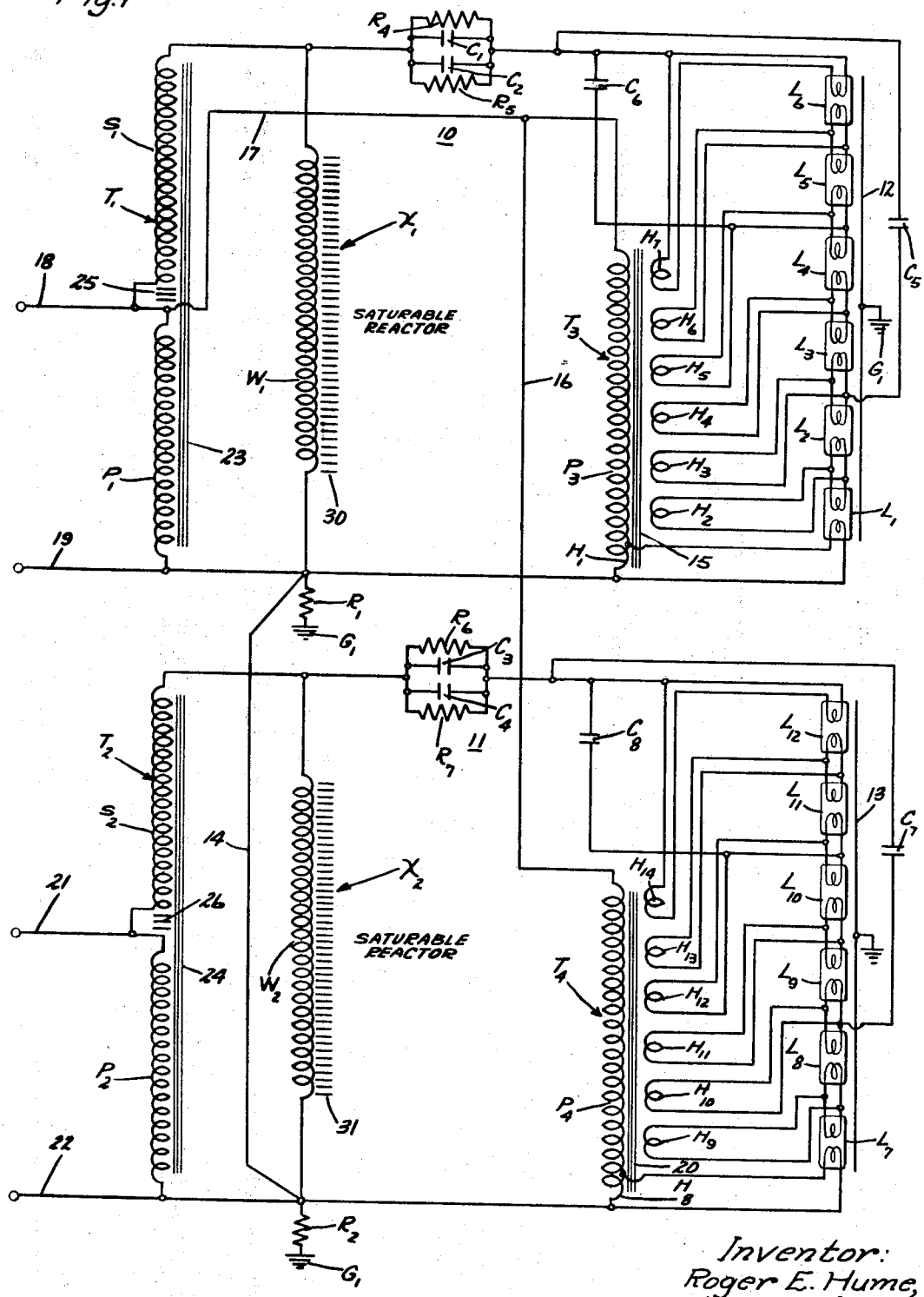
Feb. 27, 1968 R. E. HUME 3,371,245

DISCHARGE LAMP CIRCUIT HAVING SERIES CONDENSER AND SHUNT SWITCH FOR DISCHARGING CONDENSER THROUGH LAMP

Filed March 23, 1965 3 Sheets-Sheet 1

Fig. 1



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Fig. 2.

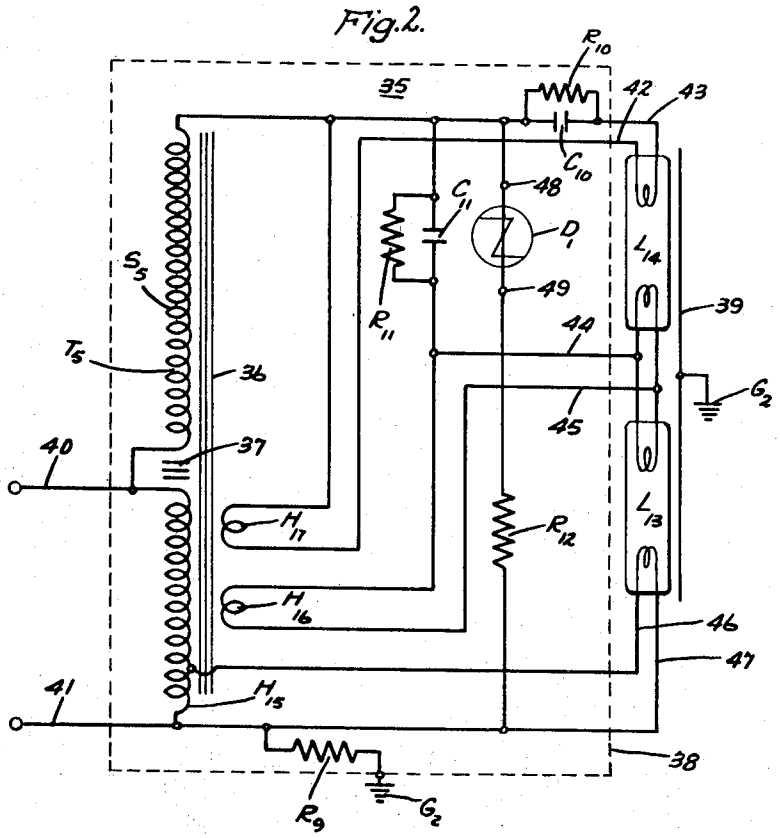
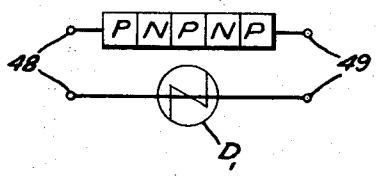


Fig. 3



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DISCHARGE LAMP CIRCUIT HAVING SERIES CONDENSER AND SHUNT SWITCH FOR DISCHARGING CONDENSER THROUGH LAMP

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Fig.4.

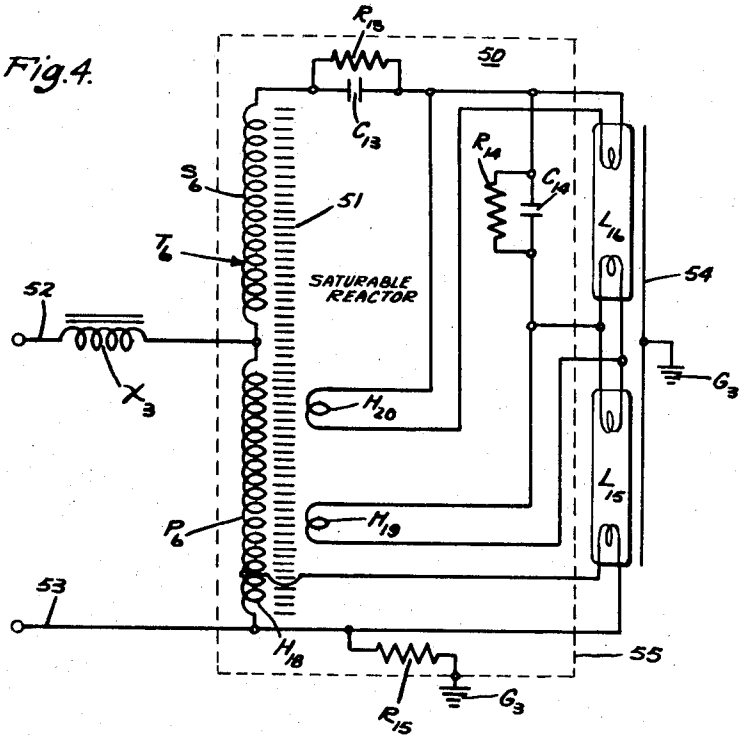
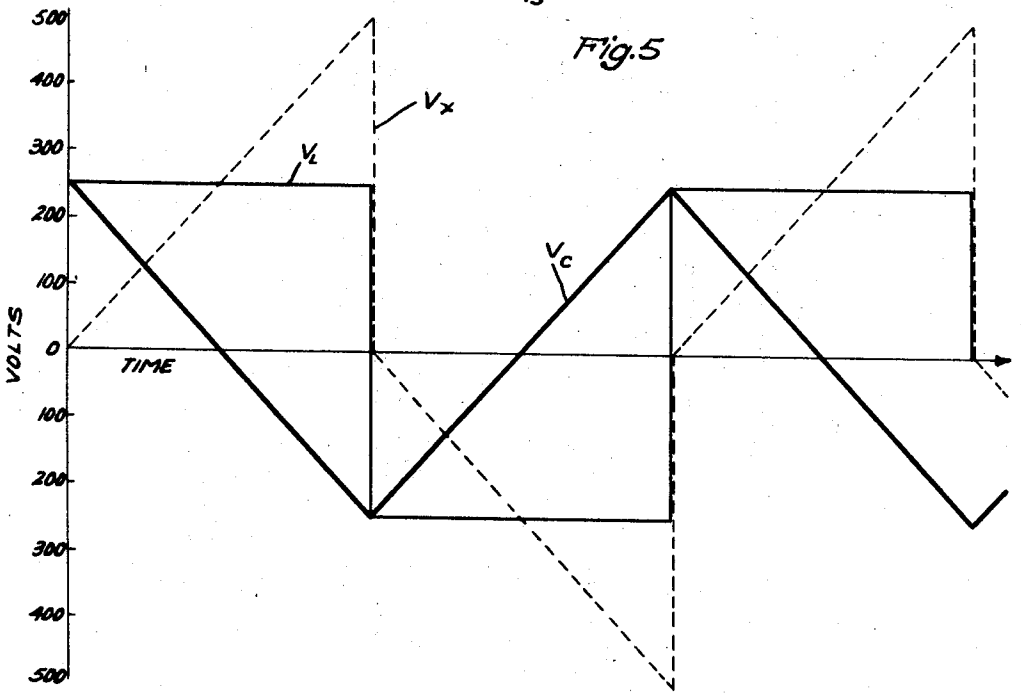


Fig.5



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3,371,245

DISCHARGE LAMP CIRCUIT HAVING SERIES CONDENSER AND SHUNT SWITCH FOR DISCHARGING CONDENSER THROUGH LAMP

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Filed Mar. 23, 1965, Ser. No. 442,068
10 Claims. (Cl. 315—240)

ABSTRACT OF THE DISCLOSURE

Apparatus for starting and operating electric discharge lamps which during operation supplies a current having a more nearly square wave shape. This is achieved by a saturable reactor or switching device in the output circuit to effect a controlled reversal of the voltage across the discharge lamp by discharging a capacitor when a preselected voltage level is reached in each half cycle.

This invention relates to systems and ballast apparatus for starting and operatnig electric discharge illumination means having a negative resistance characteristic. More particularly, it relates to such systems and ballast apparatus capable of operating electric discharge illumination means with an improved light output for a given value of lamp current.

In many lighting applications where electric discharge illumination means, such as fluorescent lamps, are used, it is particularly desirable to obtain maximum light output corresponding to minimum root mean square value of the lamp current. By minimizing the root mean square value of the lamp current, it is possible not only to increase the light output of the electric discharge lamps but also to reduce the volt-ampere requirements of the ballst apparatus. In applications where a high leakage reactance transformer is used in the ballast apparatus, reductions in heat losses can be achieved.

The relative magnitude of the root mean square value of the lamp current is dependent upon the wave shape of the lamp current. Ideally a lamp current having a square waveform would provide maximum light output for a minimum value of root means square lamp current. It is therefore desirable in many ballast applications to operate electric discharge lamps with a lamp current that is nearly square in waveshape.

Heretofore a number of arrangements have been employed for improving the shape of the lamp current waveform. In conventional apparatus employing high leakage reactance ballast transformers, the waveform of the lamp current is characterized by a pronounced peak. This peaked waveform indicates that a relatively high root mean square value of the lamp current is required to provide a predetermined light output. An arrangement for improving the waveshape of the lamp current by varying the leakage reactance through the use of nonlinear magnetic shunts is described and claimed in United States Patent No. 3,010,050 granted to Hume et al. Another arrangement for improving lamp current waveshape by controlling leakage reactance by the use of bridged gaps is disclosed in United States Patent No. 2,869,037 granted to Brooks et al.

Since commerically available power sources vary in voltage to some degree, the regulating characteristics of

a ballast apparatus are an important consideration particularly in applications where the electric discharge lamps are used in photocopy applications. Generally, a lower supply voltage will tend to reduce the light output and effect the starting performance of the ballast apparatus. On the other hand, a higher starting voltage may cause the light output to increase thereby causing variations from set levels that may impair the operation of the photocopy equipment. In a ballast apparatus adapted for use in photocopoy equipment it is therefore particularly desirable that variations resulting in light output for a given range of variations in the supply voltage be maintained within predetermined limits.

Accordingly, a general object of the present invention is to provide a system and ballast apparatus for starting and operating electric discharge illumination means wherein the lamp current has an improved waveshape.

Another object of the present invention is to provide an improved system and ballast apparatus for operating electric discharge illumination means having an improved regulating characteristic.

It is still another object of the present invention to provide an improved ballast apparatus wherein maximum light output can be achieved for a given root mean square value of lamp current.

A further object of the present invention is to provide a ballast apparatus incorporating an improved arrangement for improving the lamp current waveshape.

It is a more general object of the present invention to provide an improved system and ballast apparatus for operating a plurality of electric discharge lamps with improved operating characteristics.

In accordance with one form of my invention, I have provided a system including a ballast apparatus for starting one or more electric discharge lamps in a series lead circuit. The ballast apparatus includes an alternating voltage supply means, such as a high leakage reactance transformer, having an input circuit for connection with an alternating supply and also having an output circuit for supplying the output voltage of the alternating supply means to the lamps and including at least one series capacitor for introducing a net capacitive reactance in series with the electric discharge lamps during operation. The output circuit further includes a means for effecting a controlled reversal of the voltage across the electric discharge lamps in response to a preselected operating voltage level. Preferably, as a means for effecting the controlled reversal of the lamp voltage, a saturable reactor is provided in the lamp operating circuit, the reactor being designed to saturate at the predetermined voltage level to switch the voltage on the capacitor and thereby produce a controlled reversal of the lamp voltage in each half cycle.

In another aspect of my invention, I utilize as a means for effecting the lamp voltage reversal early in each half cycle a semiconductor switching device, such as a silicon controlled rectifier or a Shockley diode. The semiconductor switching device is connected in the lamp operating circuit in series with the capacitor. At a predetermined point in each half cycle the alternating output voltage of the ballast apparatus, the semiconductor device is switched into conduction to switch the voltage on the series capacitor, across the electric discharge lamps and thereby force a reversal of the lamp current. An important advantage of

a ballast apparatus incorporating such a means for effecting a controlled reversal of lamp current is that it is possible to achieve a more nearly square lamp current waveform and thereby obtain more light output per ampere of current supplied to the electric discharge lamps.

The subject matter which I regard as my invention is set forth in the appended claims. The invention itself, however, together with further objects and advantages may be better understood by referring to the following description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a schematic circuit diagram of a ballast apparatus embodying one form of my invention for starting and operating twelve electric discharge lamps;

FIGURE 2 is a schematic circuit diagram of another form of the improved ballast apparatus utilizing a semiconductor switching device for effecting the controlled reversal of the lamp current in each half cycle;

FIGURE 3 illustrates the P–N junction arrangement of the five layer diode and also shows the correspondence between the junction arrangement and the symbol used for the five layer diode in FIGURE 2;

FIGURE 4 is a schematic diagram of a ballast apparatus embodying another form of the invention wherein the saturable reactor not only performs the current reversing operation in accordance with the invention but also carries out the voltage transforming function to provide the stepped-up voltage required to start and operate a pair of hot cathode type of fluorescent lamps;

FIGURE 5 illustrates three curves showing the ideaized waveforms, Curve V_L representing the idealized waveform of the lamp current, Curve V_C representing the idealized waveform of the capacitor voltage and Curve V_X representing the idealized waveform of the saturable reactor voltage, the curves being presented as an aid in the explanation of the operation of the improved ballast apparatus of my invention.

Referring now more specifically to FIGURE 1, I have illustrated therein two interconnected ballast apparatuses **10** and **11** for operating two groups of electric discharge lamps L_1, L_2, L_3, L_4, L_5, L_6 and L_7, L_8, L_9, L_{11}, L_{12} respectively. The six lamps operated by the ballast apparatus **10** are disposed in close proximity to the conductive part or fixture **12** connected to a ground G_1 and providing capacitive coupling between the lamps and conductive part **12** to aid in the starting of the electric discharge lamps. Similarly, a conductive part **13** connected to the ground G_1 is disposed close to the six electric discharge lamps operated by ballast apparatus **11** and provides capacitive coupling between the filaments of the lamps and the conductive part **13** to aid in starting these lamps. It will be noted that each ballast apparatus **10, 11** is also connected to the ground G_1 through resistors R_1 and R_2 by lead **14** joining the low potential side of the ballast circuits. Such a grounding arrangement insures that in applications where the power distribution system is not effectively grounded the output voltage across high leakage reactance transformers T_1, T_2 is initially applied between the lamps and the conductive parts **12, 13** respectively to cause ionization to be initiated in the vicinity of lamp filaments and to thereby facilitate the starting of the lamps.

In the embodiment of the invention shown in FIGURE 1, which was used to provide the illumination required in photocopy equipment, separate filament transformers T_3 and T_4 were used since continuous cathode heat was required in order to obtain fast starting and better lamp life. Filament transformers T_3 has seven cathode heating windings H_1, H_2, H_3, H_4, H_5, H_6 and H_7 inductively coupled with a primary winding P_3 on a suitable magnetic core **15**. It will be seen that the upper ends of the primary windings P_3 and P_4 of the filament transformers T_3 and T_4 are connected by lead **16** to a common connection **17**, which electrically joins these ends to the high potential side of the alternating current supply. In the embodiment of the invention illustrated in FIGURE 1 the filament transformer T_4 of ballast apparatus **11** is essentially identical

to the one used in ballast apparatus **10**. The filament transformer T_4 also includes a primary winding P_4, a magnetic core **20** and cathode heating windings H_8, H_9, H_{10}, H_{11}, H_{12}, H_{13} and H_{14}.

To provide the necessary starting and operating voltages high leakage reactance type of transformers T_1 is employed in the ballast apparatus **10** with leads **18** and **19** adapted for connection to a suitable alternating current source (not shown). A similar high leakage reactance transformer T_2 is used in ballast apparatus **11** and includes a pair of input leads **21** and **22** for connecting the primary winding P_2 across an alternating current source. Step-up transformers are required since the starting and lamp operating voltages required to start six fluorescent lamps are greater than the applied 60 cycle, 115 volt line supply. The high leakage reactance ballast transformers T_1, T_2 include the primary windings P_1, P_2, secondary windings S_1, S_2, magnetic cores **23, 24** and magnetic shunts **25, 26**.

A type of magnetic core which may be used in the high leakage reactance transformers T_1 and T_2 is described in Hume et al. Patent 3,010,050. The magnetic shunts **25, 26** supply a path for the leakage flux between the primary and the secondary windings. The effect of leakage flux is that during operation the voltages induced in the windings cause the transformers T_1, T_2 to have a relatively high leakage reactance, and the load current in the output circuit supplied to the lamps is thereby limited. It will be understood that the flux leakage path, if desired, may be formed by nonmagnetic material such as air of by shunts formed integrally on the magnetic core or by inserted shunts of magnetic material or other suitable means.

A pair of capacitors C_1 and C_2 connected in series circuit with the secondary winding S_1 introduce a net capacitive reactance into the output circuit and serve as an energy storage element. Generally the net capacitive reactance in the output circuit helps to minimize the load that the ballast apparatus contributes to the distribution system. Capacitor discharge resistors R_4 and R_5 are connected in shunt with the capacitors C_1 and C_2 and provide a path for the discharge of these capacitors when the ballast apparatus **10** is disconnected from the alternating current supply. If desired, a radio interference capacitor may also be connected across the input terminal leads or across the electric lamps where it is necessary to suppress radio interference from the lamps which may feed back to the power lines through the ballast.

In balast apparatus **11** a pair of series capacitors C_3 and C_4 are also employed to provide a net capacitive reactance in the output circuit of transformer T_2, and a pair of capacitor discharge resistors R_6 and R_7 are connected in shunt with the series capacitors C_3 and C_4. Although a pair of series capacitors were used in each of the ballast circuits shown in FIGURE 1 it will be appreciated that a single capacitor may be substituted for each pair of series capacitors.

The starting of the electric discharge lamps L_1, L_2, L_3, L_4, L_5 and L_6 is effected by providing a starting capacitor C_5 connected in shunt across lamps L_3, L_4, L_5 and L_6 so that the open circuit starting voltage is initially applied across the pair of lamps L_1 and L_2. A second starting capacitor C_6 is connected across lamps L_5 and L_6 so that the open circuit starting voltage is applied across lamps L_3 and L_4 after lamps L_1 and L_2 are ignited. In ballast apparatus **11** starting capacitors C_7 and C_8 serve the same function as starting capacitors C_5 and C_6 of ballast apparatus **10**.

In accordance with one important aspect of my invention I have placed a saturable reactor X_1 consisting of a reactor winding W_1 and the saturable core **30** across the parallel-connected series capacitors C_1, C_2 and the electric discharge lamps L_1, L_2, L_3, L_4, L_5 and L_6. A saturable reactor X_2 comprised of a reactor winding W_2 and saturable core **31** is similarly connected in the circuit of ballast apparatus **11**. The saturable cores used in the illustrated exemplification of the invention are formed of laminations

and are designed to saturate at a predetermined voltage level in each half cycle of the alternating output voltage of the high leakage reactance ballast transformers T_1 and T_2. When the saturable reactors X_1 and X_2 saturate, they present a low impedance to the current in the output circuit and thereby cause the voltage across the series capacitors C_1, C_2 and C_3, C_4 to be switched across the group of lamps in its respective output circuit. The capacitor discharge current flows in a closed loop which includes a pair of series capacitors, a saturable reactor and a group of lamps. By effecting such a reversal of the lamp voltage early in each half cycle, it was found a more square-like lamp current waveform is obtained, and an improved light output is achieved for a given value of root mean square lamp current.

By way of a more specific exemplification of the invention, the ballast apparatuses **10** and **11** shown in FIGURE 1 were constructed with the following circuit components, which are given by way of illustration:

Transformers T_1, T_2:
- Primary winding P_1, P_2 ----- 396 turns of .0508 of an inch copper wire.
- Secondary winding S_1, S_2 ---- 1330 turns of .0320 of an inch copper wire.

Filament Transformers T_3, T_4:
- Primary windings P_3, P_4 ---- 703 turns of .0142 of an inch copper wire.
- Cathode heating windings H_1, H_2, H_3, H_4, H_5, H_6, H_7, H_8, H_9, H_{10}, H_{11}, H_{12} ---------- 31 turns of .0302 of an inch copper wire.

Saturable reactors X_1, X_2 ------ 858 turns of .0320 copper wire.

Series capacitors C_1, C_2 C_3, C_4 ---------- 3.8 microfarads 300 volts AC.

Starting capacitors C_5, C_6, C_7, C_8 ---------- .05 microfarads.

Resistors R_1, R_2 ---------- 2.0 megohms, ½ watt.

Resistor R_3, R_4, R_5, R_6 -------- 2.0 megohms, ½ watt.

In order to demonstrate the improved regulating characteristics and the light output achieved by the improved series capacitor switching arrangement a ballast apparatus utilizing the components as described above was operated and tested. The lamp current and percent lumen maintenance were determined for line voltages of 105, 115 and 125 volts and with series capacitors having an average capacitance of 8.022 microfarads and 8.14 microfarads. The light output of the lamps was measured by a photocell connected to a D.C. meter calibrated to indicate the lumen output with light output of the lamps assumed to be 100 percent when operated on a reference ballast adjusted for since wave current of .0800 amperes. In Table I the results of these determinations are summarized.

TABLE I

Series Capacitance (microfarads)	Input (volts)	Lamp Current (amperes)	Lumen Maintenance (percent)
8.022	115	.815	106.3
8.022	105	.793	106.3
8.022	125	.850	106.3
8.14	115	.830	107.8
8.14	105	.806	107.0
8.14	125	.862	107.8

It was found that the variation in the light output of the fluorescent lamps as the supply voltage was varied from 105 to 125 volts did not exceed 1 percent for the units tested. It will be understood that a conventional ballast generally provides a lumen maintenance of about 95 percent. The improved lumen output is believed to be attributable to the more square-like lamp current waveform.

When the input leads **18, 19** are connected to a suitable source of alternating current (not shown) the total open

circuit voltage, which is the sum of the voltages across the primary and secondary windings P_1 and S_1 of transformer T_1 is applied initially across lamps L_1 and L_2, due to the connection of the starting capacitor C_5. Since both ballast apparatuses **10** and **11** start and operate in essentially the same manner, I will describe herein only the manner in which ballast apparatus **10** is started and operated.

Due to the connection of the starting capacitor C_5 across the four lamps L_3, L_4, L_5 and L_6 substantially all of the open circuit voltage of transformer T_1 appears in the first instance across the lamps L_1 and L_2. Also, at the same instant the filaments of the lamps are being heated to electron emitting temperatures by the filament transformer T_3. After lamps L_1 and L_2 are ignited, current flows through the starting capacitor C_5 and produces a relatively high voltage drop which is now impressed across lamps L_3 and L_4. Once lamps L_3 and L_4 have ignited the voltage drop across starting capacitor C_6 is impressed across lamps L_5 and L_6, these last two lamps are fired. With all of the lamps operating the impedance across the lamps is sufficiently greater than the impedance of the starting capacitors C_5 and C_6 so that the current flow through the starting capacitors is negligibly small during operation.

The saturable reactor X_1 is designed so that at the peak value of the voltage applied across its terminals, the saturable reactor X_1 is at or near saturation, and its impedance falls down to zero to switch the voltage on capacitors C_1 and C_2 across the lamps and effect a quick reversal of the lamp current in each half cycle. The controlled reversal of the lamp current produces a lamp current having a more nearly square waveshape.

In contrast with the embodiment of the invention shown in FIGURE 1, a ballast apparatus **35** shown in FIGURE 2 does not utilize a saturable reactor to effect a quick reversal of the lamp current in each half cycle but employs a five layer diode D_1.

The voltage transforming and current limiting functions of the ballast apparatus **35** are carried out by a high reactance transformer T_5 having a primary winding P_5, a secondary winding S_5, and cathode heating winding H_{15}, H_{16} and H_{17}. The secondary winding S_5 is loosely coupled with the primary P_5 on a magnetic core **36**. A magnetic shunt **37** is interposed between the primary winding P_5 and the secondary winding S_5 to provide a path for leakage flux.

As is shown schematically in dashed outline in FIGURE 2, the ballast apparatus **35** is housed in a case or canister **38**. The ballast apparatus **35** is adapted for operating a pair of hot cathode fluorescent lamps L_{13} and L_{14}. The lamps L_{13} and L_{14} are connected so that they can be started and operated in series and are shown disposed in proximity to a conductive part **39**, usually the lamp fixture, connected to a ground G_2. The conductive part **39** provides for capacitive coupling between the lamps L_{13} and L_{14} and the conductive part **39** in order to aid in starting the lamps. The low potential side of the primary winding P_5 is connected through a resistor R_9 to the ground G_2 through the case **38**. With this grounding arrangement the voltage across the primary winding P_5 and secondary winding S_5 applied during starting condition between a lamp electrode and the conductive part **39** to initiate ionization in the vicinity of the lamp electrode thereby to facilitate the starting of the lamps L_{13} and L_{14}.

In order to energize the ballast apparatus **35**, a pair of input terminals or leads **40, 41** are brought out of the ballast case **38** for connection to a suitable alternating power supply such as a 60 cycle, 115 volt commercial supply. The output of the ballast apparatus **35** is supplied to the lamps L_{13} and L_{14} by three pairs of leads **42, 43, 44, 45** and **46, 47**.

In FIGURE 2 the capacitor discharge resistors R_{10} and R_{11} are shown connected in shunt with a series

capacitor C_{10} and a starting capacitor C_{11}, respectively. The resistors R_{10}, R_{11} provide a path for the discharge of the capacitors C_{10}, C_{11} when the power supply is disconnected from the ballast apparatus **35**.

The voltage required to start and operate the lamps L_{13} and L_{14} is applied across the lamps essentially by the output leads **43** and **47**. The voltages induced in cathode heating windings H_{15}, H_{16} and H_{17} are applied across the filaments of lamps L_{13} and L_{14} by leads **42**, **43**, **44**, **45**, **46** and **47** to maintain a continuous supply of current to these filaments when the ballast apparatus **35** is operating the lamps.

In the embodiment illustrated in FIGURE 2, the five layer diode D_1 effects a quick reversal of the currents supplied to the lamp at or near the peak value of the voltage applied across its terminals **48**, **49**. The resistor R_{12} connected in series with the five layer diode D_1 is provided to limit the current flowing through the five layer diode D_1 when it is in a conducting state.

As is shown in FIGURE 3, the five layer diode, which may be employed in the practice of the invention, is comprised of five P-type and N-type zones of semiconducting material. The five layer diode is switched from its high impedance state to its low impedance state when the voltage across its terminals **48**, **49** exceeds the switching voltage of the diode. The value of this switching voltage for the five layer diode used in this exemplification of the invention was such that when the output voltage of the transformer T_5 reached its peak value, the five layer diode D_1 switched to its low impedance state in each half cycle to cause the voltage across capacitor C_{10} to be applied across lamps L_{13} and L_{14}. It will be appreciated that the five layer diode D_1 is a bidirectional switching device and can be fired during each alternation of the voltage at approximately the point at which its switching voltage is exceeded.

Although I have illustrated a five layer diode in the ballast apparatus **35** of FIGURE 2, it will be apparent that other bidirectional semiconductor switching arrangements, such as a silicon controlled rectifier or a four layer diode in a full wave bridge, can be employed to perform the switching action to effect a controlled reversal of lamp current at about the peak point of the transformer output voltage in each half cycle.

The starting of lamps L_{13} and L_{14} by ballast apparatus **35** is accomplished in a conventional manner. The open circuit voltage of the ballast apparatus **35** is initially applied across lamp L_{13} since the starting capacitor C_{11} effectively shunts the lamp L_{14}. Also, starting of lamp L_{13} facilitated by a small auxiliary current flow between one of its lamp filaments and the conductive part **39** disposed in capacitive relationship therewith. After lamp L_{13} is ignited, the voltage across the starting capacitor C_{11} is sufficient to start lamp L_{14}. Thus in each half cycle when the voltage across the ballast transformer T_5 is at or near the peak point value, the five layer diode D_1 fires and effects a controlled reversal of the lamp current to render the waveform more square-like.

Referring now to the schematic circuit diagram shown in FIGURE 4, I have illustrated therein a ballast apparatus **50** employing a saturable reactor T_6 which not only performs the current reversing function but also supplies the step-up in voltage required to start and operate a pair of fluorescent lamps L_{16} and L_{17}. The saturable reactor T_6 includes a primary winding P_6 and a secondary winding S_6 inductively coupled with the primary winding P_6 on a saturable magnetic core **51**. The magnetic core **51** is designed to saturate at or near the peak value of the alternating voltage across primary winding P_6. Also inductively coupled with the primary winding P_6 are three cathode heating windings H_{18}, H_{19} and H_{20}. The series capacitor C_{13}, the starting capacitor C_{14} and the capacitor discharge resistors R_{13}, R_{14} perform the same functions as the corresponding parts do in ballast apparatus **35** shown in FIGURE 2. A conductive part **54** connected to a ground G_3 is positioned in proximity to the lamps L_{15} and L_{16} and a resistor R_{15} is connected to ground G_3 through ballast case **55**.

The current limiting function in the ballast apparatus **50** is effected by a reactor X_3. The reactor X_3 also serves the purpose of isolating the lamp operating loop from the alternating current supply when saturable reactor T_6 saturates to effect a reversal of the lamp current in accordance with one form of my invention.

The starting of the lamps L_{15} and L_{16} is accomplished in the same manner as was previously described in connection with the ballast apparatus **35** shown in FIGURE 2. During the starting condition the open circuit voltage of saturable reactor T_6 is initially applied to lamp L_{15} which is the first lamp to be ignited. After lamp L_{15} is ignited, the voltage drop across the starting capacitor C_{14} is sufficient to fire lamp L_{16}, and the lamps L_{15}, L_{16} are operated in series. As in the other embodiments of my invention, a controlled reversal of the lamp current is effected in each half cycle. When the saturable reactor T_6 saturates in each half cycle, it presents a very low impedance as compared with its unsaturated impedance and thereby causes the voltage across the series capacitor C_{13} to be applied across the lamps L_{15}, L_{16} and brings about a controlled reversal of the lamp current.

In order to more fully explain what I believe is the mode of operation of the improved capacitor switching arrangements, I have illustrated in FIGURE 5 idealized voltage waveforms, V_x representing the waveform of the voltage across the saturable reactor, V_c representing the waveform of the voltage across the series apacitor and, V_1 representing the waveform of the lamp voltage. It will be undrestood that these waveforms are not actual voltage waveforms but represent idealized shapes of these voltages.

It will be noted that the saturable reactor voltage waveform V_x in the first half cycle is increasing at a constant rate and the voltage waveform V_x is essentially triangular in shape, the apex of the triangle representing the point of saturation of the saturable reactor. During the same half cycle the series capacitor voltage waveform is decreasing at essentially the same rate as the saturable reactor voltage V_x. It will be understood that the sum of the instantaneous values of the saturable reactor voltage waveform V_x and the series capacitor voltage waveform are equal to the instantaneous value of the lamp voltage. Because of the relative phase relationship and position of the waveforms V_x and V_c with respect to the zero axis, it will be seen that ideally the sum of the instantaneous values of voltage waveforms V_x and V_c are constant in magnitude in any half cycle or in other words, the voltage waveform V_1 ideally would be a square waveshape. According to my understanding of the operation of the improved capacitor switching arrangement, by quickly switching the series capacitor voltage across the lamps in each half cycle when the voltage of the supply means is at or near its peak, more nearly linear type of reactor voltage and capacitor voltage relationships are approached to produce a more square-like lamp voltage waveform.

An important advantage derived from the use of the various means for effecting the improved controlled reversal of the lamp current is that it is possible to obtain a maximum lumen output per ampere of lamp current. Further, a ballast apparatus characterized by good regulating characteristics is provided wherein the light output is only minimally affected by variations in supply voltages.

From the foregoing description of the various embodiments of my invention, it will be apparent that many modifications may be made. It will be understood, however, that these embodiments of the invention are intended as exemplifications of the invention and that the invention is not limited thereto. It is to be understood, therefore, that I intend by the appended claims to cover

all such modifications that fall within the true spirit and scope of the invention.

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

1. A ballast apparatus for starting and operating an electric discharge illumination means having a negative resistance characteristic, said ballast apparatus comprising a high leakage reactance transformer having at least a primary winding and a secondary winding inductively coupled on a magnetic core, said high leakage reactance transformer including an input circuit for connection to an alternating current supply and having an output circuit for applying an operating voltage to the electric discharge illumination means, a saturable reactor having a saturable core and a winding wound thereon and connected in shunt across said primary and secondary winding in the output circuit, said output circuit including a series capacitor connected in series circuit relationship with said secondary winding, said saturable reactors having a saturating characteristic wherein the saturable core saturates in each half cycle when the operating voltage reaches a predetermined level thereby to effect a discharge of the capacitor in each half cycle and produce a current in the operating circuit having a more nearly square wave shape.

2. A ballast apparatus for starting and operating an electric discharge illumination means having a negative resistance characteristic, said ballast apparatus comprising a high leakage reactance transformer having at least a primary and a secondary winding inductively coupled on a magnetic core, said high leakage reactance transformer including an input circuit for connection to an alternating current supply and having an output circuit for applying an operating voltage to an electric discharge illumination means, said output circuit including a series capacitor connected in series circuit relationship with said secondary winding, semiconductor switching means connected in said output circuit across the primary and secondary winding of said high leakage reactance transformer for switching the voltage across the series capacitor to produce a controlled reversal of the current supplied to the electric discharge illumination means in each half cycle when the operating voltage reaches a predetermined level thereby to supply to said electric discharge illumination means a current having a more nearly square waveshape.

3. The ballast apparatus set forth in claim 2 wherein an impedance element is connected in series circuit relation with said semiconductor switching means for limiting the current discharge from said series capacitor.

4. A ballast apparatus for starting and operating an electric discharge illumination means having a negative resistance characteristic, said ballast apparatus comprising a high leakage reactance transformer having at least a primary and a secondary winding inductively coupled therewith on a magnetic core, said high leakage reactance transformer including an input circuit for connection to an alternating current supply and also having an output circuit for applying an operating voltage to the electric discharge illumination means, said output circuit including a series capacitor connected in series circuit relationship with said secondary winding for introducing a net capacitive reactance in series therewith, said transformer providing a path for charging current to said series capacitor, and means in the output circuit for periodically providing a low impedance discharge path for said series capacitor and a low impedance shunt path in the output circuit of said transformer, said last mentioned means producing a controlled reversal of the voltage supplied to the electric discharge illumination means by effecting a discharge of the capacitor when the operating voltage reaches a predetermined level in each half cycle thereby to provide a current to the electric discharge illumination means having a more nearly square waveshape.

5. A system for starting and operating electric discharge illumination means comprising: electric discharge illumination means, a high leakage reactance ballast transformer having a magnetic core with a primary and a secondary winding inductively coupled thereon for supplying operating voltage and current to the electric discharge illumination means, said high leakage reactance transformer having an input circuit for connecting to an alternating current supply and having an output circuit, said input circuit including the primary winding and the output circuit including at least the secondary winding of said high leakage reactance ballast transformer and said electric discharge illumination means, at least one capacitor connected in series with said electric discharge illumination means in the output circuit and means in the output circuit for periodically providing a low impedance path across at least said secondary winding and switching the voltage on said at least one capacitor at a predetermined point in each half cycle of the operating voltage thereby to produce a controlled reversal of the current supplied to the electrical discharge means and supply a voltage to said electric discharge means having a more nearly square waveshape.

6. The system set forth in claim 5 wherein said means in the output circuit for switching the voltage includes a semiconductor switching device and a serially connected impedance element, said semiconductor switching device being switched on in each half cycle when the operating voltage reaches a predetermined level.

7. The system as set forth in claim 5 wherein the electric discharge illumination means is comprised of a plurality of hot cathode lamps and a filament transformer having a plurality of cathode heating windings is connected in the output circuit to supply the cathode heating current to the plurality of hot cathode lamps.

8. A system for starting and operating electric discharge illumination means having a negative resistance characteristic, said system comprising: an electric discharge illumination means, a high leakage reactance ballast transformer having an output circuit connected to the electric discharge illumination means and supplying the operating voltage thereto, said high leakage reactance transformer having at least a primary and a secondary winding and also having an input circuit including said primary winding for connection to an alternating current source, said output circuit including at least the secondary winding, a capacitor in series with the secondary winding, and a filament transformer having a plurality of cathode heating windings coupled with said electric discharge illumination means and supplying cathode heating current thereto, a saturable reactor having a reactor winding connected in a closed loop with said capacitor and said electric discharge illumination means, said reactor winding wound on a saturable core having a saturating characteristic such that the saturable core saturates in each half cycle when the operating voltage reaches a predetermined value to discharge the capacitor and produce an operating current for the electric discharge illumination means having a more nearly square waveshape.

9. In a system for operating a first and second group of electric discharge lamps, a first high leakage reactance ballast transformer having a primary and a secondary winding for supplying the operating voltage and current for the first group of electric discharge lamps, a second high leakage reactance transformer having a primary and a secondary winding for supplying the operating voltage and current to said second groups of electric discharge lamps, each of said high leakage reactance ballast transformers having an input circuit for connection to an alternating current supply and also having an output circuit for supplying the operating current to its respective group of electric discharge lamps, each output circuit including a capacitor connected in series circuit with the associated secondary winding and a filament transformer for supplying cathode heating current to the electric discharge lamps of its respective groups, and current reversing means seperate from said transformers in each of said

first and second output circuits for producing a controlled reversal of the current at a predetermined point in each half cycle of the operating voltage of its respective high leakage reactance transformer thereby to supply to said first and second groups of electric discharge lamps a current having a more nearly square waveshape.

10. In the combination set forth in claim **9** wherein each of said current reversing means in the output circuits is comprised of a saturable reactor having a winding and a core that saturates in each half cycle in response to a preselected value of voltage applied across the winding of said saturable reactor.

References Cited

UNITED STATES PATENTS

3,125,705	3/1964	Feinberg et al.	315—276
3,135,894	6/1964	Oglesbee et al.	315—284 X
3,250,952	6/1966	Barriball	315—100

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