July 6, 1954 J. W. STRANGE ET AL 2,683,240

ELECTRIC LAMP CIRCUITS

Filed Sept. 20, 1949 3 Sheets-Sheet 1

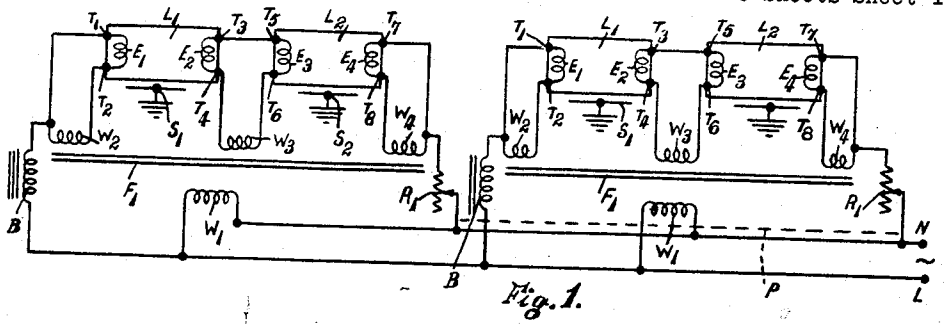


Fig. 1.

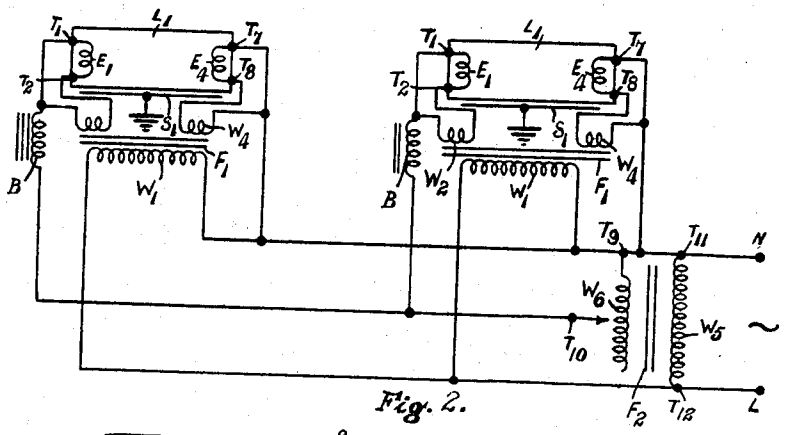


Fig. 2.

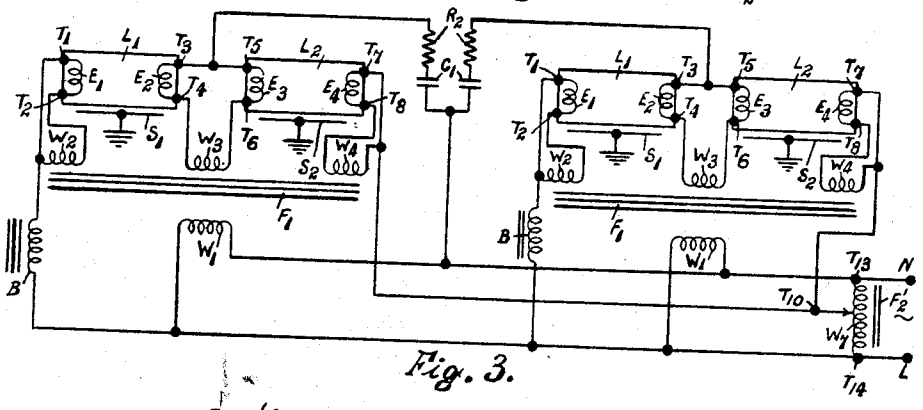


Fig. 3.

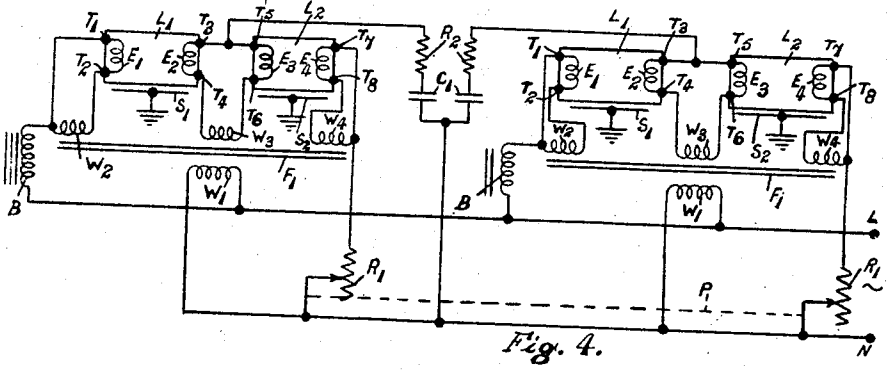


Fig. 4.

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ELECTRIC LAMP CIRCUITS

Filed Sept. 20, 1949 3 Sheets-Sheet 2

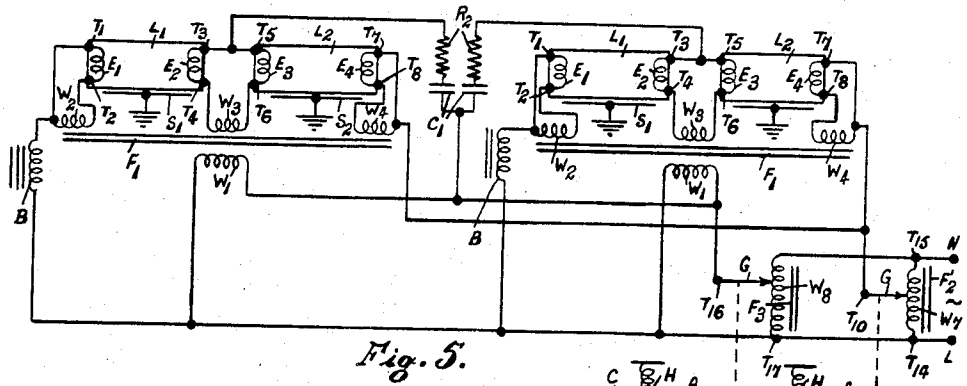


Fig. 5.

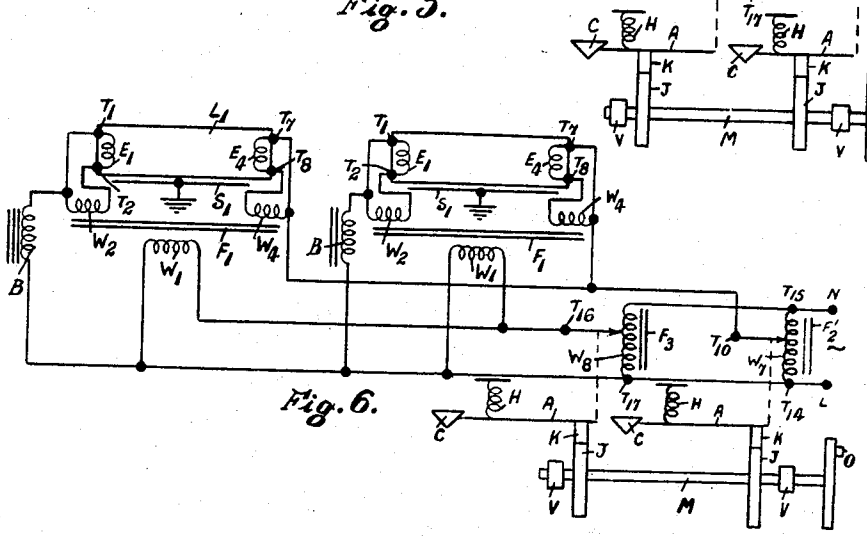


Fig. 6.

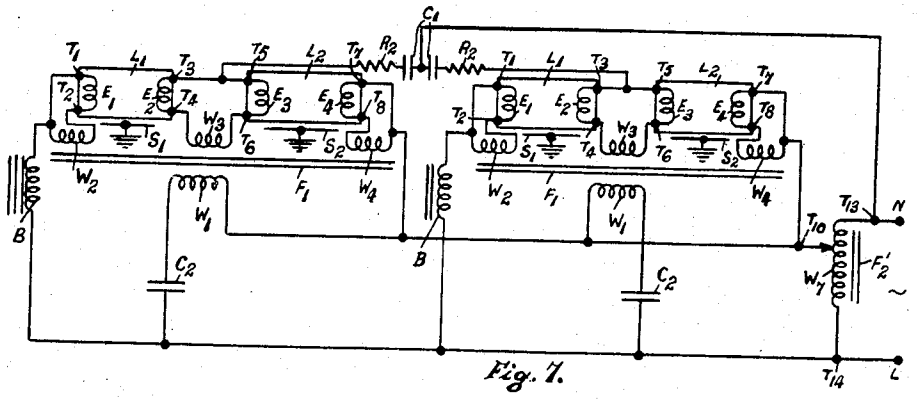


Fig. 7.

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ELECTRIC LAMP CIRCUITS

Filed Sept. 20, 1949 3 Sheets-Sheet 3

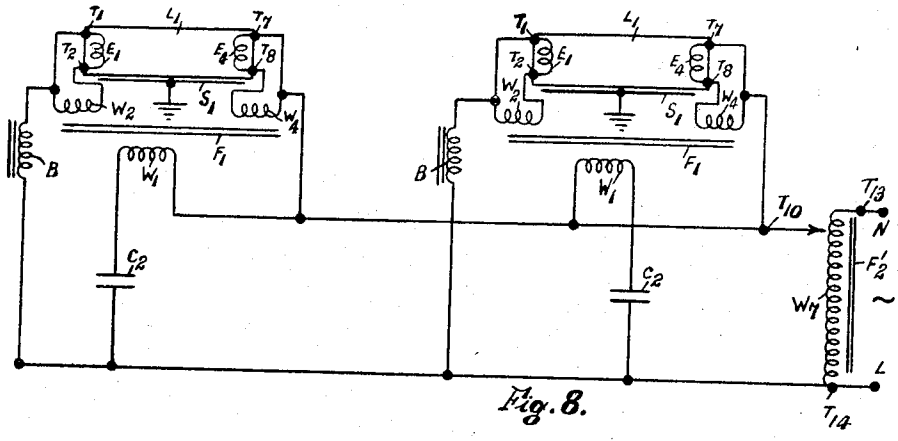


Fig. 8.

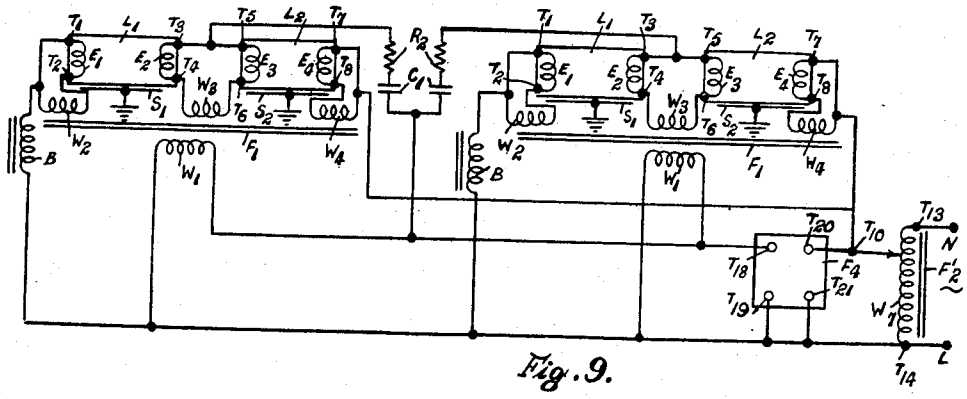


Fig. 9.

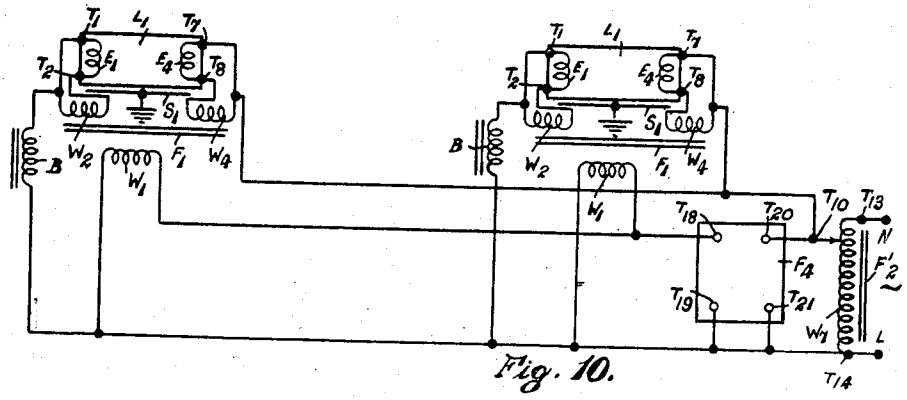


Fig. 10.

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UNITED STATES PATENT OFFICE

2,683,240

ELECTRIC LAMP CIRCUITS

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Application September 20, 1949, Serial No. 116,756

3 Claims. (Cl. 315—96)

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This invention relates to circuits used to control the brightness of low-pressure discharge lamps of the hot-cathode type. A low-pressure discharge lamp is one which operates normally at a temperature which exceeds the ambient temperature by not more than 60° C.

Filament lamps may be fed through adjustable dimming means capable of reducing the light emission progressively to zero. If coloured light is required as, for example, in theatre lighting, colour filters can be fitted in front of the filament lamps. The efficiency of the combination of filament lamp and colour filter is very low. The use of fluorescent discharge lamps has been suggested for colour lighting, since, by suitable choice of the luminescent material, a wide range of colours can be produced without the use of filters. The disadvantage of such lamps is that with normal circuits, consisting of a lamp in series with a choke and the filamentary lamp electrodes connected in series for starting by a glow or thermal switch, only a limited range of brightness is available. Attempts to use low voltages result in erratic and intermittent operation.

An object of this invention is to provide brightness control means which will permit substantial dimming of low-pressure discharge lamps of the hot-cathode type, and especially fluorescent lamps.

Another object of the invention in some of its forms is to provide an electric lamp system which can be arranged to give a substantially smooth decrease of brightness over the range from full brightness to less than one-hundredth of full brightness.

A further object is to provide an electric lamp system in which the brightness of two or more lamps may be varied simultaneously by a single operator's control.

According to this invention, an electric lamp circuit includes a lamp and ballast combination consisting of a low-pressure electric discharge lamp of the hot-cathode type having two electrodes, and a ballast impedance element connected in series with the lamp and adapted to limit the total current flowing between the electrodes, means for supplying heating current continuously to each of the electrodes of the lamp at least over the lower part of the operating range of brightness of the lamp, and means for applying between the terminals of the said combination a potential difference which is substantially continuously variable by a dimmer control member while the lamp is operating,

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both said means being adapted to be supplied from a common source of power. According to the invention in a preferred particular aspect, the said means for applying the potential difference which is variable while the lamp is operating are a variable series impedance element. This impedance element may be a variable resistor or a variable saturable reactor, or a variable resistor in series with a variable saturable reactor.

A filament lamp may be connected in parallel with the discharge lamp, the arrangement being such that, in the operating range within which the potential difference across the lamps is insufficient to cause the discharge lamp to strike, an appreciable amount of light is emitted by the filament lamp.

There may be provided a lamp system including two or more of the lamp circuits hereinbefore specified as according to this invention connected in parallel and having a common dimmer control member.

Two further particular aspects of this invention and three separate arrangements of the third aspect will now be specified.

According to this invention in its second aspect, an electric lamp circuit includes a lamp and ballast combination consisting of two low-pressure electric discharge lamps of the hot-cathode type connected in series to form a single discharge path, and a ballast impedance element adapted to limit the total current flowing in the discharge path, means for supplying heating current continuously to each of the electrodes of the lamps of the said combination at least over the lower part of the operating range of brightness of the lamps, and also means for providing between the terminals of the said combination a potential difference which is substantially continuously variable by a dimmer control while the lamps are operating, both said means being adapted to be supplied from a common source of power, and an impedance element connected between the junction of the discharge spaces of the lamps and a point on the circuit, e. g. a terminal of the source, so selected that the last-mentioned impedance element will pass a current through at least one of the lamps. The magnitude of this current should be such as to maintain the discharge at the lower limit of the controllable range of brightness of the lamp. A third lamp may be connected in series with the other two lamps, in which case a further impedance element may be connected between the junction of the third lamp with the other two lamps and a point on the circuit, e. g. the other

terminal of the source, so selected that the last-mentioned impedance element will pass through the said third lamp a current sufficient to maintain the discharge at the lower limit of the controllable range of brightness of the lamp. The said means for supplying heating current may include a transformer having its primary winding connected either across the supply terminals or in parallel with the discharge path. There may be provided a lamp system including two or more lamp circuits, specified as according to the invention in its second aspect, these circuits being connected in parallel, and the said potential difference, which is applied to the lamp and ballast combination referred to above, being substantially continuously variable by means of a common dimmer control member, e. g. associated with a common dimmer element of the kind which varies the applied voltage, such as a variably-tapped autotransformer.

According to this invention in its third aspect an electric lamp circuit includes a lamp and ballast combination consisting of a low-pressure electric discharge lamp of the hot-cathode type having two electrodes, and a ballast impedance element connected in series with the lamp and adapted to limit the total current flowing between the electrodes, means for applying between the terminals of the said lamp and ballast combination a first potential difference which is substantially continuously variable by a dimmer control while the lamp is operating, and means for applying between the terminals of each electrode a second potential difference which is substantially continuously variable by said dimmer control up to a predetermined value while a relatively low value of said first potential difference (i. e. lower than the value of the striking voltage of the lamp) is applied between the lamp electrodes, and for preventing said second potential difference from substantially exceeding said predetermined value while said first potential difference is increased beyond said relatively low value.

There may be provided a lamp system including two or more lamp circuits, specified as according to the invention in its third aspect, connected in parallel and having a common dimmer control.

In a first arrangement according to the invention in the said third aspect, an electric lamp circuit includes a lamp and ballast combination consisting of a low-pressure electric discharge lamp of the hot-cathode type having two electrodes, and a ballast impedance adapted to limit the total current flowing between the electrodes, dimmer means for providing between the terminals of the said combination a potential difference which is substantially continuously variable by a dimmer control member while the lamp is operating, and means for supplying to each of the electrodes of the lamp heating current which is substantially continuously variable by a regulator while a relatively low value of potential difference is applied between the said electrodes, both means being adapted to be supplied from a common source of power. The dimmer control member and the regulator may be ganged. There may be provided a lamp system including two or more lamp circuits specified as said first arrangement having a common regulator and a common dimmer control member actuating a dimmer element, e. g. a variably-tapped autotransformer, of the kind which varies the applied voltage. The common regulator and the common dimmer control member may be ganged.

In a second arrangement according to the invention in the said third aspect, an electric lamp circuit for use with an A. C. power source includes a dimmer element in the form of a variably-tapped autotransformer connected between the terminals of the power source and adapted to provide substantially continuously variable voltages between the terminals of a lamp and ballast combination consisting of a low-pressure electric discharge lamp of the hot-cathode type, and a ballast impedance connected in series with the lamp and adapted to limit the total current flowing between the lamp electrodes, said dimmer element also being connected to feed through a capacitor the primary winding of a second transformer having separate secondary windings connected respectively across the lamp electrodes, and the arrangement being such that for a value of the potential difference applied between the lamp electrodes slightly below the value of the striking voltage of the lamp the circuit is resonant at the frequency of the power source.

There may be provided a lamp system including two or more lamp circuits specified as said second arrangement connected in parallel and having a common dimmer element.

In a third arrangement according to the invention in the said third aspect, an electric lamp circuit for use with an A. C. power source includes a dimmer element in the form of a variably-tapped autotransformer connected between the terminals of the power source and adapted to provide substantially continuously variable voltages between the terminals of a lamp and ballast combination consisting of a low-pressure discharge lamp of the hot-cathode type connected in series with a ballast impedance element which is adapted to limit the total current flowing between the lamp electrodes, said dimmer element also being connected to feed the primary winding of a voltage limiting transformer, and the circuit also including a second transformer having a primary winding supplied through the secondary winding of said voltage limiting transformer and separate secondary windings connected respectively across the lamp electrodes.

There may be provided a lamp system including two or more lamp circuits specified as said third arrangement, connected in parallel and having a common dimmer element and a common voltage limiting transformer.

In all the above-mentioned circuits, when supplied from an A. C. power source, the means for supplying heating current to the lamp electrodes consist preferably of a transformer of the leakage-field reactance type.

In all the above-mentioned circuits an external electrode adapted to be maintained at a fixed potential is preferably placed close to the discharge lamp envelope, at least in the neighbourhood of the lamp electrodes, in order to increase the ionisation of the spaces adjoining these electrodes before the lamp strikes.

Preferred circuit arrangements embodying the invention will now be described, by way of example, with reference to the accompanying drawings, each figure of which shows a lamp system for use with an A. C. power source and consisting of two lamp circuits connected in parallel. The mains voltage is 230 unless otherwise stated. In the drawings:

Figure 1 shows a lamp system according to the invention in the said first aspect and in which

each lamp circuit includes two discharge lamps having continuously heated electrodes and connected in series to form a single discharge path; the circuits have separate adjustable electrical components acting as dimmers and ganged for operation by a common control member.

Figure 2 shows a lamp system according to the invention in which each lamp circuit includes a single discharge lamp having continuously heated electrodes; the circuits have a common adjustable electrical element acting as a dimmer.

Figure 3 shows a lamp system illustrating the invention in the said second aspect and in which the lamp circuits are provided with a common adjustable electrical element acting as a dimmer.

Figure 4 shows a lamp system similar to that shown in Figure 3 except that the lamp circuits have separate but ganged adjustable electrical elements acting as dimmers.

Figure 5 shows a lamp system illustrating the first arrangement of the invention in its third aspect; the two lamp circuits have two common adjustable electrical elements acting respectively as a dimmer and as a regulator.

Figure 6 shows a lamp system similar to that shown in Figure 5 except that each lamp circuit includes a single discharge lamp instead of two discharge lamps connected in series.

Figure 7 shows a lamp system illustrating the second arrangement of the invention in its third aspect; the lamp circuits have a common adjustable electrical element acting as a dimmer.

Figure 8 shows a lamp system similar to that shown in Figure 7 except that each lamp circuit includes a single discharge lamp instead of two discharge lamps connected in series.

Figure 9 shows a lamp system illustrating the third arrangement of the invention in its third aspect; the lamp circuits have a common adjustable electrical element acting as a dimmer.

Figure 10 shows a lamp system similar to that shown in Figure 9 except that each lamp circuit includes a single discharge lamp instead of two discharge lamps connected in series.

In each figure of the drawings elements in one lamp circuit corresponding to like elements in the other lamp circuit will be given like reference characters. All the lamps in the circuits described are of the type having directly heated electrodes.

Referring now to Figure 1, which illustrates the invention in its first aspect, in each lamp circuit two discharge lamps L_1 and L_2 having filamentary electrodes E_1, E_2 and E_3, E_4 respectively are connected in series to form a single discharge path. The terminals of the filamentary electrodes are indicated by T (e. g. T_1, T_2, T_3, etc.). The lamps are connected, in series with a ballast choke B and a dimmer element consisting of a variable resistor R_1, between terminals L and N of an A. C. power source. A transformer F_1, of the leakage-field reactance type, has a primary winding W_1 connected between the source terminals and separate secondary windings W_2 and W_4 connected to supply heating current to electrodes E_1 and E_4 respectively. Electrodes E_2 and E_3 are connected in series with a further separate secondary winding W_3 which supplies them with heating current. External electrodes S_1 and S_2 consisting of metallic strips connected to earth are disposed alongside the envelopes of their respective lamps L_1 and L_2. The dimmer elements are ganged and connected to a common dimmer control member indicated diagrammatically by P.

Each transformer F_1 is so designed that the electrodes of the lamps heated by the current from the secondary windings W_1, W_2 and W_3 are kept at such a temperature that they emit electrons freely. The presence of the adjacent earthed strips encourages ionisation around the electrodes. A stable discharge can be passed between the two electrodes of each lamp with the control set to limit the current to a value as low as 2 milliamperes. As the series impedance is decreased, by operation of the dimmer control, the current passing through the lamps increases until the lamps reach full brightness.

Thus the brightness of the lamps can be varied from their maximum to a low value without instability by operation of the resistors R_1. The ganging of these resistors enables the brightness of all the lamps in the system to be varied substantially simultaneously by actuation of a single operator's control.

This circuit arrangement is particularly suitable for a fluorescent lamp having an envelope 2 ft. in length and 1½ in. in diameter, designed to run with a lamp wattage of 40. A suitable value for each of the resistors R_1 is 130,000 ohms. Measurements made on such a circuit, with lamps having a luminescent coating of manganese activated zinc silicate, show that the light emitted by each lamp increases from 5 to 1300 lumens, reaching a peak efficiency of 50 L./watt. Any number of similar lamp circuits may be connected in parallel and their dimmer resistors ganged.

A transformer of the leakage-field reactance type is selected for F_1 since in operation the lamp electrodes have a negative impedance characteristic. This negaitve impedance characteristic is due to small potential differences which exist between adjacent portions of the electrode and which cause the establishment of minor discharges between these adjacent portions.

The arrangement shown in Figure 1 may be modified by replacing the variable dimmer resistors R_1 by variable saturable reactors. Alternatively each dimmer element may consist of a variable resistor in series with a variable saturable reactor; this arrangement can conveniently be made such that the reactor controls the brightness from full brightness to, say, one-tenth full brightness, the resistor controlling the brightness over the remainder of the range.

In another modification of the arrangement shown in Figure 1, in each lamp circuit the two lamps L_1 and L_2 are replaced by a 5-foot 80-watt lamp, the transformer winding W_3 being omitted. The circuit is designed for operation on 240 volts, and a filament lamp, designed to operate on a 130-volt supply at 60 watts, is connected in parallel with the discharge lamp. With this arrangement, increase of the potential difference across the lamps will increase the brightness of the filament lamp until the strike potential of the discharge lamp is reached, whereupon the potential difference across the lamps immediately decreases, so that a substantailly smooth increase in the brightness of the two lamps in combination is achieved through this transition period.

In each of the circuits in the system shown in Figure 2 a single lamp L_1 is connected in series with a ballast choke B between terminals T_9 and T_{10} of a variably-tapped secondary winding W_6 of a transformer F_2 which acts as a dimmer control and which is common to the two circuits. The terminals T_{11} and T_{12} of the primary winding W_5 of the transformer F_2 are connected re-

spectively to source terminals N and L. A leakage-field reactance transformer F_1 has a primary winding W_1 connected between the source terminals and separate secondary windings W_2 and W_4 connected to supply heating current to lamp electrodes E_1 and E_4 respectively. An external electrode S_1 is provided.

The brightness of the lamps may be varied by operating the dimmer control member and thus altering the potential applied to the lamp and the ballast choke in series. A discharge lamp, when in the discharging condition, has the characteristic of a constant voltage device, and variations in the potential applied to the lamp and the ballast choke in series will cause comparatively small variations in the potential difference between the lamp electrodes.

This circuit arrangement is particularly suitable for a fluorescent lamp having an envelope 5 ft. in length and 1½ in. in diameter, designed to run with a lamp wattage of 80. Any number of similar lamp circuits may be connected in parallel provided that the power rating of the dimmer transformer F_2 is increased to a sufficient value.

In the system shown in Figure 3, illustrating the invention in its second aspect, each circuit includes two discharge lamps L_1 and L_2, a ballast choke B and a leakage-field reactance transformer F_1 connected in the manner described with reference to Figure 1. External electrodes S_1 and S_2 are provided. The lamp and ballast combination is connected between terminals T_{14} and T_{10} of winding W_7 of a variably-tapped autotransformer F_2' acting as the dimmer. Terminals T_{13} and T_{14} of the dimmer are connected to terminals N and L of the power source respectively. T_{10} is the terminal of the tapping which constitutes the dimmer control. The junction of terminals T_3 and T_5 of electrodes E_2 and E_3 respectively is connected to the power source terminal N through a second impedance element consisting of a resistor R_2 in series with a capacitor C_1. The values of R_2 and C_1 are such that a small glow discharge, representing the lower limit of the controllable range of brightness, is maintained in either or both of the lamps. When the source terminals are phase and neutral, the second impedance element is preferably connected to the neutral terminal. When the dimmer control is in its position of minimum brightness, at least one of the lamps of each pair (usually L_2) is in or near the condition of small glow discharge and all the lamps will begin to increase in brightness at substantially the same rates when the dimmer control is moved from this minimum brightness position. Therefore a single operator's control may be used despite variations from lamp to lamp of the potential normally required to cause each lamp to strike.

This circuit arrangement is particularly suitable for 2-foot 40-watt lamps, and suitable values of R_2 and C_1 for use with such lamps are 100,000 ohms and 5,000 pf. respectively.

In a modification of the arrangement shown in Figure 3, the capacitors C_1 are connected to the tapping terminal T_{10} instead of to the neutral terminal N.

Any number of similar circuits may be connected in parallel provided that a separate second impedance element is provided for each pair of lamps and that the rating of the dimmer transformer is increased to a suitable value.

The lamp system shown in Figure 4 is similar to that shown in Figure 3 except that the dimmer for each circuit consists of a resistor R_1 connected in series with the lamp and ballast combination between the power source terminals. These separate resistors R_1 have their tappings ganged by means indicated diagrammatically by P to enable the brightness of all the lamps to be varied substantially simultaneously by a single operator's control member. This circuit arrangement is also particularly suitable for 2-foot 40-watt lamps. A suitable value of R_1 is 130,000 ohms.

In the system hereinbefore described the lamp electrodes are heated continuously and when the power applied to each lamp is reduced below the level at which a column discharge is visible, the ends of the lamp will still glow owing to the ionisation of the spaces surrounding the hot electrodes. If it is desired to extinguish the lamp completely the electrode heating currents may be switched off but the desired smooth decrease of brightness will not then be obtained. Circuits in which the lamps can be completely extinguished will now be described.

The arrangement shown in Figure 4 may be modified by eliminating the connections shown for each primary winding W_1 and connecting the terminals of each of these windings directly to the terminals T_1 and T_7 of the associated lamps.

The lamp system shown in Figure 5, illustrating the first arrangement of the invention in its third aspect, is similar to the system shown in Figure 3 except that the primary windings W_1 of leakage-field reactance transformers F_1 are connected in parallel between terminals T_{16} and T_{17} of winding W_8 of a variably-tapped autotransformer F_3 connected as a regulator. Thus the values of the electrode heating currents may also be varied. Also the second impedance element (i. e. the resistor R_2 and the capacitor C_1) is connected to the terminal T_{16} of the regulator instead of to the terminal N of the source, thereby enabling the lamps to be completely extinguished when the dimmer control and the regulator are set to zero.

The dimmer control and regulator transformers F_2' and F_3 are ganged by means of levers A operatively connected to the tapping selectors G and pivoted at C. The levers are moved by cams J and push-rods K and are held in contact with the push-rods by compression springs H. The cams are mounted on a shaft M rotatable in bearings V. An operator's handle O is also mounted on shaft M. The relative rates of movement of the tapping selectors of the dimmer and the regulator transformers may be altered in known manner by varying the cam contours.

This circuit arrangement is particularly suitable for 2-foot 40-watt lamps. In order to assist the ionisation of the spaces surrounding the electrodes before the arc strikes, the minimum value of the potential difference applied across each pair of lamps is set at approximately 130 volts. This potential difference is applied while the regulator is operated to increase the electrode heating currents to their maximum values, causing the ends of the lamps surrounding the electrodes to begin to glow and eventually causing the lamps to strike; the electrode heating current is then maintained substantially constant while the dimmer control is operated to increase the potential difference across the lamps until they have reached full brightness. To extinguish the lamps the sequence of operation is reversed. Thus it is possible to increase the brightness of all of the lamps at substantially the same rate over the full

range of zero to maximum brightness using a single operator's control.

Any number of similar circuits may be connected in parallel provided that the ratings of the dimmer and the regulator transformers are increased to suitable values.

The system shown in Figure 6 is similar to that shown in Figure 5 except that a single lamp is used instead of two lamps connected in series. This circuit arrangement is particularly suitable for 80-watt lamps.

The system shown in Figure 7, illustrating the second arrangement of the invention in its third aspect, is similar to the system shown in Figure 3 except that the primary windings W_1 of transformers F_1 are connected in series with capacitors C_2 and that each capacitor C_2 and its associated primary winding W_1 are connected in parallel with the lamp and ballast combination. The value of the capacitor C_2 is such that when the tap of the autotransformer F_2' is set to apply, between the terminals of the lamp and ballast combination, a potential difference which is slightly below the striking voltage of the lamps, the circuit is resonant at the frequency of the power source.

When the dimmer control is operated to increase the potential difference applied to the lamp and ballast combination, the heating current flowing through each electrode is also increased. As the sub-circuit including the transformer F_1 approaches the resonant condition, its impedance decreases until at resonance its impedance reaches a minimum. The current flowing through the primary of the transformer F_1 and the heating current flowing through the electrodes will therefore be of maximum value. The potential difference applied across the lamps assists the ionisation of the spaces surrounding the electrodes and this ionisation causes the ends of the lamps to glow. Progressive operation of the dimmer control increases the potential difference applied to the lamp and ballast combination until the lamps are at full brightness. When the dimmer control is so operated, the sub-circuit tends to go out of resonance, its impedance increases and the electrode heating currents therefore decrease. This decrease is compensated by the heating effect of the discharge which is now established.

This circuit arrangement is particularly suitable for 2-foot 40-watt lamps. Any number of similar circuits may be connected in parallel provided that the rating of autotransformers F_2' is increased to a suitable value and that a separate capacitor is provided for each primary winding W_1 of transformer F_1. When used with a 230-volt, 50-cycle power source, a suitable capacitor had a value of 2 mf. and was rated for a maximum working voltage of 440 volts A. C.

The system shown in Figure 8 is similar to the system shown in Figure 7 except that each circuit includes a single lamp instead of two lamps connected in series. This circuit arrangement is particularly suitable for 80-watt lamps.

The system shown in Figure 9 illustrating the third arrangement of the invention in its third aspect is similar to the system shown in Figure 3 except that the primary winding W_1 of each transformer F_1 is connected betwen output terminals T_{18} and T_{19} of a voltage limiting transformer F_4. The input termials T_{20} and T_{21} of the transformer F_4 are connected to terminals T_{19} and T_{14} of the dimmer transformer F_2'. Also the second impedance element (i. e. resistor R_2 and capacitor C_1) is connected to the terminal T_{18} of the transformer F_4 instead of to the terminal N of the source, thereby enabling the lamps to be completely extinguished when the dimmer control is set to zero.

When the dimmer control is operated to increase the potential difference applied across the lamp and ballast combination, the potential difference applied between the terminals of each electrode is also increased. The circuit is so arranged that, when the value of the potential difference applied across the lamp ballast combination is just less than the striking voltage of the lamps, the electrode heating currents have each reached a value sufficient to enable the lamps to strike. Under these conditions ionisation occurs around the electrodes and the ends of the lamps glow. Further operation of the dimmer control increases the potential difference between the lamp electrodes and the lamps strike, whilst the electrode heating currents are maintained substantially constant by the voltage limiting transformer. The dimmer control may then be operated to bring the lamps up to full brightness. Such a voltage limiting transformer is well known to those skilled in the art.

This circuit arrangement is particularly suitable for 2-foot 40-watt lamps. Any number of similar circuits may be connected in parallel provided that the ratings of voltage limiting transformer F_4 and dimmer transformer F_2' are increased to suitable values.

The system shown in Figure 10 is similar to that shown in Figure 9 except that each circuit includes a single lamp instead of two lamps connected in series. This circuit arrangement is particularly suitable for 80-watt lamps.

In the circuit arrangements in which variably-tapped transformers are used these transformers are so connected that the full mains potential is kept between the lamps and the external electrodes S irrespective of the positions of the transformer taps. With such an arrangement smooth variation in the brightness of the lamps is more readily obtained.

In all the circuit arrangements, when the terminals of the source are respectively phase and neutral, the ballast impedance is preferably connected between the lamps and the phase terminal.

We claim:

1. An electric lamp circuit including two power terminals for connection to an alternating current power source of fixed frequency and voltage, two electric discharge lamps and a ballast impedance connected in series between said power terminals, each of said discharge lamps having a filamentary cathode at each end thereof; means for supplying heating current to each of said filamentary cathodes; means for reducing the current to said lamps to dim the same; and a capacitative impedance connected in series with said ballast impedance and one only of the lamps between said power terminals, said capacitative impedance being small enough to pass enough current through the lamp in series with it to maintain the discharge therethrough at the lower limit of brightness of the lamp.

2. An electric lamp circuit including two power terminals for connection to an alternating current power source of fixed frequency and voltage, two electric discharge lamps and a ballast impedance connected in series between said power terminals, each of said discharge lamps having a filamentary cathode at each end thereof; means for supplying heating current to each of said

filamentary cathodes; and a capacitative impedance connected in series with said ballast impedance and one only of the lamps between said power terminals, said capacitative impedance being small enough to pass enough current through the lamp in series with it to maintain the discharge therethrough at the lower limit of brightness of the lamp.

3. An electric lamp circuit including an alternating current power source of fixed frequency and voltage, two electric discharge lamps and a ballast impedance connected in series between said power terminals, each of said discharge lamps having a filamentary cathode at each end thereof; means for supplying heating current to each of said filamentary cathodes; and a capacitative impedance connected in series with said ballast impedance and one only of the lamps between said power terminals, said capacitative impedance being small enough to pass enough current through the lamp in series with it to maintain the discharge therethrough at the lower limit of brightness of the lamp.

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