Dec. 11, 1951 J. H. BRIDGES 2,577,733

TRANSFORMER

Original Filed March 5, 1945 2 SHEETS—SHEET 1

Fig. 1

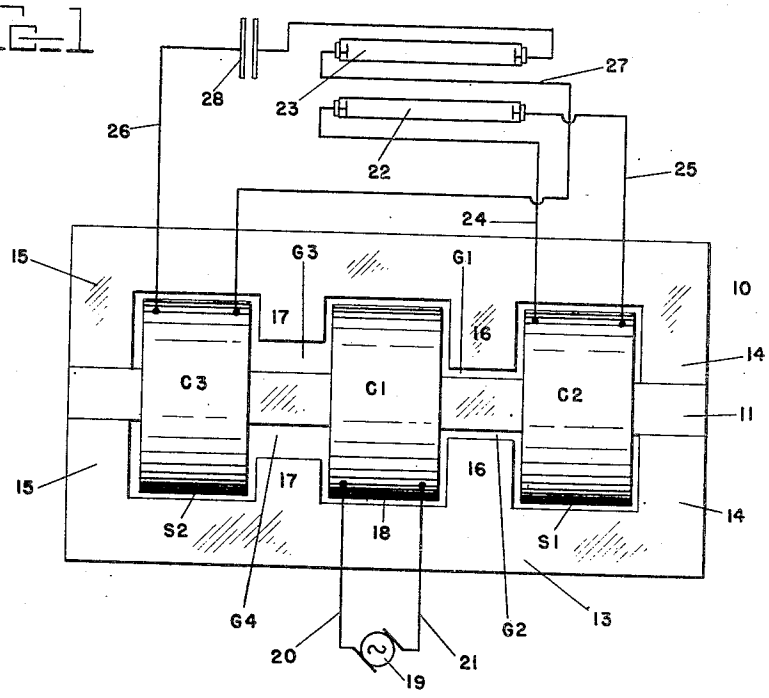
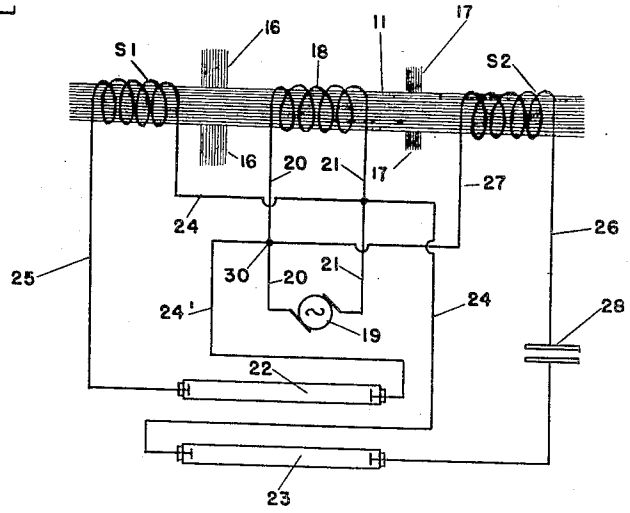


Fig. 2



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TRANSFORMER

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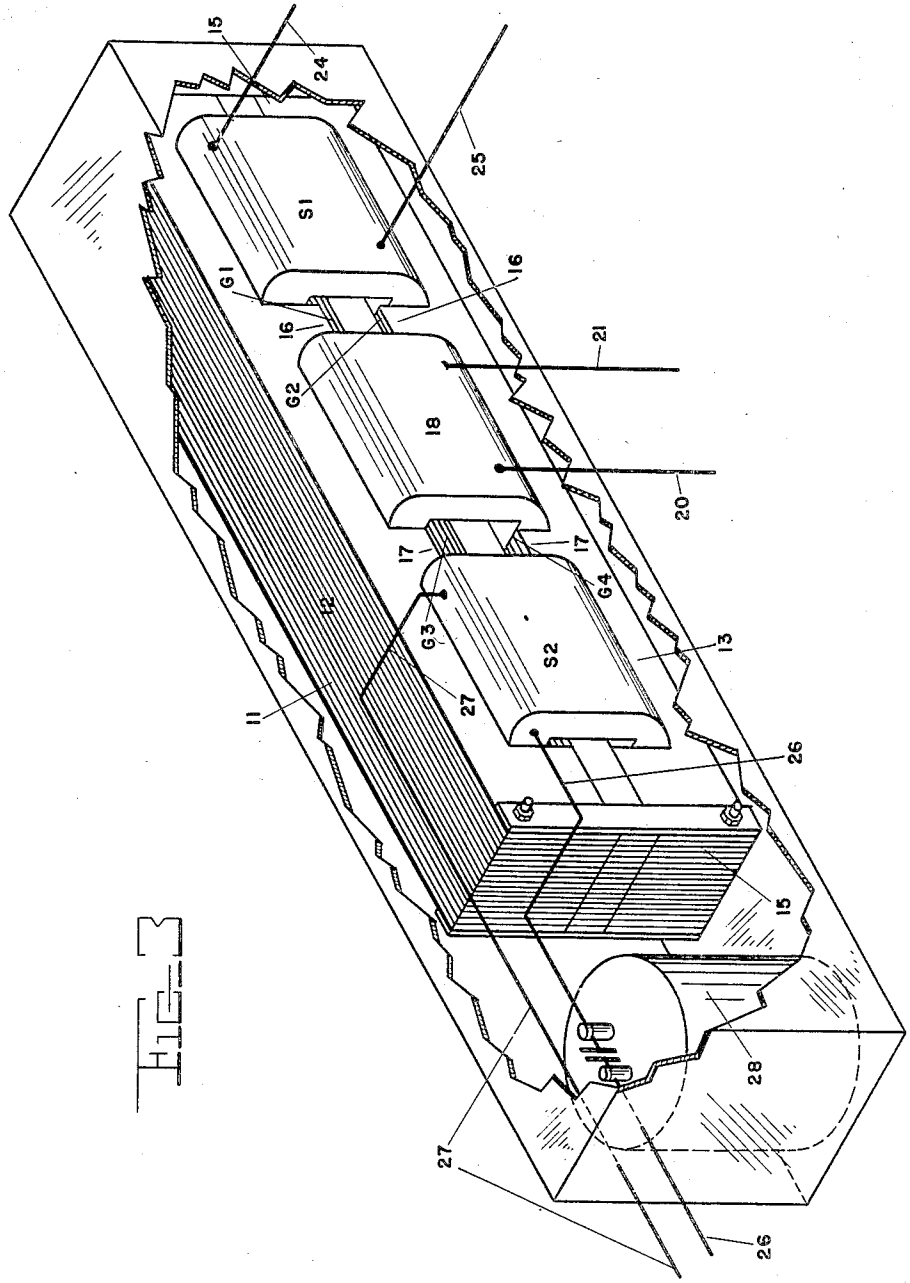


FIG. 3

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Patented Dec. 11, 1951

2,577,733

UNITED STATES PATENT OFFICE

2,577,733

TRANSFORMER

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Original application March 5, 1945, Serial No. 581,055. Divided and this application November 1, 1946, Serial No. 707,294. In Canada August 20, 1943

1 Claim. (Cl. 171—119)

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My present application for patent is a division of my copending application 581,055 of March 5, 1945, entitled Luminescent Tube System and Apparatus, now Patent 2,510,209 of June 6, 1950, which in turn is a continuation in part of my copending application, Serial No. 448,471 filed June 25, 1942, and entitled Luminescent Tube System, now Patent 2,370,635 of March 6, 1945, and the invention relates to transformers and power units for powering fluorescent lighting systems and other tube loads of negative resistance characteristics.

An important object of my invention is to provide a transformer unit characterized by its small iron and copper requirement, its consequent low weight, its compact, self-contained and unitary design, with small space requirements, its physical sturdiness and low first cost, both of materials and of assembly, and, as well, by its low core loss and high efficiency.

Another object is to provide a new transformer of such construction that detrimental over-loading is effectively prevented at all times, in which all necessity of protective fuses or other safety mechanisms is avoided, the entire construction being in full compliance with all requirements of the Fire Underwriters.

Other objects in part will be obvious and in part pointed out hereinafter during the course of the following description.

My invention accordingly resides in the various elements and features of construction, and in the combination of parts, 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 drawings wherein I have disclosed several embodiments of my invention which I prefer at present,

Figures 1 and 2 schematically illustrate two circuits embodying my inventive thought, while Figure 3 illustrates, in perspective, my new power unit.

Throughout the drawings like reference characters indicate like parts.

In my earliest parent patent, it has been fully revealed how fluorescent tube lighting, over say the past decade, has met with widespread acceptance throughout the arts, commerce, industry, and as well, in almost all types of household utilization. The marked advance in efficiency, and in reduced operational costs, the absence of heat and many other characteristic advantages as contrasted with the Edison type of filamentary lamp readily explains the warm reception with which this type of illumination has been received.

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An important object of my invention, therefore, is to provide a new transformer, which while avoiding in large measure the aforementioned disadvantages and deficiencies, possesses the multiple advantages of requiring a minimum investment in copper and iron, and consequently is neat, sturdy, compact and self-contained, lending itself to ready mounting on the reflector or other mounting of an associated fixture, and which displays high efficiency with good system power factor, quick-starting characteristics under cold weather operation, in the substantial absence of detrimental stroboscopic flicker, and which is substantially fool-proof, no circuit protective auxiliaries being required.

Referring now more particularly to the simplest embodiment of my invention, attention is directed to Figure 1 of the drawings, in which there is shown a transformer with secondary coils inductively associated with the primary winding in ordinary transformer connection. A magnetic core, indicated generally at 10, is here illustrated as being generally of the shell type, having a central, longitudinally extending leg 11, constituting an inner core portion, flanked in spaced relation, on either side thereof, by outer longitudinally-extending legs 12 and 13, constituting outer core portions. Leg 11 is designed to accommodate, without saturation, the maximum magnetic flux developed by the primary winding later to be described.

It is not essential that legs 12 and 13 be of like dimensions or shape, or that they be equally spaced from central leg 11. Accommodation for any variation in such design can be accomplished by compensating variations in other features of design. However, for symmetry as well as for many other reasons involving electrical and mechanical design, I prefer to construct legs 12 and 13 of like configuration, and to space them equi-distant from central leg 11. This gives a more readily balanced condition of magnetic flux.

Inasmuch as the flux from leg 11 divides substantially equally between legs 12 and 13, it is sufficient that each of these have a cross-sectional area substantially half that of leg 11. End members or pieces 14, 14 and 15, 15 serve to interconnect opposed ends of legs 11, 12, 13 so as to form a closed magnetic core, of the shell type. In the construction shown, these in reality constitute end-leg extensions of substantially U-shaped core members, the yoke portions of which are constituted by legs 12, 13, respectively. It is

entirely satisfactory, however, to construct them in any desired suitable manner, the controlling criterion being that the legs are stamped from suitable sheet laminations, and are subsequently assembled in the manner giving rise to the highest over-all efficiency. However, they be stamped and assembled, the legs 11, 12, 13 and end pieces 14, 14 and 15, 15 are constructed in stacks of lamina of suitable steel, displaying little residual magnetism. End pieces 14, 14 and 15, 15, for obvious reasons have cross-sectional areas approximately those of legs 12, 13.

Intermediate the lengths of legs 11, 12, and 13, and extending either from leg 11 towards but short of legs 12, 13 respectively, or as shown, from legs 12 and 13 towards but short of leg 11, are a plurality of magnetic shunts 16, 16 and 17, 17. These shunts, of laminar construction, may be formed in any suitable manner. In the present instance, they are struck integrally from legs 12 and 13, but certain savings in iron are had by employing laminated inserts wedged between the windings. Moreover, it is preferred, as generally indicated in Figure 2, that the width of shunts 17, 17 be substantially that of the shunts 16, 16. I find that shunts 17, 17 need only be about one-half as wide as shunts 16, 16 for reasons dealt with hereinafter.

The shunts 16, 16 and 17, 17, terminating short of central leg 11, provide included air-gaps G1, G2, G3 and G4 therebetween. In either the integral or insert construction, however, it will be noticed that air-gaps G1, G2 are shorter than air-gaps G3, G4, giving rise to greater reluctance. The purpose of this design will be developed at a later point. It is sufficient here to note that these air-gaps are calibrated in accordance with the particular load demands on the corresponding secondary windings later to be described.

The magnetic core shunts 16, 16 and 17, 17, together with the remaining elements of the magnetic core, define a plurality of compartments C1, C2 and C3, serving respectively to house primary winding 18 and secondary windings S1, S2. Since primary 18 serves to energize both secondaries S1, S2, only a single primary winding 18 is required. While this winding must be of substantially larger size wire than would be required were separate primaries used, nevertheless a substantial saving in copper results from the use of one primary winding only. Moreover, the reduction in physical dimensions made possible by the elimination of one primary winding employed in certain prior construction makes feasible a substantial decrease in the total iron content of the transformer. This is brought about by decreasing the lengths of the magnetic paths, and results in appreciable decrease in weight, with corresponding gain in compactness. A small, neat-appearing unit is thus made possible.

Primary 18 of step-up transformer 10 is therefore constructed of a relatively small number of turns of comparatively heavy gauge wire. It is energized from any suitable source of alternating current energy indicated generally at 19. In my preferred embodiment this comprises either a 110 volt or 220 volt line. Leads 20, 21 serve to establish this connection.

Paired fluorescent discharge tubes 22, 23 are included in circuit with secondary windings S1, S2, respectively. These fluorescent tubes may either be especially designed for cold-cathode operation, in which instance they will likely be fashioned with a single, solid electrode at each end of the tube, or else the conventional hot-cathode tube, now readily available on the market, can be adapted in comparatively simple manner for entirely satisfactory operation under cold-cathode conditions. The electrodes of these tubes are conditioned for such cold-cathode operation by installing a jumper across the paired terminals of the filamentary electrode provided at each end of the tube. The short-circuit thus established ensures that all parts of the electrode are at the same potential.

Tube 22 is connected by leads 24, 25 across the terminals of secondary S1, while tube 23 is energized through leads 26, 27 from secondary S2. Contributing to the elimination of stroboscopic effect, the relation of tube 23 to its secondary S2 is reversed with respect to the relation of tube 22 to secondary S1. That is, while the right terminal of tube 22 is connected to the right terminal of secondary S1, it is the left terminal of tube 23 which is connected to the right terminal of secondary S2.

A power-factor correcting condenser 28 is provided in lead 26 between tube 23 and secondary S2. It will be recalled that it is this secondary, in compartment C3, which is associated with the short shunts 17, 17. The purpose of this will be developed. The condenser 28 is chosen of sufficient size and capacity effectively to restore system power factor, made lagging by the highly inductive nature of the transformer load, to substantially unity value. Additionally, the leading characteristic imparted by this condenser to its corresponding secondary circuit effectively throws the tubes 22, 23 out of phase. One will ignite while the other is dark, and vice versa, so that detrimental stroboscopic effect, evidenced as an undesirable flicker is substantially removed.

It will now be in order to describe the operation of my new construction. Let us assume that for a given half-cycle of primary current, this current flow is such that a primary flux courses to the right in Figure 1, along central leg 11. At this time no arc has been struck across secondaries S1 and S2, so that no limitative values are imposed on the coursing of flux due to saturation effects.

It is in order to digress momentarily at this point and call attention to the fact that while the magnetic core which I disclose and prefer is of the shell type, with symmetrically constructed and disposed legs, nevertheless, as has already been pointed out, these legs may be of asymmetrical construction and disposition. In point of fact, it is entirely possible to dispense entirely with one outer leg, increasing the dimensions of the other outer leg, and resulting in a core-type construction. I find somewhat better transformer performance with improved wave-form however, when the shell-type transformer is employed.

The flux stream interlinks secondary S1, which at that time is under open-circuit conditions, and generates a secondary voltage therein at the right end of leg 11 this flux stream separates into two substantially equal branch streams. One of these courses up upper end member 14 to leg 12, and across this to the left in Figure 1, and then down upper end piece 15, back along the right through leg 11, interlinking secondary S2, then under open-circuit conditions, and thence back to winding 18.

At 11, the other branch stream courses down across lower end piece 14, across leg 13 to the left in Figure 1, and up lower end piece to the left end of leg 11. There it reunites with the stream first

described, whereupon the combined stream courses to the right along leg 11, back to the primary coil section.

Inasmuch as no current flows through secondary windings S1 and S2 at this time, no back or secondary magnetomotive force is developed in the respective secondaries, impeding the coursing of the primary flux. Thus, no reluctance is interposed in the main magnetic paths, interlinking the secondary windings. The primary flux courses unimpeded across them. Thus, at these times air-gaps G1, G2, G3 and G4, particularly the last-mentioned, have reluctances which are comparatively much greater than those of the main magnetic path. Accordingly, both during the coursing of the main flux stream across leg 11, and of the branched streams across legs 12, 13, respectively, there is no tendency for any substantial part of the flux to course across the magnetic shunts 16, 16 and 17, 17. All of the flux is available for voltage build-up in the secondary coil sections.

During the next succeeding half-cycle of primary current, the coursing of developed flux is just the reverse of that described.

As has already been described in connection with the generation of flux during the preceding half-cycle, the reluctance of the air-gaps G1 through G4, inclusive, are such compared to the reluctance interposed by windings S1, S2 under open-circuit conditions that practically no flux courses the branch paths provided by shunts 16, 16 and 17, 17. This reversal of flux during each half-cycle, say 120 times per second for ordinary 60 cycle current, ensures rapid build-up of voltage in the open-circuit secondary coils. Voltage rises and falls cyclically in these coils to a value substantially in excess of that required to strike arcs across the corresponding tube loads. Finally, after the passage of a number of cycles of current, one of the tubes is conditioned to start. That is, the stresses produced across the tube electrodes so excite the gas content of the tube as to ionize the latter, and condition it for carrying an arc across from one electrode to the other. The rapid reversal of these stresses, and the tremendous value thereof due to the high open-circuit voltages, quickly brings about this phenomenon. In the space of but a fraction of a second, then, the arc is struck across one of the tubes. This compares most favorably with the earlier tube assemblies, in which a starting time of at least six or seven seconds is required, and even more during cold weather operation. I find that on the contrary, weather has little if any effect in the striking and maintenance of the arc across the tubes of my new system. I am satisfied that this advantageous operation is accountable in large measure to high open-circuit voltage.

For illustration, we will assume that it is tube 23 across which the arc first strikes initially. Of course, were it the tube 22 across which the arc is first established, the operation would be just the reverse of that described, as will be clearly apparent to those skilled in the art. We will further assume that at this moment, the half-cycle of primary current is such that primary flux courses to the right along leg 11, from primary 18. As soon as the arc strikes across tube 23, a current flow occurs across this tube. Because of the negative resistance characteristics of this tube load, this current may attain a substantial value. The secondary current induces a secondary or back magnetic flux which links leg 11 and courses in a direction opposite to the primary flux, effectively bucking the same. On the other hand, unless adequate protective devices are provided across the line, the secondary current will build up indefinitely, resulting in rapid failure or even destruction of the tube or system, or both.

It is for this purpose, and to interpose effective and permanent control, simple in nature, that the shunt leakage paths are provided. Whereas the leakage path interposed by air-gaps G3 and G4, of fixed magnetic reluctance, were heretofore of substantially greater reluctance than the main magnetic path or paths on open-circuit conditions, they are now of substantially smaller reluctance than the main magnetic paths, across which the back magnetomotive forces hold sway, bucking the primary flux.

To illustrate, let us trace the primary flux paths under these conditions. Primary flux courses to the right along leg 11, from primary 18. It interlinks secondary S1, across which no load has as yet been established. Separating at the right end of leg 11, one branch courses up, and the other down, the end pieces 14, 14. Since the two branch paths are in parallel and are almost exactly alike, it will be sufficient, for illustration, to describe but a single one of them. The flux courses up the upper end piece 14, to the left along leg 12. Because of the minimum reluctance interposed by coil section S1, little flux courses across air-gap G1.

When the primary flux comes opposite the region defining compartment G3, however, housing secondary S2, it is met and bucked by a substantial flow of reverse or secondary flux. Choosing the path of least reluctance, the greater part of the primary flux courses down across shunt 17 and air-gap G3 to leg 11, to the left of primary 18, and thence back to the right along this leg to primary 18. Thus, the greater part of the flux combines with the back magnetic flux in coursing down this branch leakage path and across air-gap G3, the secondary flux returning the shortest path to secondary S2, and the primary flux similarly returning by shortest path to primary 18.

The calibrated design of shunts 17, 17 is such, relative to the intended secondary load, that only that quantity of primary flux will at this time course to the left along leg 12, down upper end piece 15, and to the right along leg 11, interlinking S2, as will be sufficient to generate a voltage which will induce the required operating current for tube 23 under load conditions, that is, which an arc is established across this tube. At this time, by far greater part of the primary flux is short-circuited across the high-reluctance shunt path, directly back to primary 18.

During the next primary current half-cycle, the situation is just the reverse of that described.

Shortly after the arc has struck across tube 23, the full primary flux, interlinking secondary S1, conditions the latter for striking. This is all but a matter of a fraction of a second. As soon as the arc strikes across tube 22, load conditions are established across this secondary circuit, and current begins to flow of substantial value. A secondary magnetomotive force is developed, just as in the case of secondary S2, giving rise to a secondary magnetic flux of substantial importance. This is in a direction which is the reverse of one which bucks the primary flux. It effectively prevents the interlinking of all the primary flux with secondary S1. Only enough flux interlinks the turns of this winding to induce a voltage sufficient to provide required secondary current across tube 22 to maintain the established arc. This phenomenon is occasioned by the high

leakage reactance shunts 16, 16 and included air-gaps G1, G2.

In the embodiment of Figure 1, a three-coil transformer has been disclosed in which the secondaries and primary are only inductively connected, and are physically independent of each other. This, for convenience, I term ordinary transformer connection. It is entirely feasible under many circumstances, however, and from an economic standpoint, oftentimes preferable, to employ autotransformer connections between the primary and secondary windings. When these connections are employed, and the design is such that secondary maximum voltages do not substantially exceed 600 volts, so as to comply with the requirements of the fire underwriters, a substantial saving is accomplished in copper required, inasmuch as duplication of winding is avoided. Additionally, corresponding savings in physical dimensions of the core are attendant with possible diminution in over-all dimensions of the core. A neater, smaller, lighter and more compact power unit is thus achieved, with substantial savings in iron content.

In Figure 2, I have disclosed the mode of carrying into effect such autotransformer connection. Therein lead 24 from secondary S1 is connected to lead 21 of primary 18 at junction 29, while lead 27 from secondary S2 is connected to lead 20 of primary 18 at junction 30. Primary current flow is just as has been traced in Figure 1. Secondary circuit is established from the left side of secondary S1, lead 25, tube 22, lead 24', junction 30, lead 20, primary 18, lead 21, junction 29, lead 24, and back to the right side of primary S1. For secondary S2, a similar current can be traced: From the right side of S2, lead 26, including condenser 28, tube 23, lead 24, junction 29, lead 21, winding 18, lead 20, junction 30, and lead 27, back to winding S2. For reversal of primary current, during reverse half-cycle, the current flow is just the opposite to that traced.

In Figure 3 I have disclosed the relation of the condenser 28 to the transformer unit in the assembled power unit, the combination of transformer and condenser conveniently being referred to as the power unit. It is entirely possible, in final assembly, to contour condenser 28 differently from what is shown in the drawing, and to associate it closely and snugly with the transformer unit in the interest of small compass, compactness and self-contained construction, of pleasing appearance to the purchaser. The general relation of the several parts of the transformer of Figure 3 is exactly in conformity with Figure 1, so that no amplification is necessary.

I have stated hereinbefore that the design of both sets of transformer core shunts is in calibrated conformity with the nature of the particular tube loads serviced by the corresponding secondaries. The load of secondary S1, for example, gives rise to a comparatively low reluctance when the tube 22 is in operation. Accordingly, were the leakage reactance of the associated shunt path to be of appreciable value, the primary flux, always seeking the path of minimum reluctance, would still in large measure traverse the main flux path, even when the arc had been struck across tube 22. In nicely calibrated manner, therefore, the reluctance of the air-gaps G1, G2 is closely computed, and the air-gaps design accordingly, to provide just the proper ratio under load conditions between the quantities of primary flux shunted across the leakage paths, and that still traversing the main path.

In the case of the secondary S2, servicing the power-factor correcting condenser and associated tube load 23, the condenser 28 interposes a high reactive flux, so that if air-gaps G3, G4 have no more reluctance than gaps G1, G2, they will bleed substantially all the primary flux when the tube load is energized. Insufficient primary flux would course the main circuit to maintain the required arc voltage. The arc would extinguish, and the tube would remain de-energized. Accordingly, therefore, the air-gaps G3 and G4 are made substantially longer than the air-gaps G1 and G2. Moreover, I have found that the width of shunts 17, 17 need only be about half as wide as shunts 16, 16, thus permitting a very compact unit which nevertheless is protected in the event of a short-circuit of condenser 28 or grounding of tube 23. In addition, I find a better distribution of flux is had with shunts 17, 17 being narrower than shunts 16, 16, there apparently being a functional relationship between the length of air-gaps and narrowness of the associated shunts.

It is readily apparent that with the excess of voltage in open-circuit conditions made available by my new construction, it is possible to diminish the applied line voltage, and still provide for an induced secondary voltage of sufficient value to strike the arc. The only difference would be that the arc would strike later in each half-cycle, and extinguish earlier. Thus, a dimmer operation is available, of practical utility.

By the practice of my invention, iron and copper requirements have been minimized, so that a more compact and self-contained unit has been made possible, at a substantial saving in initial investment. The new assembly is sturdy and subsequently fool-proof, it being virtually impossible to damage the installation permanently, even upon short-circuit in both secondaries. Not only the transformer unit considered alone, but as well, both the power unit and tube assembly, rigidly comply with all requirements of the Fire Underwriters. All necessity of protective auxiliaries, expensive in themselves, has been effectively eliminated. No fuse or other circuit protecting device is required in the condenser circuit because full protection against excessive short-circuit current is had with the fore-shortened core shunts. Stroboscopic effect has been avoided, and good system power-factor achieved. Long and satisfactory tube has been made possible, even under cold weather conditions, and quick-striking characteristics have been imparted to the tubes.

All these and many other thoroughly practical and important advantages have been imparted by the practice of my invention. Since many modifications may be made of the embodiments which I have disclosed, and since many embodiments of my basic principles may be evolved, the foregoing description is to be considered as merely illustrative and not by way of limitation.

I claim:

A three-coil transformer comprising a shell-type closed magnetic core having a central leg and two outer legs flanking said central leg on opposite sides thereof and providing a pair of main magnetic flux paths; two pairs of magnetic core shunts, those of one pair being shorter and substantially narrower than those of the other and defining three compartments between said pairs of shunts and providing two pairs of magnetic flux paths shunting across said main magnetic flux paths; a primary coil positioned on said central leg in the middle compartments; and two

secondary coils positioned on said central leg, one in each compartment on opposite sides of said shunts from that housing the primary coil.

JOHN HEROLD BRIDGES.

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