circuit through said resistance, and means for impressing across said discharge device a high starting voltage exceeding that of said main discharge circuit, including a relay switch in said starting circuit; an auxiliary electrode for coating with said cathode; and means for delaying application of said high starting voltage including a control circuit for said relay switch connected between said co-

acting auxiliary electrode and cathode, and a transformer operatively connecting the main discharge circuit to said control circuit for energizing the control circuit with a voltage that does not deleteriously exceed the cathode-disintegration voltage and is so low that the current in said control circuit cannot open the relay switch until the cathode means of the discharge device has been preheated by the aforesaid heating current to a temperature at which its thermionic emission of electrons suffices to obviate destructive disintegration.

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