April 17, 1951 J. H. BRIDGES 2,549,288

LIGHTING SYSTEM AND APPARATUS

Filed July 12, 1946 3 Sheets-Sheet 1

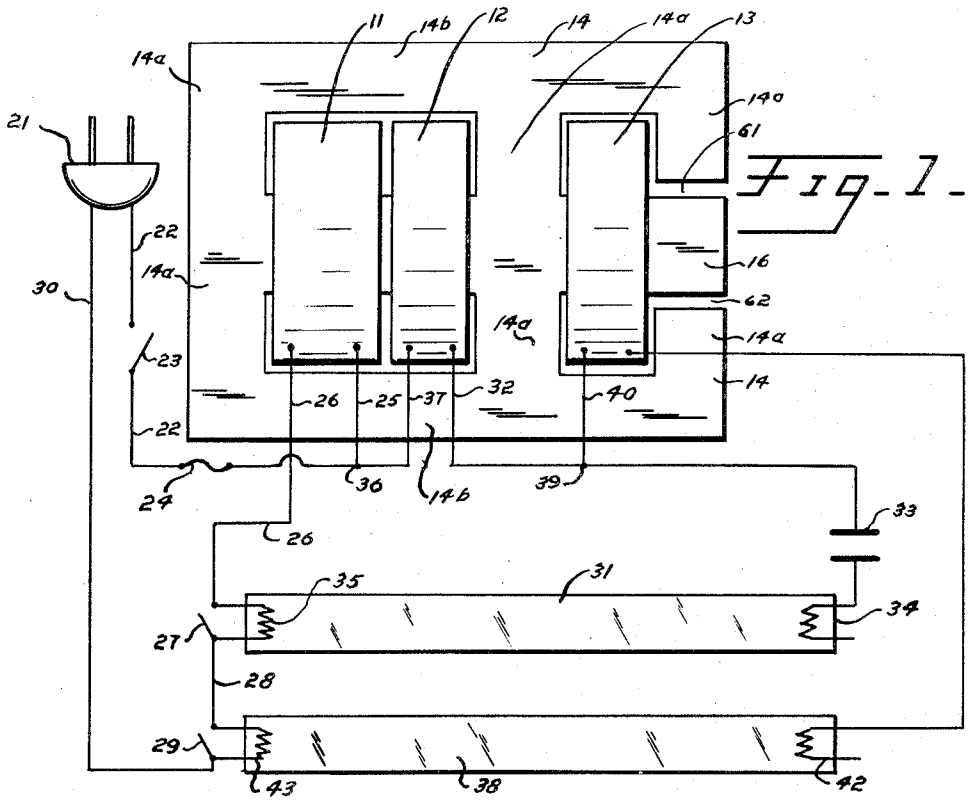


Fig. 1.

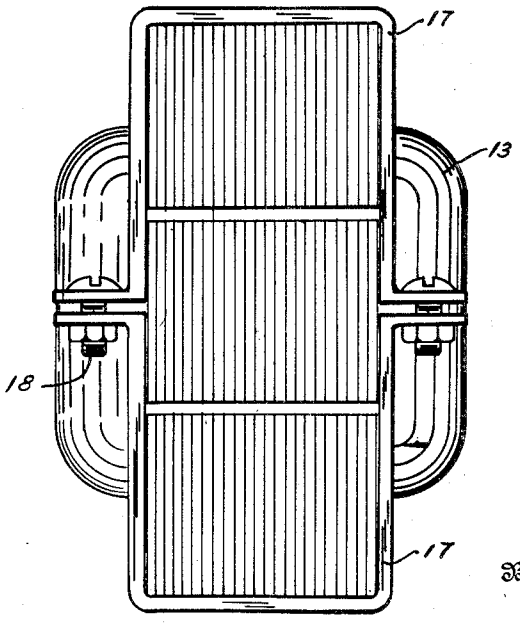


Fig. 3.

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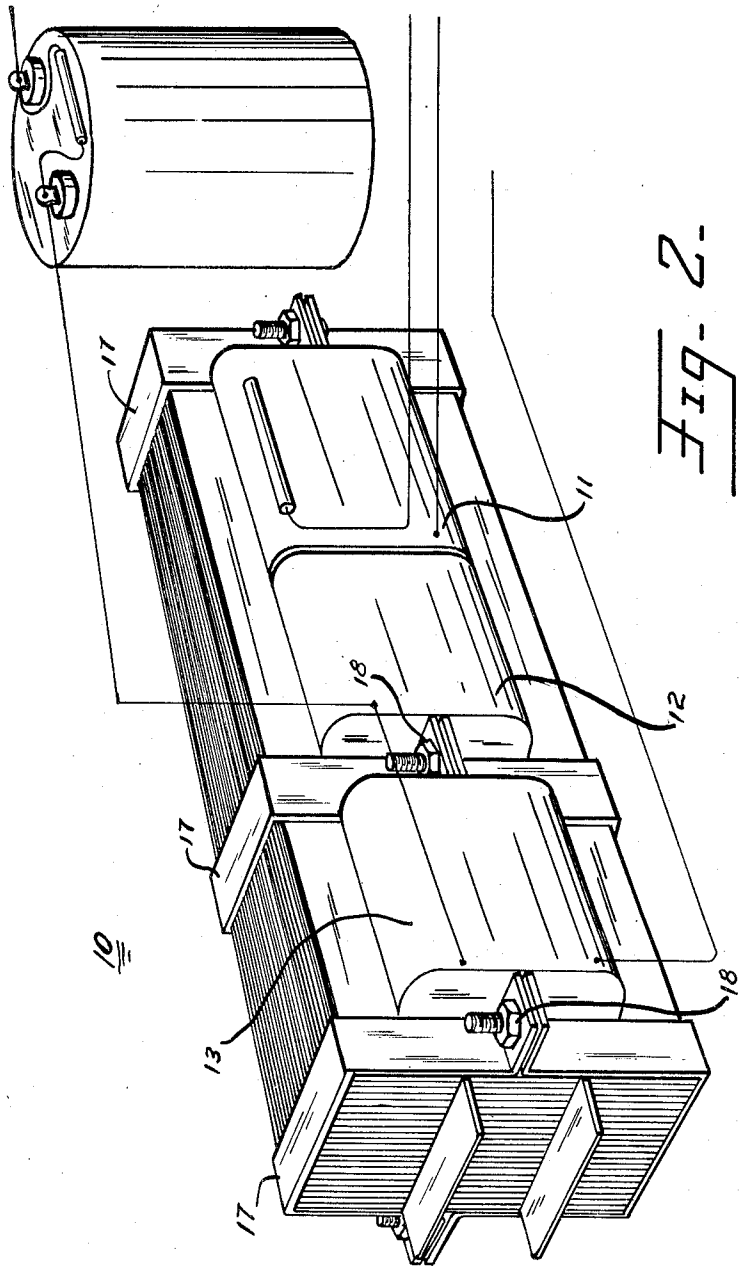


Fig. 2.

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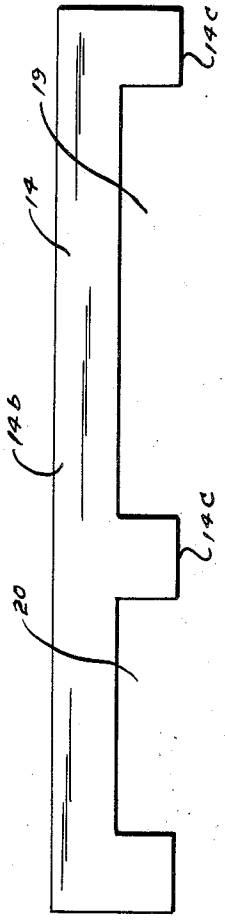
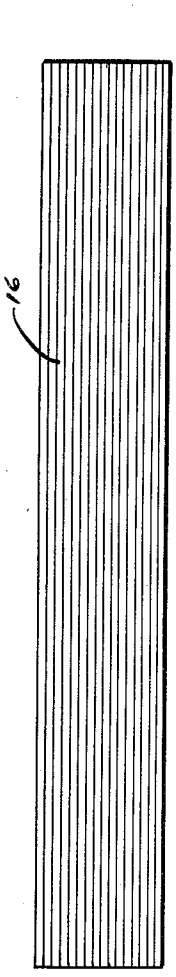


Fig. 4.



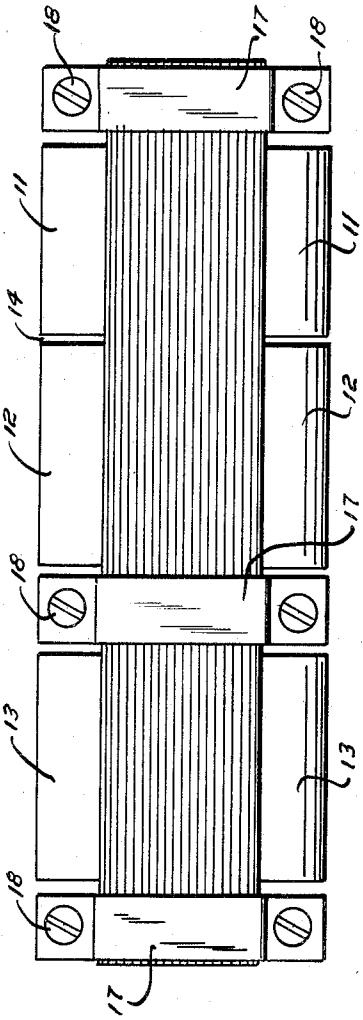


Fig. 6.

Fig. 5.

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2,549,288

UNITED STATES PATENT OFFICE

2,549,288

LIGHTING SYSTEM AND APPARATUS

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Application July 12, 1946, Serial No. 683,067

3 Claims. (Cl. 315—254)

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My invention relates to electrical gas discharge tube systems and to means for powering the same. More particularly, it concerns a fluorescent tube lighting system and a power unit therefor.

An object of my invention is the provision of a simple, reliable and efficient fluorescent tube lighting system, which is quick starting, has good system power factor and operates with multiple tube illumination in the substantial absence of detrimental stroboscopic effect, in which at all times the current is limited within safe bounds, and in which tube energization is effectively maintained even upon substantial decrease in primary voltage.

Another object is to provide a power unit for powering multiple fluorescent gas discharge tubes and similar loads embodying many of the aforementioned advantages and which is small, compact, highly efficient, of low first cost, and which operates the tubes with good wave form at high power factor and with minimum stroboscopic effect, which minimizes iron and copper requirement, and in which, by proper correlation of the reactance load with the capacitative load, long condenser life is insured.

A further object is the provision of a transformer for powering fluorescent tube lighting systems and the like, which is characterized by its compactness, sturdiness, and ruggedness, by its low iron and copper content, and by its high efficiency, and which insures that tubes in the system powered thereby will start promptly, and remain energized even when the line voltage on the primary side falls off considerably from rated value.

Other objects and advantages will in part be obvious and in part pointed out hereinafter, during the course of the following description, taken in the light of the accompanying drawings.

My invention accordingly resides in the several arrangements of parts, combinations of elements and features of construction, as well as in relation of each of the same to one or more of the others, the scope of the application of all of which is more fully set forth in the claims at the end of this specification.

In the accompanying drawings, wherein I disclose at present one preferred embodiment of my invention:

Figure 1 represents an electrical system having negative resistance characteristics, here particularly applied to the energization of fluorescent gas discharge tubes;

Figure 2 is a view, partly schematic, partly in

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perspective, disclosing a power unit according to my invention;

Figure 3 is an end view of an assembled transformer in accordance with my invention;

Figure 4 discloses one of the outer elements of the transformer core;

Figure 5 represents the central leg of the transformer core; while

Figure 6 is a view, partly in front elevation and partly schematic, disclosing more particularly the association of the several coils with the transformer core.

Throughout the drawings like reference characters indicate like parts of the transformer and system.

As conducive to a clearer understanding of certain features of my invention, it may be noted at this point that in the past several decades fluorescent illumination has assumed greater and greater prominence in many fields of illumination. In many instances it has to a large measure replaced the more conventional incandescent type of illumination. Thus, the acceptance of fluorescent lighting has been widespread in industrial, commercial and domestic uses. Offices and homes afford increasingly abundant fields of utilization for this new type of illumination.

Many reasons combine to account for this phenomenal growth. From an industrial standpoint fluorescent lighting is desirable because of its high energy efficiency, its low heat output and its high intensity of illumination in the substantial absence of brilliance whereby it gives rise to sharp definition attended by almost complete absence of detrimental shadow effect. The light is more flexible both as to color and orientation. In commercial use such for example as in stores and the like, fluorescent tube lighting either with single units or in batteries of two, three or four tubes or more, or even in combinations of batteries, enables the achievement of highly pleasing and delicate color effects. Soft diffused illumination of desired intensity and color effect can be achieved for both the office and the home. Batteries of lamps and combinations of such batteries produce intense flood lighting effects at but moderate costs. The tubes themselves have an operating life of some two and a half times or more that of the best incandescible lamps known; as well, their operating efficiencies are approximately two and one-half times that of the known incandescent lamps. Usually operating in parallel circuits, failure of one tube does not jeopardize the proper operation of the remaining units of the system. Thus,

in general, it is clear that as contrasted with incandescent tube lighting, fluorescent tube illumination inherently possesses fundamental and sweeping advantages.

It remains, however, that fluorescent tube lighting still exists in what may be accurately termed a pioneer state of development. Much remains to be done before full exploitation of such lighting can be practical. In this connection, substantial room exists for appreciable increase of actual operating efficiencies, approaching theoretical optimum values. This is true both from a service, an electrical and an illumination standpoint. Thus, while fluorescent tube life is vastly superior to that of incandescent lamps, further substantial increase in maximum life span is entirely predictable. Stabilized arc under operating conditions is desirable. So too is the elimination of the heretofore essential auxiliaries, costly, fragile and extremely temperamental in operation. These parasitical yet heretofore necessary adjuncts represent both a substantial increase in first cost and a substantial source of annoyance to the user of fluorescent tube lighting equipment. Space provision must be made for them; they must be properly connected in circuit; and supervision must be given thereto to insure that their failure does not go unobserved, resulting in ultimate impairment of the system itself. Moreover, they represent an added space requirement in the physical set-up and must be duplicated for each tube inserted in the combination. That is to say, a complete set of auxiliaries is required for each tube in operation.

The inherent disadvantage of fluorescent tube lighting equipment as at present known, employing the familiar and conventional hot cathode tube, is that it is slow in starting, requiring approximately six or seven seconds in which to strike under favorable conditions, and even longer under low temperature operating conditions. Insulation problems are severe. Filament failure due to localized concentration of the arc and to other reasons is rapid. Tube life is impaired.

In an endeavor to avoid at least to some extent the several disadvantages and defects hereinbefore recited, I, along with other workers in the field, have suggested a radical simplification of fluorescent tube lighting operation whereby the tubes, operated under cold cathode conditions as distinguished from the hot cathode operation theretofore so widespread in the art, display radically improved operating characteristics. A transformer is employed as the source of electrical energy for the tubes, which are operated in parallel. The cold cathode operation hereinbefore referred to is achieved according to such practice either by shorting the terminals of the conventional hot cathode tube readily available on the market, or by the provision of a specially designed cold cathode tube. In either event such tube is no longer dependent upon the proper operation of a fragile and delicate filament, and displays useful tube life several times that of the hot-cathode operated tube. By making available a starting voltage substantially higher than has been suitable in hot cathode tube operation, starting times have been reduced to the order of but a fraction of a second. The arc is strong and intense once struck, even under extremes of operating conditions.

It was quickly found in the early days of fluorescent tube lighting that when operating these tubes in parallel in the manner aforesaid, a detrimental stroboscopic effect was observed,

whereby an undesirable flicker was apparent to the observer. It will be recalled that a characteristic of fluorescent tube operation is that the arc is struck and extinguished twice in each operating cycle. Thus, for 60 cycle operating current the arc makes and breaks 120 times per second. When each tube of a nest strikes and extinguishes practically simultaneously, this result is apparent to the eye of the observer, the effect being that of a detrimental flicker. This I have avoided by displacing certain tubes electrically out of phase with the remaining tubes, as by the insertion of a capacitance in one leg of the tube lighting circuit. Moreover, since the combined effect of the transformer and load is inductive, giving rise to lagging current power factor, such stroboscopic-correcting capacitance also serves to restore the system power factor to approximately unity value.

The cure thus achieved, however, introduces its own problems. Uneven wave form frequently results, particularly on the condenser side with high peaks and with resonance jogs therein. Power efficiency is thereby lowered, while at the same time, tube life is diminished below theoretical expectations, due to insulation puncturing and the like. Moreover, with direct coupling between the primary winding and the secondary windings, it was observed that, up to the saturation value of the iron core, current would build up indefinitely through the negative resistance tube load until the tubes themselves failed or the system was ruptured at some point or points therein. Shunt leakage reaction transformers, of either the shell or core type, in substantial measure abated this last-mentioned deficiency.

In this highly competitive art, wherein the various manufacturers and operators are continually vying among themselves to secure optimum manufacturing and operational efficiencies together with lowest possible costs of production, extreme importance attaches to any development which will enable appreciable savings in iron and copper content, or offer advantages in over-all dimensions, or improved system operating conditions.

An important object of my invention, therefore, is to minimize in substantial measure and at least to a certain extent eliminate, the many disadvantages, defects and deficiencies of the prior art and provide a fluorescent tube lighting system including associated power unit and transformer, in which power factor is in substantial measure restored to unity value, in which low temperature rise is observed in the power unit itself while iron and copper loss are reduced to a minimum value, in which minimum core loss occurs between primary and secondary windings, and in which stroboscopic effect is substantially eliminated and improved wave form is achieved.

And now, having reference more particularly to that embodiment of my invention illustrated in the several views of the drawings, a transformer core is indicated generally at 10, having a primary winding 11, a secondary winding 12 and a third winding 13, this latter winding serving the dual function of a secondary winding and a reactor coil. All these windings are mounted on the same transformer core. The primary winding 11 and the secondary winding 12 are disposed side by side, in close-coupled arrangement, while the reactor winding 13 is spaced therefrom, and is inductively or what may be termed loosely coupled with the primary coil. Winding 13 is wound in electrically aiding rela-

tion to winding 12. The winding 11 may be operatively disposed closer to winding 13 than to winding 12, but to minimize and control flux leakage, I prefer to dispose it as shown.

As has already been pointed out, it is an important object of my invention that iron and copper loss be reduced to a minimum, and that as well, the total iron and copper content of the transformer be minimized. These desirable and advantageous results are brought about by the novel design of the core elements. In the preferred embodiment, here undergoing description, I elect to employ the highly efficient shell type of transformer. Having reference, therefore, more particularly to Figures 4 through 6, inclusive, it will be seen that each outer portion 14 of the transformer is constructed of a large number of substantially E-shaped laminations, thus having outer and intermediate stubs legs 14*a* extending laterally from stem 14*b*. One stack or bundle of these laminations is disposed on each side of a central longitudinally extending leg 16 shown in Figure 5.

Leg 16 is comprised of a stack or bundle of laminations for purposes which will be obvious to those skilled in the art. The legs 14*a* of each bundle of laminations 14 are disposed inwardly towards the central leg 16, so that the faces 14*c* thereof abut firmly against leg 16. Straps 17 are disposed about the bundles 14 and 16 at the ends and intermediate the lengths thereof, and serve by such means as screws 18 to clamp the several bundles of laminations against each other in tight and firm manner as effectively to remove all possibilities of vibration, chattering or the like. This manner of clamping is conventional in the art, and no more need be said concerning the same at this point. The intermediate and rightmost legs 14*a* (Figure 4) and stems 14*b* combine with the leg 16 to form a low reluctance magnetic core circuit and define spaces 19 for the reception of the closely grouped primary winding 11 and secondary winding 12. Similarly, the left-most legs 14*a* shown in Figure 4 combine with the central leg 16 and stems 14*b* to form a shunt extension of relatively high reluctance and define spaces 20 for the reception of the reactor coil 13.

While I have shown the primary coil 11 as being disposed in the left-most position in Figure 1, and in the right-most position in Figure 6, this is by no means essential. The positioning of the coils illustratively may be reversed so that the primary coil is disposed intermediate and the secondary coil disposed in the right in Figure 6. Ordinarily, however, as suggested, I find it preferable to dispose the primary coil 11 and secondary coil 13 remote from each other, to diminish flux leakage. It is preferred, however, that the reactor coil 13 retain its isolated position with the shunts as suggested in the several figures of the drawings.

Although considerably more will be said concerning one phase of this matter at a later point herein, it will be seen from the foregoing that the construction disclosed herein utilizes a minimum of space requirement, and accordingly, employs minimum iron content. Particularly in the case of the winding 13, the total quantity of iron is materially reduced as contrasted with the use of a separate iron core reactor. Moreover, material advantages from electrical and operational standpoints attend upon the present construction. The assembly is much more compact and much more readily adapted for utilization. In manner as will be more fully pointed out hereinafter, this disposition of the winding 13 permits it to participate in transformer action in the operation of an associated tube load. This, of course, is quite impossible with an iron core reactor which is magnetically separate from the transformer itself. Further, the arrangement of the winding 13 permits proper and continued operation in the system even when some appreciable decrease in primary voltage is observed from rated voltage conditions. A separate reactor would be valueless in that respect.

In the operation of my new system, it is to be noted that the close-coupled windings 11 and 12 may be connected together either in auto-transformer or ordinary transformer relationship. When auto-transformer connections are employed, certain important economies are usually inherent. For this reason, among others the use of auto-transformer connection is desirable when the transformer is operated within the voltage range permissible under the rating system of the Fire Underwriters, say 600 volts or less. The present embodiment illustrates the use in accordance with auto-transformer connections, although it is of course to be understood that ordinary connections can be employed where desired. A fuse 24 is inserted in the main primary energizing system, serving as an ultimate safeguard upon continued maintenance of some short circuit conditions as upon tube failure or the like. Ordinarily, however, the power-factor correcting condenser hereinafter more fully described will serve to protect the tube circuit with which it is associated, while the secondary winding 13 acting as an iron core reactor will protect its associated tube.

With these points in mind, it now appears to be in order to describe the electrical circuit and its included secondary coils 12 and 13. Let it be assured that a half-cycle of primary current flow is maintaining such that the current courses from the alternator or other source of electrical current 21 (Figure 1) to the right therein, through lead 22. Further, single knife blade switch 23 or similar switching element is assured to be in closed position. The current is thus free to course along lead 22, past protective fuse 24, up through lead 25 to the right-hand terminal of primary coil 11, and through the coil. From the left-hand terminal of the coil, the current courses through lead 26, knife blade switch 27, lead 28, knife blade switch 29, and return lead 30 back to the alternator 21. During the next half cycle of current flow in the alternator 21, the coursing of current is just the reverse of that which has been traced.

Usually during the first few cycles of primary current flow in the manner just described, no arc is struck across the associated tube load hereinafter to be described. Accordingly, no back electromotive force is built up in either secondary windings 12 or 13, and no magneto-motive force is developed therein. Thus, the secondary coils for the time being interpose no reluctance preventing the coursing of primary flux developed by primary coil 11. We will assume that the coils are wound in such direction that for the half cycle of current flow heretofore trace, flux courses to the right in central leg 16, interlinking secondary coil 12 and to a slight extent, the secondary coil 13, in which of course, no back electro-motive force is generated as yet. Choosing the path of least reluctance, by far the greater part of the primary flux courses the intermediate stub legs 14*a*, and thence to the left along upper

and lower stems 14b to the left-most legs 14a back to central leg 16. From there, the flux courses along the central leg back to the primary winding 11.

For a purpose which will be more fully described hereinafter, the right-most legs 14a in Figure 1 (these of course are the left-most legs 14a in Figures 2 and 4) terminate short of the central leg 16 to a desired or calibrated extent. Calibrated air gaps G1 and G2 are thus included in the right-most end of the core. The extent of the reluctance thus imposed and the purpose of these air gaps will be more fully developed hereinafter. As has been stated, the greater part of the primary flux, unimpeded by any back magneto-motive force, courses the intermediate legs 14a. A small quantity thereof, however, courses the right end of the leg 16, linking winding 13 and developing a voltage therein. The small quantity of flux thence courses across air gaps G1, G2 and to the left across upper and lower stems 14b, combining with the major quantities of flux coursing intermediate stub legs 14a.

During the next half cycle of primary current flow the coursing of the flux is just the opposite to that which has been traced. The flux from primary winding 11 courses to the left across leg 16 to the left-most stub legs 14a. There it courses left-most legs 14a and to the right across upper and lower stems 14b. A larger quantity of the flux following these paths crosses intermediate legs 14a and return to the left along leg 16 to the primary winding, thus interlinking the secondary coil 12 and inducing a voltage in the same. The small remainder of the flux continues, coursing to the right across upper and lower stems 14b, along the right-most legs 14a, across air gaps G1, G2, and to the left through central leg 16, interlinking coil 13, and thence to intermediate legs 14a, where it recombines with the main portion of the flux and returns to the primary winding.

After the passage of but a comparatively few cycles of primary current, a voltage is built up in coil 12 to such a value that it is conditioned to strike an arc across its associated tube 31. We will assume that at the time that the arc is struck across the tube 31, the current flow through the primary coil 11 is in such direction as to induce a secondary current flowing to the right in Figure 1. With this assumption, it will be seen that current flows from the right side of coil 12 through lead 32, across condenser 33, terminal 34 of tube 31, across the tube to terminal 35 thereof, and thence back through lead 25 to the left side of primary coil 11, thence through the right lead 25 thereof to junction 36, and returning through lead 37 to the left side of secondary coil 12. During the next half-cycle of current flow, the direction of current from the secondary coil is the reverse of that just traced, the current flowing from the left lead 37 from secondary coil 12, through junction 36 to lead 25 on the right side of primary coil 11, through the latter to the left lead 26 thereof, thence through electrode 35 of tube 31 across the tube to the right electrode 34 thereof, across condenser 33 and thence through lead 32 back to the right side of the secondary coil 12.

As soon as the load, here comprising tube 31, strikes across the secondary coil 12, the current flow is maintained by the primary flux from primary coil 11. The flow of current through coil 12 in itself induces back magnetomotive force. This back magnetomotive force is in direct opposition to the primary flux and thus tends to buck the same. Assuming for the moment that the flux from the primary coil 11 is normally to the left in Figure 1, then the secondary flux from coil 12, bucking the primary flux, will tend to course to the right in Figure 1, across central leg 16, through intermediate legs 14a, and thence to the left across upper and lower stems 14b.

Of course, this back magnetomotive force is by no means sufficient to counteract the primary flux. Accordingly, and because of the close coupling between the primary coil 11 and the secondary coil 12, the negative resistance characteristic of the tube load 31 shortly tends to lend increased induced current flow through the tube. It is for this reason, among others, that the condenser 33 must be interposed in the circuit of the secondary coil 12. Moreover, this condenser serves the additional function of introducing a quadrature component in the current supply. This leading component as introduced compensates for the inherently inductive nature of the system as a whole, and tends to restore the power factor to approximately unity value. This, of course, lowers appreciably the cost of energy supply. I usually combine the transformer 10 and condenser 33 by suitable electrical interconnections to form a compact power unit, as for example, in the same casing for connection across tubes such as the tubes 31 and 38.

Because the bucking component of induced magnetomotive force is by no means sufficient to inhibit the coursing of the primary flux, there will remain some primary flux coursing the secondary 13, thus tending to energize the same. The air gaps G1, G2, however, limit the quantity of this flux to such value that the voltage induced will be insufficient in itself to strike an arc across tube load 38, with which the coil 13 is connected in series. The combination of the current induced in coil 12, however, with the small amount of current induced in coils 13 is sufficient, after the passage of a few cycles of such current and very shortly after the arc has first been struck across tube 31, to strike the arc across tube 38.

This tube 38 is in series circuit with the secondary coil 13, which additionally serves as a reactor coil. It will be recalled that the secondary circuit consisting of the coil 13 and tube 38 is branched in parallel off of secondary coil 12. Thus, this tube circuit under no-load conditions is energized by a voltage comprised of two components, namely, the voltage induced in the secondary coil 12 and that induced in the secondary coil 13. As soon as the arc is struck across tube 31 the voltage induced in coil 12 diminishes sharply. Thus, the total voltage induced in coil 13, still under no-load conditions, is substantially diminished. In the meantime, however, the tube 38 has been so conditioned for striking that an arc strikes thereacross a few cycles later despite the diminished voltage.

Assuming the same conditions of primary energizing current as have heretofore been assumed in connection with the description of current flow through coil 12, it will be seen that current flows through the right-hand lead 32 from coil 12, through junction 39, up across left-hand lead 40 of coil 13, through the right-hand lead 41 thereof to terminal 42 of tube 38. Passing across the tube to left-hand terminal 43, the current courses through lead 28 and lead 26 to the left-hand side of primary coil 11 connected in autotransformer connection with coil

12. Coursing through the primary coil to the right lead 25 thereof, the current flows back through junction 36, lead 37 to secondary coil 12, thus completing the circuit.

During the immediately subsequent half cycle of primary energizing current, the circuit through through coil 13 and tube 38 is the reverse of that just traced. In such instance, the induced current flows to the left through secondary coil 12, down lead 37 to junction 36, up through lead 25 to the right-hand side of coil 11, across the latter coil to lead 26 thereof, switch 27 lead 28, and terminal 43 of tube 38. Thence, the current flows across tube 38 to terminal 42, lead 41 to the right-hand side of coil 13, down through left-hand lead 40 thereof to junction 39, and thence back to lead 32 to the right-hand side of coil 12.

The secondary coil 13 gives rise to its current-limiting property by building up a back magnetomotive force therein as soon as the arc strikes across the tube 38, when current begins to flow through this branch secondary circuit. This secondary coil 13 thereupon induces a back magnetomotive force. It will be recalled that the induced current follows a generally sine wave form. It builds up from zero to maximum value, falls therethrough back to zero during a particular half cycle, then builds up to a maximum value in the opposite direction, and then again goes back to zero, to complete a full operating cycle. During the early stages of current build-up in either direction, the back magnetomotive force imposes relatively little reluctance to the passage of induced flux. Thus, during these early stages of current build-up the secondary coil 13 introduces but little current-limiting value. Primary flux linking the same, therefore, is not opposed by any substantial reluctance initiated by the coil 13.

As soon as the induced current builds up to the point where the magnetomotive force induced thereby is sufficient to carry the flux in substantial quantities across the air gaps G1, G2, however, his back flux courses through the magnetic core effectively bucking the primary flux and thereby interposing definite limits on the quantity of primary flux which will course the reactor coil 13. By nicely calibrating the size of wire, number of turns, etc., of these coils, definite assurance is readily achieved that at no time will excessive current flow through tube 38. On the contrary, the current through the tube will always be maintained within safe limits.

As soon as the induced current flowing through coil 13 in any particular half cycle reaches its optimum value and begins to fall off, it will shortly reach the point where the induced magnetomotive force is insufficient to force substantial quantities of induced flux across the air gaps G1, G2. When this point is reached, the coursing of the secondary flux from coil 13 through the magnetic core will terminate until the striking point is reached in the subsequent current half-cycle. When this back flux stops, no further impedance is interposed to the coursing of the primary flux through the coil 13. The current limiting effect of coil 13 ceases momentarily, and is not substantially reestablished during this low voltage stage, until the induced current again builds up to a value where correction and limitation are again required.

During that portion of the current half-cycle when the counter-magnetomotive force from coil 12 is sufficient to force an effective counter flux

across the air gaps G1, G2, the following circuit may be traced, assuming current flow such that the coursing of secondary flux is to the right in leg 16 (Figure 1). The back flux courses across leg 16 to the right end thereof. Thereupon, it courses across air gaps G1, G2, along the rightmost legs 14*a* and to the left across upper and lower stems 14*b*. There bucking the primary flux, the flux courses intermediate legs 14*a*, to the leg 16 and back to the coil 13. During that portion of the next subsequent half-cycle in which the back flux courses the magnetic core, the direction of flow is of course just the reverse of that traced.

Expressed in other words, the coil 13 serves the dual function of a transformer secondary winding, aiding in the quick striking of the arc across the associated tube load 38, and of a reactor, interposing definite limitations on the current across the tube during that portion of each current half-cycle during which the tube is energized. In short, during the preliminary conditioning of the tube for the maintenance of an arc thereacross, the secondary winding 13 participates in inducing added striking voltage across the de-energized tube. When the arc is struck, however, and current flows across the tube 38 and through the associated secondary circuit including coil 13, a back magnetomotive force is developed thereby, which forces a back flux through the magnetic core, bucking the primary flux and definitely limiting the voltage across the tube 38 through calibrated inductance. As soon as the voltage in any half-cycle falls below a value sufficient to maintain the arc across the tube, however, so that this arc is momentarily extinguished, the development of back magnetomotive force in coil 13 instantly terminates, and primary flux is unimpeded for rapidly building up a voltage in coil 12 and in the coil 13. The tube is quickly conditioned for re-establishment of the arc at an early stage in the next successive current half-cycle. This cutting in and out of the current-limiting properties of coil 13 continues during each half-cycle of current, as in the manner described.

It will be observed from the foregoing description that the air gaps G1, G2 serve effectively to calibrate the extent and degree of the current limiting action of the coil 13. By increasing the air gaps so as to block the flux passage thereacross until higher magnetomotive forces are available, it is clear that the coil 13 will be prevented from effecting its regulatory action until higher voltage values are achieved. Conversely, by diminishing the width of the air gaps the regulatory action is increased, and is effective at lower applied voltage.

A very important advantage inherent in my new construction is that striking of the tube load is achieved, particularly across tube 38, even when for any reason a substantial decrease of the primary voltage from rated value occurs. This is because secondary winding 13, serving as a reactor, and with fixed air gaps G1, G2, is designed to operate only at a voltage having a certain minimum momentary value. Upon decrease in primary voltage from rated value, the required instantaneous voltage value usually is not achieved in a particular secondary voltage half-cycle until a substantially later point therein.

Accordingly, upon decrease in primary voltage the winding 13 usually does not subserve its regulatory function until at a later point in each secondary voltage cycle, and similarly cuts out

at a much earlier point therein. With the diminution in this inhibiting action, it is possible to maintain the arc across the tube 38 even upon substantial decrease in primary voltage off of rated values.

It will be helpful to recapitulate briefly in order to facilitate a more complete understanding of the exact operation of the present embodiment. Alternator 21 or other suitable source of primary charging current energized, upon closure of switch 23 in the primary circuit, the primary coil 11. The fuse 24 protects the system against ultimate failure, should short circuit occur in secondary coil 12, or perhaps in secondary coil 13. Upon energization of the primary coil 11, primary flux begins to course the magnetic core 10. Unimpeded by any back magnetomotive force, this primary flux quickly induces a secondary voltage of comparatively high value in the coils 12 and 13.

After the passage of but a comparatively few cycles of charging current, representing only a fraction of a second interval, the arc will be struck across tube 31, in series with the condenser 33. The design of the system is such that ample voltage is always present to insure ready striking of this arc and maintenance thereof, once the same is established. The condenser 33 serves to limit the current flow through tube 31 and at the same time to correct the power factor of the system. Moreover, it causes the current across this tube to lead the primary current. This latter effect, coupled with the lagging characteristic of the essentially inductive secondary load including tube 38, throws the two tubes out of phase so that stroboscopic effect is substantially eliminated.

Shortly after the load strikes across tube 31, the arc through the parallel-connected tube 38 and its associated secondary 13 is struck, so that current passes through this tube 38. The limiting effect of the reactor coil 13 is interposed only during those portions of each half-cycle where the current would otherwise tend to run away. Thus, regulatory action is interposed only at those times when it is needed. At all other times the coil 13 interposes only moderate impedance to the coursing of energizing current, so that ready re-establishment of the arc is achieved during each current half-cycle.

My new construction will be seen to give rise to remarkable economies in both copper and iron. Important savings in space requirements also are made possible. The included tubes strike quickly even under low temperature conditions. Adequate tube protection is achieved at all times, almost entirely regardless of the nature and extent of any localized failure. To illustrate, the condenser 33 effectively protects the tube 31, while the reactor 13 affords similar guaranty against damage to tube 38 and its associated circuit. Finally, fuse 24 protects the system upon continued short-circuit conditions.

While auto-transformer connections have been illustrated as constituting the preferred embodiment of my invention, I have likewise pointed out that ordinary transformer connections can be employed where desired. While side-by-side disposition of the close-coupled coils 11 and 12 have been illustrated as preferred, it is of course entirely practical to superimpose them, upon recognized sacrifice of certain advantages inherent in the side-by-side relationship. Similarly, while primary coil 11 preferably is disposed remote from secondary coil 13, the positions of coil 11 and

secondary coil 12 can of course be reversed so that primary coil 11 is disposed intermediate the two secondary coils.

Not only may full autotransformer connections be employed if desired, or ordinary connections utilized; but as well, where desired, one secondary coil may be autotransformer-connected to the primary and the other coil coupled in ordinary connection therewith. Some increase in copper content usually is attendant upon such arrangement.

While a shell-type core has been illustrated as preferred, a core type transformer is employed if desired. As a further alternative, I contemplate the provision of a shell-type core for the close-coupled ordinary transformer windings 11 and 12 and the use of but a core-type magnetic core for the winding 13. This would simply mean the removal of the extended portion of one of the outer legs 14. Efficient, reliable operation is insured at all times, while detrimental stroboscopic flicker is substantially eliminated. Either cold or hot-cathode tubes, the latter converted for cold-cathode operation, are employed. Improved wave form, with the substantial elimination of detrimental harmonics and peaks, contribute to materially increased life of the tubes. The power unit is neat, small, compact, sturdy and reliable. Its cost is minimized as contrasted with similar power packs heretofore available. All these and many other highly practical and advantageous results attend upon the practice of my invention.

It is apparent from the foregoing that once the broad aspects of my invention are disclosed, many embodiments thereof will suggest themselves to those skilled in the art. Moreover, many modifications will occur of the embodiment herein described. Accordingly, I intend the foregoing description to be considered as merely illustrative, and not by way of limitation.

I claim:

1. An electrical gas discharge tube lighting system, comprising a source of alternating current electrical supply; an auto-transformer having one primary coil and one secondary coil in low reluctance magnetic circuit with the primary coil thereof connected to said source of supply, and a second secondary coil adapted to produce current limiting reactance outside said low reluctance magnetic circuit and magnetically coupled in shunt circuit of relatively high reluctance with said primary coil and electrically connected in series with said auto-transformer; a condenser also connected in series with said auto-transformer but in parallel with said second secondary coil; and two electrical gas discharge tubes, one tube being connected in series circuit soley with said condenser and the auto-transformer and having the flow of current therein limited by said condenser, and the other tube being connected in series circuit solely with said second secondary coil and auto-transformer and having the flow of circuit therein limited by said second secondary coil, said condenser being of such capacity as compared to the inductance had with said second secondary coil as to assure balanced lighting of the two tubes and minimum stroboscopic effect.

2. In a unit for powering a pair of electrical gas discharge tubes, the combination which consists of a casing; a transformer for connection to a particular source of alternating current supply and housed within said casing and comprising a core forming a low reluctance magnetic circuit, a primary coil and an auto-transformer-

connected secondary coil disposed on said core, a shunt core extension from said low reluctance magnetic core and in relatively high reluctance magnetic circuit with said primary coil, and a second secondary coil mounted on said core extension and connected in series with said primary coil and first-mentioned secondary coil for connection in series circuit directly to one of said tubes and adapted to limit the current in the circuit to that tube; and a condenser also housed within said casing and connected in series with said primary coil and first-mentioned secondary coil but in parallel with said second secondary coil for connection in series circuit directly to the other of said tubes and of such capacity as to limit the current in the circuit to such other tube and assure balanced lighting of the tubes.

3. In a unit for powering a pair of electrical gas discharge tubes, the combination which consists of a casing; a transformer housed within said casing for connection to a particular source of alternating current supply and comprising a shell-type core forming a low reluctance magnetic circuit, a primary coil and a secondary coil disposed in side-by-side relation on the central leg of said core, a core extension from said shell-type core and having a central leg and two separate outer legs each having an individual air-gap included therein, and a secondary coil mounted on the central leg of said shunt core extension and connected in series with said first secondary coil for connection in series circuit directly to one gas discharge tube and adapted to limit the current therein; and a condenser also housed within said casing and connected in series with said first-mentioned secondary coil but in parallel with said second-mentioned secondary coil for connection in series circuit directly to the other of said discharge tubes, said condenser being of such capacity as to limit the current in said other tubes and assure balanced lighting of the tubes.

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