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[72] Inventors Michael Alfred Patrick Brighton; Derek John Brittain, Goring-by-Sea, both of England

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[73] Assignee Patrick and Drew Limited Sussex, England

[54] **METHOD AND APPARATUS FOR OPERATING A GAS DISCHARGE TUBE**

19 Claims, 9 Drawing Figs.

[52] U.S. Cl. .... 315/177, 315/227 R, 315/280, 315/289

[51] Int. Cl. H05b 41/00, H05b 41/10, H05b 41/16

[50] Field of Search .... 315/100 H, 100 U, 289, 284, 280, 100, 119, 127, 177, 182, 227, 261, 362, 107, 206, 41, 57–59, 62, 107; 336/160, 165, 155

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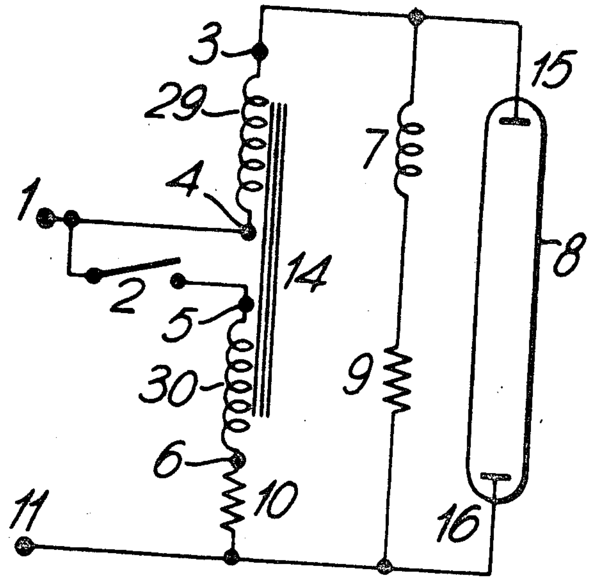
Primary Examiner—Herman Karl Saalbach

Assistant Examiner—Marvin Nussbaum

Attorney—Baldwin, Wight and Brown

ABSTRACT: Circuits for starting and operating a gas discharge tube without the need to preheat filamentary electrodes prior to starting, including an autotransformer to provide sufficient starting potential to the discharge tube, and switch means for inhibiting transformer action following arc discharge within said tube whereupon part of the autotransformer winding performs the function of a series connected inductive ballast with said tube. Said autotransformer having a predetermined leakage inductance coacting with stray capacitance in circuit therewith to provide a high-frequency component to said starting potential for lowering said requisite starting potential. Said switch means comprising either an electromagnetic relay or magnetic shunt in the autotransformer core. There is also provision for dimming the light output of said tube by limiting its discharge current.



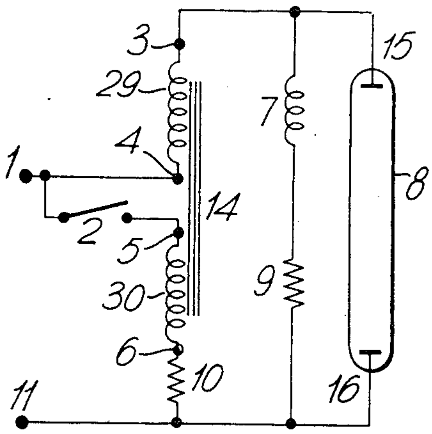


Fig. 1.

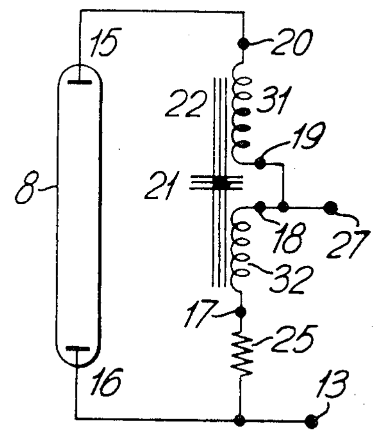


Fig. 3.

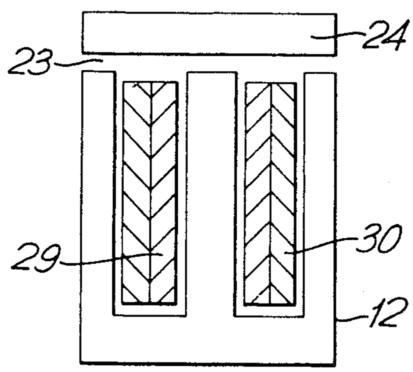


Fig. 2.

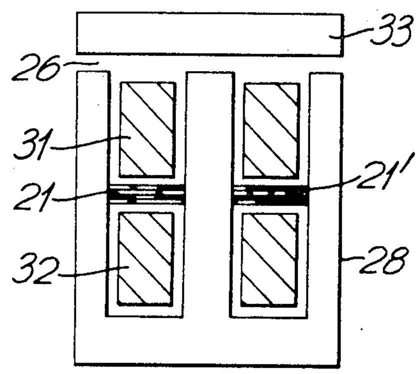


Fig. 4.

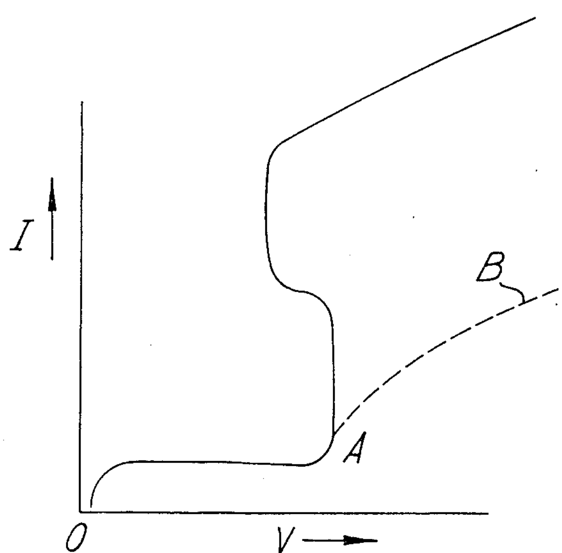


Fig. 5.

Inventors:
Michael Alfred Patrick
and
Derek John Buttain
BY Baldwin Wight Diller & Brown
Attorneys

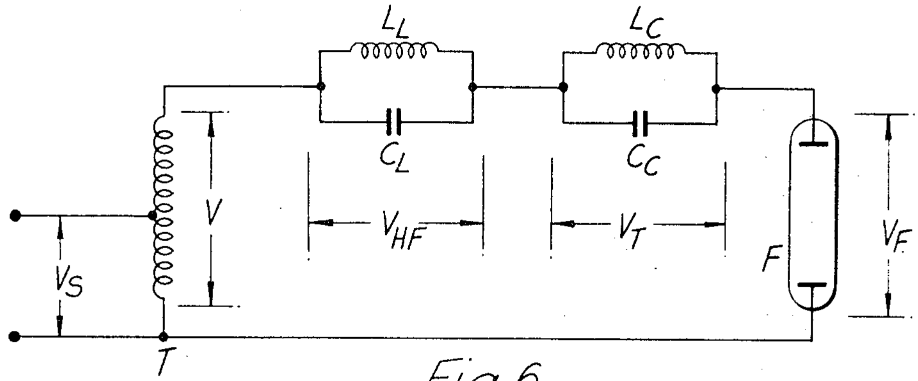


Fig. 6.

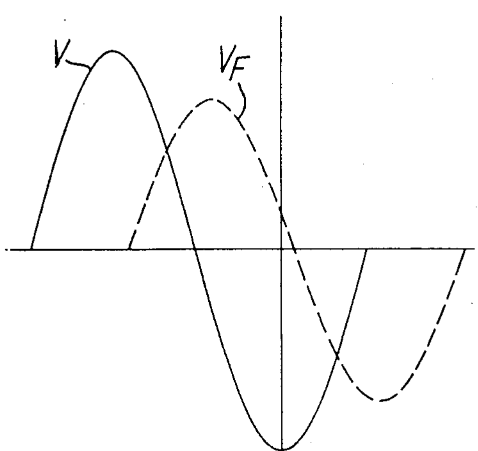


Fig. 7.

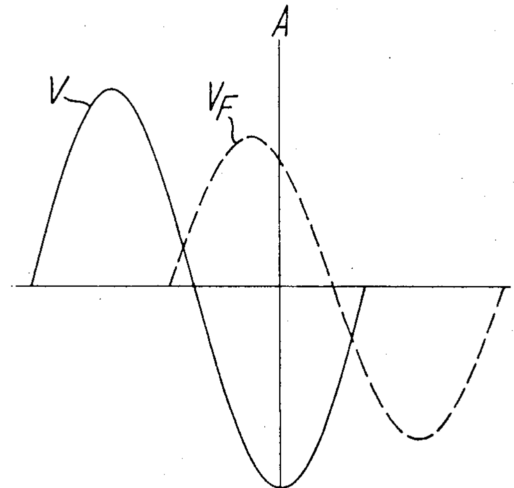


Fig. 8.

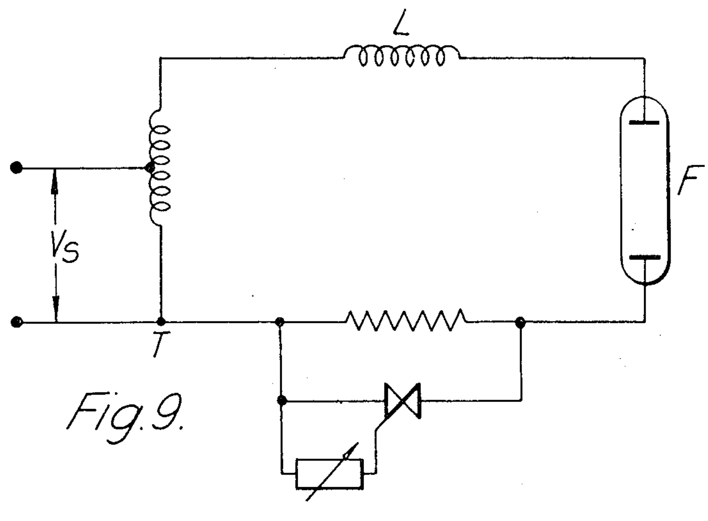


Fig. 9.

METHOD AND APPARATUS FOR OPERATING A GAS DISCHARGE TUBE

This invention relates to a method and apparatus for controlling gas discharge tubes when supplied with alternating current.

It is known to start gas discharge tubes, for example low-pressure fluorescent lamps, by first applying a preheating current to filamentary electrodes of the tube to obtain copious electron emission, whereupon a suitable starting potential is applied across the tube to initiate a discharge. After this discharge has taken place, the electrodes need not be supplied with the preheating current since thermionic emission is maintained by ion bombardment of the electrodes. Switch means, for example a thermal switch or glow discharge tube may be used to switch off the preheating current and sometimes to initiate the supply of a starting potential having a high peak value to start the discharge. A current limiting device, such as a choke, is connected in series with the tube for limiting the subsequent discharge current to an operating value. Clearly one of the disadvantages of the above arrangement is the need to maintain circuit continuity in each tube electrode, for example, if the electrodes are each connected to a filamentary coil, the coil must remain intact. There is also a delay between switching-on and obtaining a stable light from the tube. Frequently, malfunctioning of the switch means leads to flicker or complete failure in starting the tube, whereupon the starting operation must be repeated. Preheating of the tube electrodes may be dispensed with if a high starting potential is used, e.g. of the order of 10 times the operating potential, but this is not generally a practical possibility.

It is also known to use auxiliary starting aids such as earthed strips located alongside the tube envelope. A so-called 'ignition strip' may form part of the tube or use may be made of an electrically conductive earthed casing adjacent the tube envelope. Such expedients clearly require the connection of an earth lead from the alternating current supply to the tube and add to the expense of the system.

It is further known to use systems employing at least two discharge tubes wherein a lead-lag relationship is established between the two tubes to promote starting. The disadvantage of such systems is clearly the necessity for more than one tube.

Other known devices use either stray field transformers or high reactance ballast transformers sometimes with capacitors for power factor correction or to form capacitive loads to facilitate starting and improve operation. Yet other known devices may employ expedients such as thermistors connected across the tube for the starting operation. However, these devices lead to increased expense and complication.

Furthermore, it is known to employ circuits having an autotransformer, one of the windings being used as an inductive ballast for limiting the discharge current. However, special tubes are usually required and sometimes the circuit does not operate automatically.

Some of the above-known devices can be used to start gas discharge tubes without preheated electrodes but disadvantages are usually present either due to complicated circuitry, expense, or unreliable or nonautomatic operation. Unreliability can result from malfunctioning of elements in the tube circuitry and/or from operation under adverse ambient conditions such as high humidity or operation under extreme ambient temperatures.

Accordingly, it is an object of the present invention to provide means for starting a gas discharge tube without the need to provide for the direct heating of the tube electrodes while starting.

Another object of the present invention is to permit substantially instantaneous starting of a gas discharge tube and thereafter maintain stable operation with increased light output and less flicker.

A further object of the present invention is to provide a relatively simple and reliable circuit for the almost instantaneous starting of a gas discharge tube without the need for prior art expedients such as earthed conducting strips.

Still a further object of the present invention is to provide a circuit for starting a gas discharge tube, which circuit does not require any earth connection from the electrical supply to the tube.

Yet another object of the present invention is to provide a relatively simple and reliable circuit for starting and operating a gas discharge tube under adverse ambient conditions such as high humidity or over a wide temperature range, for example, −10° to +100° C.

A feature of the present invention is the use of an autotransformer having first and second series connected coils wound on the same limb of a laminated core stack forming a magnetic circuit; the first coil being the primary winding, the first and second coils being the secondary winding, and the second coil being adapted in operation to act as a current limiting inductive ballast. The autotransformer is arranged to have a measure of leakage inductance whereby a "leakage inductance ring" or the generation of a high-frequency current, for example of a frequency between 10–100 kc./s. is obtainable, for application to a gas discharge tube connected to the secondary of said autotransformer. This high-frequency current results in lower values of "striking," or the potential required to initiate an arc discharge. The leakage inductance of said transformer is tuned by stray capacity in a discharge tube circuit to which said autotransformer is connected.

Another feature of the invention is to provide automatic switch means between the first and second coils of said autotransformer whereby said coils enable autotransformer action between the primary and the secondary prior to "-striking" of said tube, the turns ratio being such as to provide a sufficient starting potential across the secondary winding and said tube when connected thereto, and to cause the second coil to act as an inductive ballast for limiting the discharge current to an operating value after the tube has "struck." The autotransformer action is inhibited after an arc discharge has taken place within the tube. The starting potential and the parameters of said discharge tube circuit are such that during the half cycles of the potential applied to tube immediately following switch-on, corresponding lagging half cycles of discharge current flow in the tube and the tube electrode temperatures are progressively raised by electron flow and ion bombardment. Eventually, the reverse voltage pulse arising from the decrease of the discharge current to zero at the end of the half cycles becomes capable of causing, in a particular half cycle of current, ion bombardment of one electrode sufficiently intense to raise its temperature substantially to its operating temperature. The temperature of the other electrode being raised to its operating temperature during subsequent half cycles of polarity opposite to that of said particular half cycle. Subsequent arc discharge takes place within said tube (or the tube strikes) due to the presence of a sufficient starting potential and high-currency current in the secondary winding of said autotransformer. After striking, the discharge current through the tube is automatically limited by said inductive ballast action of the second coil of said autotransformer.

Said switch means may comprise an electromagnetic relay having a coil responsive to the tube discharge current after striking, and contacts connected between the first and second coils of said autotransformer to disconnect automatically the first coil from the second coil to inhibit said autotransformer action following full discharge within the tube.

Alternatively said switch means may comprise a magnetic shunt or shunts, placed between the first and second coils of said autotransformer, such that the effective magnetic coupling between said coils is automatically reduced to inhibit said autotransformer action following full discharge within the tube.

A further feature of the present invention is the provision of a nonmagnetic gap or gaps within said magnetic circuit, the size of which may be selected so that, in use, the desired operating discharge current is achieved. The gaps may be adjustable airgaps.

An advantage of the invention is that it allows the starting of a gas discharge tube having filaments intended for direct heating before starting, but no longer capable of such electrical direct heating because one or both filaments has become discontinuous. In such a case the two external connections of each filament electrode are shorted together to provide a tube connection.

Other objects, features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a circuit diagram of an apparatus for starting and operating a gas discharge tube according to the present invention, which apparatus employs an electromagnetic relay;

FIG. 2 is a diagrammatic cross section through an autotransformer constructed according to the present invention and forming part of the apparatus illustrated by FIG. 1;

FIG. 3 is a circuit diagram of another apparatus for starting and operating a gas discharge tube according to the present invention, which apparatus employs an magnetic shunt;

FIG. 4 is a diagrammatic cross section through an autotransformer used, constructed in accordance with the present invention and forming part of the apparatus illustrated by FIG. 3;

FIG. 5 is a graph illustrating the relationship between the potential across a gas discharge 17 tube and the current through it, when the electrodes are not providing thermionic emission;

FIG. 6 is an equivalent circuit diagram for explaining high-frequency effects;

FIGS. 7 and 8 are graphs illustrating the relationship between autotransformer secondary winding voltage and gas discharge tube voltage respectively without and with additional high-frequency transient voltage; and

FIG. 9 is a circuit diagram showing a dimming arrangement incorporated in a schematic circuit representation of FIGS. 1 and 3.

In FIG. 1 a first coil 30 has a first terminal 6 connected to terminal 11, for connection to one terminal of a source of single-phase alternating current; for example, alternating current mains. A second terminal 5 of the coil 30 is connectable to a first terminal 4 of a second coil 29, through switch contacts 2. The first terminal 4 of the coil 29 is connected to a terminal 1, for connection to the other terminal of the single-phase alternating current source. A second terminal 3 of the second coil 29 is connected to one side of a relay coil 7 and to one electrode 15 of a fluorescent lamp 8. A second electrode 16 of the lamp 8 is connected to the other side of the relay coil 7 and to the terminal 11.

The coils 30 and 29 are closely coupled on a magnetic core 14, the arrangement being shown in FIG. 2 and further described hereinafter. A resistor 10 is shown connected in series with the terminal 6 of the first coil; this resistor may, in practice, be comprised in the coil 30, as the resistance of the winding.

The switch 2 comprises the contacts of a relay, actuable by the relay coil 7, the switch being open when the relay is not actuated. A resistor 9 is shown connected in series with the relay coil 7 but this may be the resistance of the winding.

When an alternating electrical supply, of suitable voltage and frequency (for example 240 volts and 50 c./s.) is applied to the terminals 1 and 11, for example by means of mains switch, current first flows through the coil 29, relay coil 7 and resistor 9; the voltage applied across the electrodes 15 and 16 of the lamp is then near to, but less than, the supply voltage. The circuit constants are so selected that the relay is then actuated, and the switch 2 closes. The switch connects the coils 30 and 29 together, so that they act as an autotransformer and apply a sufficient voltage (for example 400 volts) to the electrodes 15 and 16, to start a discharge.

The coils 30 and 29, the resistor 10 and the magnetic core 14 are so cooperatively proportioned that, as the discharge current rises, the voltage applied between the electrodes 15 and 16 falls to a value, less than the supply voltage but greater than the lamp operating voltage, at which the relay characteristics are such that the switch 2 opens. The coil 30 is thus disconnected and the autotransformer action ceases, the discharge current flowing through the coil 29 which then has such an inductance as to limit the current to within the rated operating current range of the lamp. This inductance L, is given approximately by the equation

$$L=(V_S^2-V_L^2/2\pi f I_L) \qquad (1)$$

where

L = inductance in henries,
f = supply frequency,
V_s = supply voltage (r.m.s.),
V_L = lamp operating voltage (r.m.s.),
I_L = lamp operating voltage (r.m.s.).

In FIG. 2 there is shown, diagrammatically, a suitable arrangement of the coils 30 and 29 and the magnetic circuit. The core (14 in FIG. 1) comprises magnetic laminations indicated by 12 and 24, and three nonmagnetic gaps as indicated at 23. The gaps may be airgaps so selected that, at the operating current of a particular lamp, or type of lamp, the coil 29 has the desired inductance. Thus, for example, for a particular pair of coils and set of laminations, 0.015 inch airgaps were satisfactory for standard 40 watt fluorescent lamps, while 0.020 to 0.025 inch airgaps were satisfactory for larger lamps.

FIG. 3 illustrates a second embodiment of this invention. In this figure a first coil 32 has a first terminal 17 connected to a terminal 13, for connection to one terminal of a source of single-phase alternating current. A second terminal 18 of the coil 32 is connected to a first terminal 19 of a second coil 31, which terminal 19 is also connected to a terminal 27, for connection to the other terminal of the single-phase alternating current source. A second terminal 20 of the second coil 31 is connected to one electrode 15 of a fluorescent lamp 8. A second electrode 16 is connected to the terminal 13.

The coils 32 and 31 are coupled together by a magnetic circuit, indicated conventionally at 22, the magnetic circuit being provided with a shunt, between the coils, indicated at 21. A resistor 25 is shown connected in series with the terminal 17 and the first coil; this resistor may, in practice, be comprised in the coil 32, as the resistance of the winding.

When an alternating electric supply, of suitable voltage and frequency, is applied to the terminals 13 and 27, for example by means of a mains switch, current flows through the coil 32 and induces a voltage across the coil 31. The coils and associated magnetic circuit are so proportioned that, so long as no discharge current flows in the lamp 8, the arrangement acts as an efficient autotransformer and the voltage applied across the electrodes 15 and 16 is sufficiently high to start a discharge in the lamp. As soon as a discharge starts, however, current flows in the coil 31; because of the presence of the shunt 21, between the coils, and the resistor 25, the efficiency of the autotransformer decreases and the voltage induced in the coil 31 decreases. The coils, magnetic circuit and resistor 25 are so cooperatively proportioned that, when the current flowing in the coil 31 is within the rated operating current range of the lamp, the voltage applied across the electrodes 15 and 16 is a corresponding operating voltage.

FIG. 4 shows diagrammatically a suitable arrangement of the coils 32 and 31 and the magnetic circuit. The magnetic circuit comprises conventional magnetic laminations, indicated by 28 and 33, and additional laminations 21 and 21′ inserted between the coils 31 and 32 to provide a shunt. The magnetic circuit further comprises nonmagnetic gaps, as indicated at 26; these gaps may be airgaps selected in a manner similar to that described in connection with the arrangement shown in FIG. 2.

In the embodiment just described, the magnetic shunt, in cooperation with the other parameters of the coil and magnetic circuit arrangement, provides means responsive to the lamp discharge current, whereby the second coil acts as a choke to limit the discharge current to the desired operating value. The effective inductance of the second coil, when the lamp is operating, is given approximately by equation (1).

In embodiments comprising a magnetic shunt and having a circuit substantially as illustrated in FIG. 3, the parameters of the coil and circuit arrangement may be so proportioned as to operate a lamp whose operating voltage is greater than the supply voltage. In such a case, the coil arrangement will continue to exhibit an appreciable autotransformer action even when the operating current is flowing through the second coil.

The method, according to this invention of starting an electrical discharge between unheated electrodes in a gas discharge tube enables control of the discharge so that the electrodes are rapidly heated to a predetermined operating temperature at which the discharge is maintained, by thermionic emission, at a predetermined intensity. The discharge must be so controlled that the operating conditions of the tube pass rapidly and reliably from those associated with a cold cathode, to those pertaining to a hot cathode; the discharge must thereafter be maintained at the conditions under which the tube is particularly adapted to operate.

Referring to FIG. 5, when an alternating voltage, whose value V is initially zero, is applied to the cold electrodes of such a tube, the discharge current I will initially be represented by the curve OA. Initially, there appears to be no electron supply. However irradiation of the cathode will release some electrons photoelectrically, and a current will flow to the anode. However the supply of electrons is limited and the current finally does not increase with the voltage but becomes constant. The nearly constant small current will flow as a Townsend discharge, the current being carried by electrons only. As the applied voltage approaches the value corresponding to the knee of the curve at A, it accelerates electrons to such energies that they produce, by collision with the gas molecules, pairs of positive ions and electrons of such respective velocities that a significant number of the pairs cannot recombine, the electrons contributing to an increase in the discharge current. There is thus a rapid increase in the current for a small increase in the voltage. However, it is possible to reach the ionized state by external ionization, without electron emission from the cathode. (Cosmic ray ionization may often be a factor.) In the low-voltage region of the tube operation, the anode current is approximately proportional to be anode voltage. As the voltage is increased, there is a rapid change from the Townsend discharge of above, to a spark or arc discharge, provided that there is an adequate supply of electrons and the discharge current increase will then follow the full line characteristic beyond A is the peak value of the voltage half cycle is sufficient to initiate an arc discharge. The characteristics of the arc discharge are constant or falling voltage and an increasing current. In illumination tubes, the light output becomes intense.

A copious supply of electrons, drawn from the space charge around the cathode, are accelerated by the anode potential, and during the cathode/anode traverse cause intense ionization by electron/gas atom collision. However, should the supply of electrons be insufficient, then the arc discharge is not reached, the tube current remains low, the tube voltage high, and the light output minimal. In this case the discharge current I follows the broken line characteristic B in FIG. 5. The behavior of the discharge, as the applied voltage increases, will then be complicated and, in particular, will be dependent on the parameters of the control circuit external to the tube. The above (extremely) simplified explanation of ionization is given to assist the following explanation of the present invention. Usually, it is arranged that a good supply of electrons exist, before switch-on, by preheating the tube electrodes, for example, by coils through which a current can be passed, and on which (or in contact with) is placed the electron emitter. Thus, application of a (high) voltage will fire the tube which then goes from the Townsend discharge to the arc discharge very quickly.

However, in the present invention a tube electrode can be suitably and adequately heated (and supply enough electrons) by using the positive-ion bombardment of the electrode which occurs while the arc discharge exists. In this event, continuous circuit heating coils (for the electrodes) are not necessary, and open circuit heaters are perfectly satisfactory. The arc-discharge must first be obtained as a discharge between each tube electrode and not for example, from a cathode to an adjacent "earthy-strip," i.e. ignition strip.

A supply of ions is generated, (by an external source) in the tube, such that the arc discharge is just reached, i.e. at a relatively low current, the applied high anode voltage then causing the ions to fall on the cathode with sufficient energy to release enough electrons to cause a cumulative transition to the full arc-discharge at the maximum current (limited by some external agency). The application of high-frequency voltages results in lower values of "striking" i.e. arc-discharge voltage, and the application of a high-frequency voltage at the same time as the high voltage a low frequency, reduces the time of transition from the Townsend discharge to the full arc-discharge. Such action may be considered as follows but it must be remembered that all ionization actions are extremely complex and it is very difficult to be certain of all facts.

A voltage is applied to a tube with cold cathodes, the Townsend discharge is initiated, either with the aid of photoelectrical electron emission or by cosmic ray irradiation (ionization) of the gas. However, the electron, and therefore, the ion supply is limited. Now the high-frequency signal is added and the applied low-frequency voltage which hitherto was a reasonable value, in terms of striking an arc-discharge, is now a considerable overvoltage due to the striking voltage reduction effect of the HF signal. The result of this overvoltage, is to increase the positive ion bombardment of the cathode, with consequent increase of cathode temperature, increase of electron emission, and therefore a cumulative transition from the Townsend discharge to the full arc-discharge. Actually, several cycles of both the high- and the low-frequency voltages are required and the cathode heating is progressive.

To generate and apply an independent RF signal is expensive, therefore in the present invention, the high-frequency signal is generated by "ringing" the circuits used to supply and control the tube. Both the frequency and voltage of this high-frequency signal must be correlated between applied low-frequency (mains supply) voltage, initial Townsend discharge current, final (i.e. recommended) arc-discharge current, and the need to obtain substantially instantaneous starting.

The autotransformer of FIGS. 1 or 3 used to feed the system has a measure of leakage inductance by suitable arrangement of the windings to obtain a "leakage inductance ring" of a few cycles, of a frequency between 10 kc./s. and 100 kc./s.

To this extent, the frequency is under the control of the transformer designer, and the design criteria is to obtain an arrangement whereby not all the primary flux links with the secondary winding. Such leakage inductance is present to some extent in all transformers but the purpose of this design is:

a. To increase the leakage.

b. To control its value.

c. To control the capacity "tuning" the leakage inductance.

It is important to realize that while the series ballast choke is operating under the usual conditions, this additional, high-frequency, voltage is added to the transients generated by the choke. Thus the tube voltage is the result of:

d. the applied AC supply mains voltage

e. The choke transient

f. The leakage inductance "high-frequency" ring.

The circuits employing the above arrangements are those of FIGS. 1 and 3, but an equivalent circuit is shown in FIG. 6. In FIG. 6, the leakage inductance, tuned by a stray capacity C_L, generates a high frequency (Ω 25 kc./s.) which is applied to the tube. The choke L_C, is of fairly normal type except that the impedance of the parallel combination of L_C and C_C must be made low at the generated high frequency. Thus L_C needs special design and controlled manufacture, so that C_C is high, and of low impedance to VHF. Consider a current is flowing round the loop L_L, L_C, F and back to the transformer T, and that the tube is operating under low-current discharge conditions. The mains voltage reaches a peak and decreases. At some point in time the voltage V is insufficient to maintain the discharge, which abruptly extinguishes. Under these low-current conditions, the tube acts somewhat, like a resistor, thus the voltage conditions (for an inductive/resistance circuit) are as FIG. 7.

Now consider, that the tube extinguishes at point A in FIG. 8, when the supply voltage V_S has already reversed. A reverse transient will be generated by L_C in the usual way, and at the same time L_L and C_L will oscillate and generate a few cycles of HF voltage.

The combined effect of the reversed increasing supply voltage V, the L_C transient (albeit not of great amplitude) and the high-frequency voltage V_{HF}, is to refire the tube F quickly, to increase the electron speed, to enhance electron/atom collision possibility, and to increase positive-ion bombardment of the cathode. The result is a cumulative and rapid transition from the weak glow discharge to the light emitting arc-discharge, during which current limiting is effected by L_C as usual.

In practice the analysis of the equivalent circuit is extremely complex. Usually mathematicians treat L_C as having no self capacity and give the transient voltage as

$$V_T = -L((di)/(dt))$$

However, the presence of C_C modifies this. The action of L_L and C_L is clear. This acts as a high-Q tuned circuit, where C_L is usually small. Thus the frequency of oscillation is

$$f_{HF} = (1/(2^{\pi}\sqrt{L_2C_2}))$$

and the peak value of the high-frequency voltage is equal to twice the tube extinguishing voltage.

Considering a leakage inductance of 10 mh. and a stray capacity of 100 pf., the high frequency is 160 kc./s. If the tube extinguishes at 100 v., the peak HF voltage is 200 v. At 160 kc./s. the peak is reached (in quarter cycle) in 7 μsec. If C_C is of the order of 250 pf. most of the high-frequency voltage is applied to the tube within 7 μsec. of switch off. There would have been no chance for recombination of electrons and ions, or loss by diffusion to the walls, thus the tube immediately restrikes as detailed above.

It is possible to arrange for leakage inductance to appear in the choke but this is more difficult to control and the transformer method is preferred.

Several methods of increasing the leakage flux of a transformer exist. Most of these, though, require that the leakage inductance be contained within part of the iron core. In the present invention, it has been found that sufficient leakage inductance can be obtained by winding the secondary, or part of the secondary, spaced from the primary, although on the same bobbin. Another method is to wind part of the secondary over the whole of the transformer. Yet another method is to wind the primary on one limb and the secondary on the other.

Thus, it can be seen that most of the aforementioned objects are achieved by the use of an autotransformer having a small leakage inductance which is allowed to "ring" at a high frequency. This system should not be confused with that which uses an autotransformer which has a large value of leakage inductance, and this inductance is used as the ballast choke.

By careful choice of the parameters, i.e. applied (i.e. secondary) voltage, leakage inductance, stray capacities, ballast choke inductance and its stray capacity, a start within 0.2 second is possible. By "start" is meant the obtaining of the full arc-discharge, running current.

Further,

i. No ignition strip is needed.

ii. The supply may be free from earth.

iii. The heaters need not be intact, as long as a part of them exist.

iv. Temperature range is at least −10° to +100° C.

v. System operates with tube under water.

vi. Any combination of above does not affect the operation except that at −10° C., the time of striking is slightly increased and may reach 0.4 seconds, with a poor tube.

vii. No auxiliary starting arrangements are necessary beyond those of the circuits shown in FIGS. 1 or 3.

viii. Because of the high voltage applied to the tube (approx. 400 volts RMS to a 40 or 80 watt tube) and the fact that, due to the higher frequency ring, restriking is very rapid, the light output is very nearly continuous and shows an increase over the standard system.

The apparently greater light output is at least partly due to more uniformly distributed emission along the length of the tube. It is also possible that the tube remains lit for a greater proportion of the cycle; the high value of the applied voltage implies that the unused portion of each half cycle, during which the potential between the tube electrodes is insufficient to sustain the discharge, is less than in conventional operation at, for example, 240 volts. Light would thus be emitted for a greater portion of each half cycle and the average light emitted, over a number of cycles, would be correspondingly greater. The reduction in flicker may arise from the same effect.

These effects are further enhanced by the decreased decay of the ionization, during the shorter unsustained intervals.

It is also possible that the efficiency of production of ultraviolet radiation, capable of exciting the fluorescent material of the tube, is increased by the improved method of operation. Furthermore, the number of unexcited gas atoms, capable of absorbing such radiation, may be reduced; at least when considered in terms of the mean over an interval greater than several complete cycles.

Capability of dimming a discharge tube is desirable, but infrequently used. One difficulty with standard systems is that as the emission of electrons from the heaters decreases when the tube is dimmed, (since the positive-ions bombardment lessens) the tube finally refuses to strike. Thus, reducing the current in a standard system, results in the tube abruptly extinguishing at about 75 percent light output.

In the present invention dimming, by reduction of the current, cannot result in the tube being extinguished, and thus dimming may be obtained from full brilliance down to approximately 10 percent light output by control of the tube current. It is important to note that tube current is being controlled since it is an essential part of the present invention that the high-frequency, oscillatory voltage must remain unaffected.

To control the tube current, the ballast inductance or a resistance in series with the tube may be increased. The first is uneconomic, but the second can be applied easily to the present invention.

Consider the circuit of FIG. 9. A resistor in series with the tube, has a value such that the light output is reduced to some 10 percent. When fully shorted, the tube current is maximum and limited, as usual, by the ballast choke.

If now the resistor is shunted with either two back coupled silicon controlled rectifiers, or a single TRIAC, the effective value of the resistor may be varied by controlling the firing angle of the SCR's or the TRIAC.

Although the foregoing describes specific examples of the present invention, such description is not intended to limit the scope of the appended claims in any way. Variations and modifications may be apparent to those skilled in art without departing from the scope and spirit of the invention.

Variations and/or modifications of the foregoing specific examples may be apparent to those skilled in the art, without departing from the scope and spirit of the invention as defined by the following claims.

We claim:

1. In a circuit for starting and subsequently operating a gas discharge tube from an AC source, the combination of an autotransformer comprising a first and second series connected coil, said first coil being the primary winding, said first and second series connected coils being the secondary winding, and said second coil being adapted for operation as an inductive ballast for said tube during operation thereof from said AC source after starting, switch means interposed between said first and second coils for enabling transformer action therebetween upon the application thereto of current from said AC source to produce a sufficient potential across said secondary winding for starting said tube, said switch means in-

hibiting said transformer action following arc discharge within said tube, whereupon said second coil acts as said inductive ballast in series with said tube during operation thereof from said AC source after starting, said autotransformer possessing a predetermined value of leakage inductance for coacting with stray capacitance in said circuit to generate transient high-frequency currents in said secondary winding to lower said requisite starting potential.

2. The combination according to claim **1** wherein said first and second coils are wound on one limb of a laminated core stack forming a magnetic circuit.

3. The combination according to claim **1** wherein said switch means comprises an electromagnetic relay having a relay coil connected across said secondary winding capable of drawing sufficient current therefrom for operating relay contacts connected between said first and second coils, said contacts remaining closed during the starting operation for enabling said transformer action, and being opened by said relay coil following arc discharge within said tube.

4. The combination according to claim **2** wherein said switch means comprises a magnetic shunt in said magnetic circuit including additional laminations interposed between said first and second coils to impede substantially the current flow therebetween for inhibiting said transformer action following arc discharge within said tube, the arrangement being such that said first and second coils coact in said transformer action during the starting operation, said second coil acting as said inductive ballast following said arc discharge.

5. The combination according to claim **2** wherein nonmagnetic gaps are provided in said magnetic circuit having a width related to a requisite inductance for said inductive ballast to suit the operating characteristics of said tube.

6. The combination according to claim **5** wherein said nonmagnetic gaps are adjustable airgaps.

7. Apparatus for starting and subsequently operating a gas discharge tube from an AC source comprising an autotransformer consisting of a first and a second series connected coil, said first coil being the primary winding, said first and second series connected coils being the secondary winding and said second coil being adapted for operation as an inductive ballast for said tube during operation thereof from said AC source after starting, switch means interposed between said first and second coils for enabling transformer action therebetween upon the application thereto of current from said AC source to produce a sufficient potential across said secondary winding for starting said tube, said switch means inhibiting said transformer action following arc discharge within said tube whereupon said second coil acts as said inductive ballast in series with said tube during operation thereof from said AC source after starting, a relay coil connected across said secondary winding for automatically opening and closing said switch means respectively before and after said arc discharge within said tube, connecting means adapted for connecting one end of said primary winding and said switch means to said AC source, and further connecting means adapted for connecting said gas discharge tube across said secondary winding, said autotransformer possessing a predetermined value of leakage inductance for coacting with stray capacitance in said apparatus to generate transient high-frequency currents in said secondary winding to lower said requisite starting potential.

8. The apparatus according to claim **7** wherein said first and second coils are wound on one limb of a laminated core stack forming a magnetic circuit, said stack comprising a plurality of E-shaped laminations, and a corresponding plurality of laminations arranged across and closing the open side of the E-shaped laminations, said first and second coils being wound on the central limbs of the E-shaped laminations.

9. The apparatus according to claim **8** wherein nonmagnetic gaps are provided between the ends of the parallel limbs of the E-shaped laminations and said closure laminations, said gaps being of a width to suit the operating characteristics of said tube when connected across said secondary winding such that said second coil has the required inductance for said inductive ballast.

10. The apparatus according to claim **9** wherein said gaps are adjustable airgaps.

11. Apparatus for starting and subsequently operating a gas discharge tube from an AC source comprising an autotransformer consisting of a first and a second series connected coil, said first coil being the primary winding, said first and second series connected coils being the secondary winding, and said second coil being adapted for operation as an inductive ballast for said tube during operation thereof from said AC source after starting, a laminated core stack forming a magnetic circuit, said first and second coils being wound one above the other on one limb of said stack, a magnetic shunt for said magnetic circuit interposed between said first and second coils enabling transformer action to take place between said first and second coils upon application to said first coil of current from said AC source to produce a sufficient potential across said secondary winding for starting said tube, said shunt inhibiting said transformer action following arc discharge within said tube whereupon said second coil acts as said inductive ballast in series with said tube during operation thereof from said AC source after starting, connecting means adapted for connecting said primary winding to an alternating current supply, and further connecting means adapted for connecting said gas discharge tube across said secondary winding, said autotransformer possessing a predetermined value of leakage inductance for coacting with stray capacitance in said apparatus to generate transient radiofrequency currents in said secondary winding to lower said requisite starting potential.

12. The apparatus according to claim **11** wherein said laminated core stack comprises a plurality of E-shaped laminations and a corresponding plurality of laminations arranged across and closing the open side of the E-shaped laminations, said first and second coils being wound on the central limbs of the E-shaped laminations, and said magnetic shunt comprises a plurality of laminations, for shunting said magnetic circuit between said first and second coils.

13. The apparatus according to claim **12** wherein nonmagnetic gaps are provided between the ends of the parallel limbs of the E-shaped laminations and said closure laminations, said gaps being of a width to suit the operating characteristics of the tube when connected across the secondary winding such that said second coil has the required inductance for said inductive ballast.

14. The apparatus according to claim **13** wherein said gaps are adjustable airgaps.

15. An apparatus for starting and subsequently operating a gas discharge tube from an AC source comprising an autotransformer consisting of a first and a second series connected coil, said first coil being the primary winding, said first and second series connected coils being the secondary winding and said second coil being adapted for operation as an inductive ballast for said tube during operation thereof from said AC source after starting, switch means interposed between said first and second coils for enabling transformer action therebetween upon the application thereto of current from said AC source to produce a sufficient potential across said secondary winding for starting said tube, said switch means inhibiting said transformer action following arc discharge within said tube whereupon said second coil acts as said inductive ballast in series with said tube during operation thereof from said AC source after starting, and variable current limiting means in series with said tube for dimming the light output thereof, said autotransformer possessing a predetermined value of leakage inductance for coacting with stray capacitance in said circuit to generate transient high-frequency currents in said secondary winding to lower said requisite starting potential, said high-frequency currents being substantially unaffected by operation of said variable limiting means.

16. The apparatus according to claim **15** wherein said variable current limiting means comprises a resistance in series with said tube and gate controlled rectifying means possessing both forward and reverse rectifying characteristics, said rectifying means being provided for shunting said resistor whereby said light output may be varied.

17. The apparatus according to claim **16** wherein said switch means comprises an electromagnetic relay having a relay coil connected across said secondary winding capable of drawing sufficient current therefrom for operating relay contacts connected between said first and second coils, said contacts remaining closed during the starting operation for enabling said transformer action, and being opened by said relay coil following arc discharge within said tube.

18. The apparatus according to claim **16** wherein said first and second coils are wound on one limb of a core stack forming a magnetic circuit, said switch means comprising a magnetic shunt interposed between said first and second coils to impede substantially the current flow therebetween for inhibiting said transformer action following arc discharge within said tube, the arrangement being such that the first and second coils coact in said transformer action during the starting operation, and said second coil acting as said inductive ballast following said arc discharge.

19. The apparatus according to claim **15** wherein said first and second coils are wound on one limb of a laminated core stack forming a magnetic circuit, said magnetic circuit being provided with adjustable airgaps for varying the inductance of said inductive ballast to suit the operating characteristics of said tube.

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