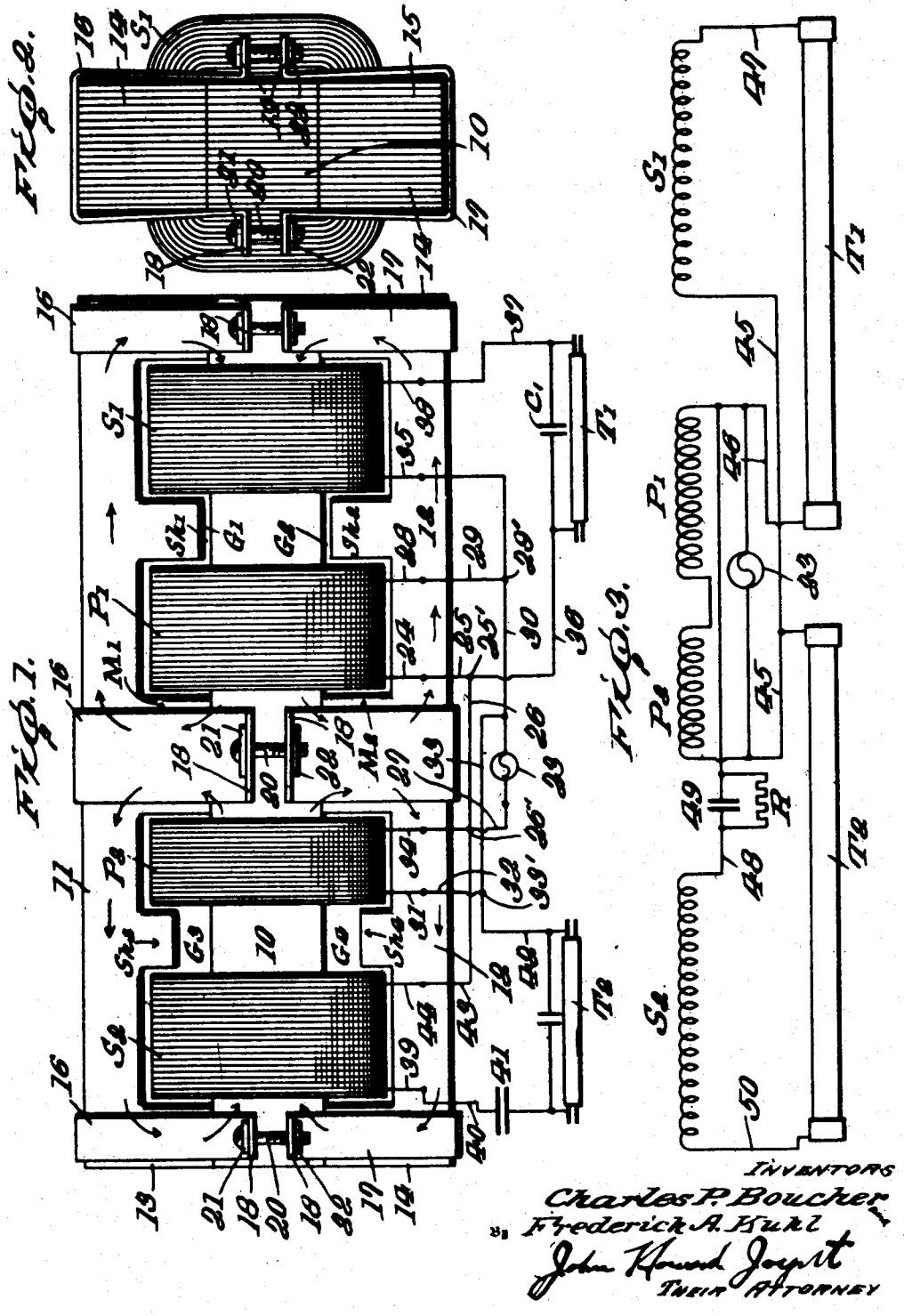
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TRANSFORMER

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TRANSFORMER

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2 Claims. (Cl. 175—356)

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Our application for patent is a division of our copending application Serial No. 402,411, filed July 14, 1941, now Patent No. 2,317,844, entitled Luminescent tube system and apparatus and the invention relates to fluorescent tube lighting, and more particularly concerns a new electrical system for such illumination, as well as a new transformer forming part of, and for energizing such system.

One object of our invention, therefore, is to produce a new fluorescent tube lighting system, possessing the advantages of simplicity, small size, small number of parts, compactness and sturdiness, and which at the same time is characterized by its high system power factor, and the minimization of detrimental flicker or stroboscopic effect of the light emission therefrom.

Another object is to produce a high leakage reactance transformer for energizing such electrical system, comprising batteries or banks of two or more tubes, the tube-energizing circuits each requiring a different circuit input, which transformer serves to produce just the required current to energize those tube circuits properly and to maintain proper arc discharge across the respective tubes and to limit the current flow to the rated values.

Other objects and advantages in part will be obvious and in part pointed out hereinafter, in connection with the following description, considered in connection with the accompanying drawings.

Our invention accordingly resides in the several elements and features of construction, and the relation of each of the same to one or more of the others, all as described herein, the scope of the application of which is indicated in the claims at the end of this specification.

In the drawings:

Figures 1 and 2 comprise side and end elevations, respectively, of a transformer according to our invention, Figure 1 also illustrating the associated system connections according to one embodiment.

Figure 3 depicts in schematic manner, another embodiment of circuit connections, to be associated with the transformer core depicted in Figure 1.

Like reference characters denote like parts throughout the several views of the drawings.

As conducive to a more complete understanding of our invention, it may be noted at this time that the introduction of fluorescent tube lighting into the arts and sciences has been accompanied by the realization that there are certain serious

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drawbacks and disadvantages in the energizing systems for such tubes which have hitherto been in use. The importance of this comparatively new lighting technique, however, can be appreciated when a moment's consideration is given to the widespread acceptance of this new type of lighting. Not only is the acceptance by the industries, but in the stores and in household lighting, as well. As soon as certain operational problems have been solved, we may safely predict the even more widespread acceptance of fluorescent lighting systems in all fields of illumination.

We confidently attribute the popularity of fluorescent tube lighting to the higher efficiency and hence lower operational costs of such lighting as compared to the old incandescible lamps—their luminous efficiency is about 2½ times as great, so that they cost less than half as much to operate for the same light output; they operate cooler, since not nearly so much current is dissipated in radiant energy; they produce a quieting, soothing light in a variety of color tones and combinations; they produce a more even distribution of light and are admirably adapted, when used in batteries, for flood lighting. Additionally, when used in batteries, such lamps are particularly well suited for color mixing and blending. Because of their comparatively long tube life, about 2½ times those of present day incandescible tubes, the higher first-cost of such systems is more than offset by the lower operational and maintenance costs.

Despite these many advantages attendant upon these new lighting systems, however, much room for improvement awaits the worker in the art. Hitherto, practically all development work has been directed to the use of fluorescent tubes having incandescible electrodes, incandesced to prepare the tube for striking the arc thereacross. Because of these incandescible electrodes the tubes are known as hot cathode tubes. The auxiliary equipment has all been designed for such tubes, with the purpose of both starting them and operating them on service voltages. Because auxiliaries were thought to be necessary in any event for providing starting voltage surge and for current limiting purposes, the use of transformers has been discouraged, to maintain both initial and operation costs at a minimum.

Furthermore, the presence of incandescible filaments introduces a factor of fragility in the system. When it is recalled that this filament, at each electrode, is essential in preparing the tube for starting, and when it is further recalled that after starting, the arc is maintained across these

very same electrodes, then it will readily be appreciated that despite efforts made to shield these filaments, they are subjected to both ionic and electronic bombardment, and when the arc settles on the filament, to detrimental vaporization as well. Thus, despite the increased longevity of these tubes, their life span is definitely limited. Additionally, inasmuch as these filamentary electrodes are oxide coated, to increase their electron emission, blackening of the tube walls occurs, due to deposit thereon of spent oxide material volatilized off the filaments.

Unstable operation at low temperatures limits the use of known tube lighting systems in outdoor use, or show window display use, to conditions where at least moderate temperatures prevail. Where the temperatures are low, or the tube is exposed to extreme cooling effects, such as winds or the like, the mercury tends to condense out, and the service voltage is found to be insufficient to maintain a steady arc in the rarefied atmospheres prevailing under such conditions. Somewhat similarly these known systems, operating at service voltages of from 120 up to 250 volts supply, are unable to operate at dimmer light outputs because with any appreciable decrease in impressed voltages, the peak voltage of the current supply will approximate or fall below the value at which an arc can be struck across the tubes. Experience shows that the arc extinguishes when the service voltage falls 25% below rated values.

In our application for Patent Serial No. 402,410, filed July 14, 1941, now Patent No. 2,352,073, and entitled Luminescent tube system and apparatus, we have set forth novel means for avoiding in large measure the difficulties and disadvantages pointed out in the foregoing. To that end, we have described in that application a fluorescent tube lighting system in which the operational and maintenance costs are materially reduced below those hitherto current, which has a greater light output per unit of power input than was hitherto possible of achievement, in which the useful life of the tube is greatly increased, and which is capable of satisfactory dimming operation. However, no provision was made in the systems according to that application, for avoiding the detrimental flicker or stroboscopic effect. Our present invention is directed to the substantial decrease of that stroboscopic effect in systems according to our prior invention, and which employ our new high leakage reactance autotransformer for energizing the tube load, and also the production of a high leakage reactance autotransformer which will operate at high efficiencies while energizing such tube circuits. A further object of our invention is to produce a system of fluorescent tube lighting employing our new transformer, all as aforesaid, which system has high power factor, and which is capable of steady and satisfactory operation under cold weather conditions.

While in incandescent lighting operation on alternating current supply, of say 60 cycles, wherein the voltage rises and falls from zero to peak voltage and back again to zero some 120 times per second, the heat retentivity of the tungsten filament is such that the light emission persists during the momentary periods of no voltage, there is no such heat retentivity in the case of fluorescent gas discharge tubes; and even where the service mains are of as high as 60 cycles frequency, the arc strikes and extinguishes during each half cycle as the voltage rises and falls,

first to the striking potential and then below the extinguishing potential. This phenomenon of alternate striking and extinguishing during each half-cycle of current flow gives rise to a perceptible and objectionable flicker, known in the art as stroboscopic effect. Much attention has been directed by the workers in the art to the satisfactory elimination of this source of annoyance.

While the invention as set forth in our copending application presents an effective solution of many of the fluorescent tube lighting problems stated herein, nevertheless, while some effort is made according to that application to correct the system power factor by the use of a large capacity condenser, without, however, disturbing the design of the transformer core to that end, we find that more effective use of the power factor regulating condenser can be obtained if it be disposed asymmetrically of the transformer load system, in one branch of its double current secondary. When so disposed, the condenser not only fulfills its function of power factor regulation, but at the same time, produces a phase unbalance in the double secondary circuits so that when one tube of a battery or bank of tubes is in its period of darkening when the arc is extinguished, the other tube will be energized and an arc struck thereacross.

The use of our high leakage reactance transformer as the power source interposes some interesting questions of design to ensure proper operation with high efficiency. The solution of these problems, forming the subject matter of this application, involves many features of novelty, and accordingly a further object of our invention is to produce a system of fluorescent tube lighting characterized by the minimizing of detrimental flicker or stroboscopic effect, and having high system power factor, as well as to produce a new double circuit, high leakage reactance autotransformer capable of energizing such system at high efficiency while maintaining the current flow thereacross within safe practical limits.

It will be recalled that, to prevent hysteresis loss, the iron core ballasts used in the conventional tube lighting systems have been constructed with cores which are formed of a number of iron laminations. In operation, however, these laminations give rise to a detrimental hum or chattering which has been found to make the use of such systems objectionable in places where extreme quiet ordinarily prevails, such for example, as in homes, libraries and the like.

For the same reasons as controlled in connection with the iron core ballasts, the core of our new transformer likewise is comprised of a large number of iron laminations. In the absence of special precautions our new transformer, too, would therefore give rise to detrimental hum or chattering. An important object of our invention is thus seen to reside in the construction of a transformer which, when in operation, is substantially free from detrimental hum or chattering.

Referring now to the practice of our invention, attention is directed to Figure 1, in which there is illustrated a double-circuit high leakage reactance core-type transformer, having parallel magnetic flux paths, and with its windings connected in autotransformer connection, which transformer is associated in novel circuit arrangement with fluorescent gas discharge tubes connected for cold cathode operation.

The transformer illustratively consists of a core frame, having a central leg 10, outer legs

11, 12, parallel and in spaced relation with, and arranged one on each side of central leg 10, and end pieces 13, 13 and 14, 14 extending at right angles to said legs, and joining them at their respective ends. Mid core portions M1, M2 extend at right angles from outer legs 11, 12, respectively, towards central leg 10. In practice we prefer to form the legs which comprise core portions M1, M2 about .002 inch longer than the ends comprising end pieces 13 and 14, for reasons which will appear hereinafter.

As will be apparent from Figure 2, the transformer core is comprised, in conventional manner and to prevent hysteresis loss, of a large number of lamina 15, shown in the illustrations as being of greatly exaggerated width, for clarity. As has already been suggested these lamina, under the influence of rapidly alternating electromagnetic stress, give rise to a detrimental chattering—a chattering which is also experienced in conventional installations employing iron-core inductive ballasts as current-limiting means, and retarding to a certain extent the acceptance of fluorescent lighting systems in household lighting and in other locales where the prevailing quiet is such that the hum of the inductance is noticeable.

To avoid this chattering we provide silencing clamps transversely about the core, and serving to clamp the lamina firmly together. Preferably we provide such clamps at the mid-portions of the core legs 11 and 12 and at both ends of these core legs. Each of the clamps consists of two substantially U-shaped members 16, 17, each terminating at their free ends in outwardly extending tabs or wings 18, 19. These tabs are bored for the reception of a clamping screw 20. As shown, these clamping screws are each associated with a pressure-distributing washer 21 and a take-up nut 22. When the pair of U-shaped clamps are disposed in opposed relation about the lamina 15, and the screws 20 are tightened down, the clamps engage firmly about the lamina, and substantially all chatter or hum in the transformer core is eliminated, and perfect magnetic butt joints are achieved. Moreover, when clamping pressure is properly exerted, the magnetic reluctance per unit of bearing area is the same at both the mid-core portions and end pieces. It is also advantageous at times to employ C-shaped silencing clamps (not shown) at shunts *Sh*1, *Sh*2, *Sh*3 and *Sh*4.

Spaces for the reception of the transformer windings are formed in the core by the described association relative to each other of the outer and inner legs, the mid-core portions and the end pieces. These spaces, rectangular in shape, are disposed in pairs, one pair on each side of mid-core portions, and the spaces of each pair being disposed on opposite sides of said central leg. The primary coils and secondary coils are disposed in pairs about said central leg, one pair of coils in each said pair of spaces.

A primary coil and a secondary coil constituting each pair, are disposed about the link each parallel flux path. Primary coils P1, P2 are disposed adjacent mid-core portions M1, M2, one of each side thereof. Secondary coils S1 and S2 are disposed adjacent end pieces 14, 13 respectively. Primary coil P1 and secondary coil S1 are linked in magnetic circuit with each other, while primary coil P2 is linked in magnetic circuit with secondary coil S2.

An important feature of our transformer is its high leakage characteristics. To impart these

desired characteristics, in each said magnetic circuit, between each primary and its associated secondary, intermediate magnetic shunts *Sh*1, *Sh*2, *Sh*3, *Sh*4 extend towards but short of central leg 10, thus providing corresponding air-gaps G1, G2, G3, G4 of magnetic reluctance calibrated in accordance with the load for which the transformer is adapted. Shunts *Sh*1, *Sh*2 and air-gaps G1, G2 are associated with primary coil P1 and secondary coil S1, while shunts *Sh*3, *Sh*4 and air-gaps G3, G4 are associated with primary coil P2 and secondary coil S2. The function of these intermediate shunts will be developed at a later point herein.

The primary coils P1, P2 are connected across a source of electrical supply 23, which preferably is an ordinary alternating-current service line. While the primary coils may be parallel or series-connected across this service, in aiding or opposed relation, we prefer to connect them in parallel-opposed relationship, for reasons which will develop. Thus terminal 24 of primary coil P1 is connected through leads 25, 26 and 27 to left-hand side of source 23. Similarly, terminal 28 of primary coil P1 is connected through leads 29, 30 to right-hand side of source.

In like manner, terminal 31 of primary coil P2 is connected through leads 32, 33, to the right-hand side of source 23, while terminal 34 of the primary coil is connected through lead 27 to the left-hand side of the source.

For a given half-cycle of the alternating-current supply, current flows from the right-hand side of source 23, through leads 30, 29 to terminal 28, thence to the left (in Figure 1) through primary coil P1, terminal 24, and thence through leads 25, 26, 27 back to the left-hand side of the source. Simultaneously a parallel circuit may be traced from the right-hand side of source 23 through leads 33 and 32 to terminal 31, thence to the right (in Figure 1) through primary coil P2, terminal 34, and thence through lead 27 back to the left-hand side of the source. During alternate half-cycles of the current supply the direction of current flow through the two parallel paths is of course just the reverse of those just traced. It will be observed that the primary coils are in bucking relation, so that the flux produced thereby tends to flow in opposite directions. This means that the principal body of flux courses the mid-core portions M1, M2, so that they must be designed to serve as conduits for the flux, without saturation effects.

By connecting the primary coils P1, P2 in parallel across the source 23, the full supply potential is impressed across their windings. Where series connection of the primary coils across the energy source prevails, however, each primary coil receives only its share of the total potential output of the supply source. For a given operating voltage, the number of turns in two parallel connected primary windings must be double the number in two series connected primaries, in order to maintain a constant volt per turn relationship. Thus, where a transformer core of particular cross-section is employed and a constant flux density is desired, the number of turns in the primary coil sections must be altered when the particular manner in which the coil sections are connected is changed.

We prefer to connect each secondary coil electrically in series across the network consisting of the two parallel opposed primary coils. With the tubes in series circuit with their corresponding secondary coils, then with the electrical circuits

as described, upon the arc across either tube striking, increased current flows through the associated secondary coil. Thus current necessarily courses the network electrically connected therewith, and splits there across in accordance with the relative impedance of the branches of that network. Since the impedance of the branch including the primary coil magnetically linked with the energized secondary coil increases materially in response to such energization, however, only a small part of this current flows through that branch. By far the larger part flows through the other branch, including the primary coil linked with the other magnetic circuit. Consequently, an increased quantity of flux is generated in this other magnetic path, so that increased voltage is induced in the associated secondary coil. This increased potential, impressed across the terminals of the tube in circuit with that secondary coil, ensures positive striking of arc across that tube.

Thus a circuit may be traced from secondary coil S1, terminal 35, through conductor 30, to junction 29'. The other leg of this circuit includes terminal 38 of the secondary coil, lead 37, tube T1, and lead 36, to junction 25'. At junctions 29' and 25' the secondary coil circuit is connected across the primary coil network. One branch may be traced from junction 29', lead 29, terminal 28, to the left in Figure 1 across primary coil P1, terminal 24, and lead 25 to junction 25'. The other branch may be traced from junction 29', leads 30, 33, 32, terminal 31, to the right in Figure 1 through primary coil P2, terminal 34, leads 27 and 26, back to junction 25'. During the next half-cycle, of course, the direction of current flow is just the reverse of that described.

Since electrical disturbances are produced in tube T1 due to electrical discharges across the gas and mercury vapor filling thereof, and since due to the autotransformer connections, primary coil P2 is in circuit therewith, any disturbance in tube T1 will be carried into the primary circuit. To eliminate this detrimental source of annoying radio disturbance, condenser C1 is connected across the tube to trap the high-frequency oscillations which otherwise would reach the primary circuit. Since condenser C1 need have only a small capacity, say about .005 microfarad, and consequently has a high capacitative reactance, it consumes but little energy, and does not in any way interfere with tube starting. Condenser C1 has no effect on the normal operation of the transformer.

Similarly, secondary coil S2 is electrically connected across the same primary coil network. Circuit may be traced as follows: from terminal 39 of secondary coil S2, lead 40, across condenser 41, tube T2, and lead 42 to junction 33'. The other leg of this circuit includes terminal 44 of secondary coil S2, and leads 43 and 26 to junction 26'. The current flows through one parallel branch from junction 33' up through lead 32, terminal 31 to the right in Figure 1 through primary coil P2, terminal 34, lead 27 to junction 26'. The other branch can be traced from terminal 33', leads 33, 30 and 29, terminal 28, to the left in Figure 1 through primary coil P1, terminal 24, and leads 25 and 26 back to junction 26'. In the next half-cycle of course, the direction of current flow is the reverse of that described.

A large part of the foregoing, with the exception of the silencing clamps, has already been set forth in our said copending application, and does not per se form part of this invention. The novelty herein resides in large measure in the production of a high leakage reactance transformer capable of satisfactory operation with a large capacity condenser disposed in one secondary circuit which results in power-factor correction with substantial minimizing of stroboscopic flicker, while maintaining high system and transformer efficiency.

Condenser 41 serves the dual function of correcting system power factor, and due to its asymmetrical location in one branch of the secondary circuits, produces a phase unbalance so that the arc discharges across the two tubes are out of phase with each other. This minimizes flicker, or what is known as stroboscopic effect, in batteries of two or more lamps.

Condenser 41 is necessarily of considerable size to introduce such balancing impedance. Its capactiy is comparatively large even though it is placed in the high voltage secondary side of the transformer. Because primary coil P1 is connected in series with the condensive branch of the secondary, it has imposed on it not only the 60 cycle frequency of the service mains, but the superposed frequency of the condensive secondary circuit. Thus primary coil P1 must be wound of larger size wire to handle the larger current resulting therefrom.

The high impedance of the condenser 41 tends to resist the coursing of flux through leg 10 and interlinking secondary coil S2. Shunts Sh3 and Sh4 accordingly must be designed to have reluctance such that when the arc across tube T2 is struck, they will at that time by-pass the greater part of the primary flux coursing that magnetic circuit, their design is such that a quantity of primary flux sufficient to induce the required potential in secondary, coil S2 will still interlink that coil. This requirement necessitates designing shunts Sh3 and Sh4 of higher reluctance than shunts Sh1 and Sh2, for if they had an admittance as high as those two shunts, they would by-pass practically all the primary flux around coil S2, leaving the latter practically deenergized. Accordingly, shunts Sh3 and Sh4 are shorter than shunts Sh1 and Sh2, while air-gaps G3 and G4 are wider than air-gaps G1 and G2.

It is to be noted that since secondary coil section S2 has a leading current, the counter electromotive force generated therein is not in phase with that of secondary coil S1. Moreover, the effective value of the primary flux in the condensive branch of the transformer remains higher than in the inductive branch. It follows from this that the primary coils P2 is not required to supply as much flux as does primary coil P1. Advantage is taken of this fact to reduce the size of the transformer by reducing the size of the wire constituting primary coil P2.

It is advantageous at this time to consider the manner in which the flux courses the several magnetic circuits of the transformer, and to consider how the leakage reactance of the transformer serves to limit the current flow through the fluorescent tube load.

Because of the leading current of the capacitative branch flux is first generated in primary section P2. Choosing the path of least reluctance, the flux may be considered as coursing to the right in Figure 1, and splitting into two substantially equal streams (because of the substantially equal physical and magnetic characteristics of the two paths) passes in the direction of the arrows. One part passes up through core portion M1, to the left along leg 11, down through

end piece 13, and the other part passes down through M2 to the left along leg 12, up through end piece 13 and there reunites with the flux from the other path at central leg 10. The reunited flux travels to the right across leg 10 back to M1 and M2 thereby linking P2 and S2. Potential is induced in secondary coil S2, which potential is impressed across the terminals of tube T2. Approximately 90 electrical degrees later, flux starts to flow from primary coil P1, and passing in the direction of the arrows, courses to the left along leg 10. Bucking flux from the condensive branch of the transformer for the first 90 electrical degrees, the flux, choosing the path of least reluctance, branches and flows in substantially equal streams, one stream through core portion M1, to the right along leg 11, down through end piece 14, and reuniting with the other stream of flux in leg 10, courses back to primary coil P1, traversing secondary coil S1. Meantime the other stream courses down through core portion M2, to the right along leg 12, up through end piece 14, and joining the other stream at leg 10, courses back to primary P1.

One of the lamp circuits, usually the condensive branch of the secondary circuit containing lamp T2, may be expected to have an impedance sufficiently lower than the other to strike first, after the passage of but a few current cycles, assuming now a 440-volt supply.

Upon establishment of an arc across the tube, a high current flows through secondary S2. Consequently, this current flows through the primary network, electrically connected therewith. Since impedance builds up in primary coil P2 simultaneously with arcing of tube T2, because coils P2 and S2 are in the same magnetic path, it is the smaller part of this current which flows through coil P2. The larger quantity flows through coil P1, still of low impedance, and induces a larger quantity of flux in the second magnetic path, which flux, interlinking coil S1, induces a higher voltage therein. Tube T1 thus strikes more positively upon application of this higher voltage across its terminals.

Of course, in alternate half-cycles of the energizing current, the direction in which the flux courses is the reverse of that just described. All in all, the time consumed from the closing of the switch across the service mains until both tubes are energized is a matter of but a few current cycles, as contrasted to the some 4 to 6 seconds or more as has been the case with systems currently in use.

As soon as both tubes are energized, steady current flow conditions maintain. The intermediate shunts Sh3—Sh4, formerly paths of high reluctance, are now, due to the build-up of back magnetomotive force generated by secondary coils S1, S2, the paths of least reluctance. In fact, so great is the impedance in coil section S2 due to condenser 41, that were not the air-gaps G3 and G4 so designed as to provide sufficient reluctance, they would by-pass practically all the flux around the secondary coil S2, and would render the latter practically inactive. An important feature of our present invention accordingly, is the design of these air-gaps so that they are made much larger than the air-gaps G1, G2. These air-gaps G3—G4 are calibrated so as to produce nearly unitary power factor, in conjunction with condenser 41.

The flow of larger currents through secondary coil S2 and tube T2 makes it necessary, as pointed out hereinbefore, to provide primary coil P1 of considerably larger gauge wire than that constituting primary coil P2.

More specifically, with steady flow conditions maintaining, flux flows to the right from primary coil P2, splits into two substantially equal and parallel streams and courses one stream up through core portion M1, thence to the left along leg 11. A small amount of flux continues, coursing through secondary S2. To induce just the necessary voltage to maintain tube T2 energized, however, the greater quantity flows down through shunt Sh3, across air-gap G3 to leg 10. The other stream flows down through core portion M2, thence to the left along leg 12, from whence the greater part flows up shunt Sh4 across air-gap G4. The two streams of flux reuniting at leg 10, flow back to the right along this leg, to primary coil P2. A half-cycle later the direction of flow of these flux streams is reversed.

About 90 electrical degrees out of phase with the streams of flux just traced, the flux coursing from primary coil P1 passes to the left in Figure 1, and splitting at core portions M1, M2, passes one stream up and to the right along leg 11, whence the greater part courses down across shunt Sh1 and air-gap G1, and the other stream down and to the right along leg 12, whence the greater part courses up across shunt Sh2 and air-gap G2. All the flux reuniting at leg 10, including that part just sufficient to induce in secondary coil S1 the voltage necessary to energize the tube T1, courses as a single stream to the left in Figure 1, back to primary coil P1. A half-cycle later the direction of coursing of the flux is reversed.

The presence of the condenser 41 results in an increase in the voltage in the condensive circuit. Accordingly, to produce the same open circuit voltage in both secondaries, we find it advantageous to form coil S2 with a few less turns of wire than coil S1. In our 100 watt unit, for example, this difference in potential is found to be 35 volts.

Another embodiment of our electrical system is illustrated in Figure 3. Since the core employed in connection with the embodiment now to be described is much like that employed in the embodiment first described, its description has been omitted from the illustration of Figure 3.

In this new embodiment, primary coils P1, P2 and secondary coils S1, S2 are provided, primary and secondary coils P1, S1 and P2, S2, being paired in separate parallel magnetic circuits. Primary coils P1, P2 are connected together in series-opposed relationship across a source of alternating current supply 23, the winding of primary coil P1 being wound in a direction reverse to that of the winding of coil P2. Secondary coils S1, S2 are associated in autotransformer connection across the primary coils P1, P2, and to avoid the necessity of a large number of turns in the secondary coils to produce rated secondary voltages since the primary coils are series-connected, each secondary coil is in separate series circuit with both primary coils. Thus secondary coil S1, for example, is electrically series-connected through conductor 45, first with primary coil P2 in the opposite magnetic circuit, thence by lead 46 to tube T1, and through lead 47 back to the secondary coil. Similarly, and in separate secondary circuit, an electrical series-circuit may be traced from secondary coil S2 through lead 48, across condenser 49, first to the primary coil P1 in the opposite magnetic circuit, thence through lead 45 to tube T2, through lead 50, back to the secondary coil. If desired, a high resistance R

can be provided about condenser 49, to bring about slow discharge of the condenser, after circuit operation and thus prevent electrical shock.

Just as in the first embodiment, the condensive branch of the secondary has a leading current. The increased current flow from the 60 cycle induced supply plus the impressed harmonies from the condenser action requires the primary coil P1 to be wound of larger size wire.

Because of the impedance interposed by the condenser 49, the back magnetomotive force generated by coil S2 is so great that without proper design of shunts Sh3, Sh4 (Figure 1), practically all the flux would be shunted through the paths comprising these shunts and their associated air-gaps G3 and G4, around coil S2, leaving the latter de-energized. We purposely, therefore, increase the width of air-gaps G3, G4, and hence the reluctance of the shunts of which they form part, to an extent that even after energization of the load across secondary coil S2, and the consequent generation of back magnetomotive force from that coil, enough primary flux interlinks that coil to impress required operating potential across the secondary load.

The condenser 49 produces a condition of phase unbalance in the two secondary circuits, so that one of tubes T1, T2, remains energized while the arc is extinguished in the other tube. By consequence, tube flicker is reduced to a minimum, and no longer constitutes a source of annoyance. Because of the out-of-phase coursing of the two streams of primary flux from the primary coils P1, P2, we find that there is less weakening of the primary flux in the condensive side of the transformer, so that the primary coil P2 can be wound of a smaller size wire.

In this embodiment let us assume a half-cycle of charging current flow such that flux is developed by primary coil P1 in the direction according to the arrows in Figure 1. Then the flux, passing to the left in coil P1 along leg 10, bucks the flux streaming in the opposite direction from primary coil P2. The stream from coil P1 splits into two branches. One branch courses up mid-core portion M1 and to the right along leg 11. Only a small part courses down the high reluctance shunts Sh1. The greater part of it courses down first end piece 14, to the right hand end of leg 10. At the same time, the other branch of flux from coil P1 courses down mid-core portion M2 and to the right along leg 12. Only a very small part of the flux courses across the high reluctance shunt Sh2. By far the greater part moves up second end piece 14 to the right hand end of central leg 10. The two branches of the stream of primary flux reuniting at leg 10, the combined stream now courses to the left along leg 10, back to the primary coil P1. During its passage, it interlinks secondary coil S1 and induces a high potential therein.

In the meantime, flux from primary coil P2, which as indicated by the arrows, flows in a direction opposite from the flux in coil P1, courses to the right in Figure 1 along central leg 10. Here the stream splits, and one branch courses up mid-core portion M1 and to the left along leg 11. Only a small part of the flux courses across high reluctance shunt Sh3. The greater part courses down first end piece 13, to the lefthand end of central leg 10. Meanwhile, the other branch courses down core portion M2 and to the left along leg 12. Only a small part of this flux courses across high reluctance shunt Sh3. The greater part courses up second end piece 13. The

two branches reunite at leg 10. The combined stream then courses back to primary coil P2. During its passage it interlinks secondary coil P2 and generates a high voltage therein.

During the next adjacent half-cycle, the direction of the magnetic flux of course is reversed. It will be sufficient for purposes of illustration, to describe the reverse coursing of flux at this time, for but a single one of the two parallel magnetic paths. Confining our attention, therefore, to the magnetic path about which are disposed coils P1 and S1, coursing of the magnetic flux will be observed to be in a direction opposite to that indicated by the arrows in Figure 1. The flux from coil P1 courses to the right along leg 10, and only a small part of it branches across shunts Sh1 and Sh2, the greater part interlinking secondary splits into two branches. One branch courses up end piece 14 and to the left along leg 11. It is joined by the small quantity of flux which courses shunt Sh1. This branch courses down core portion M1 to central leg 10 and back to coil P1. The other branch courses down second end piece 14 and to the left along leg 12. It is joined by that path of the flux which courses shunt Sh2. This branch courses up core portion M2, to central leg 10 and back to coil P1.

The circuit for one of these tubes, usually for tube T2, will be found to have a lower impedance than the other tube circuit. After several reversals of the secondary current, therefore, the voltage impressed across the terminals of the tubes, excites the gas contents thereof to such a degree of excitation that the arc strikes across the tube. As soon as that happens, a large current begins to flow in the related secondary coil S2. Since coil S2 is electrically in circuit with primary coil P1 and P2, this same current flows through these two coils. Furthermore, since the primary flux depends on the ampere turns in the primary coils, this increased current flow induces increased primary flux. This increase of flux in the second parallel magnetic paths, including secondary coil S1, results in increase in the potential induced in that coil. The elevated potential impressed across tube T1 causes more positive striking of the arc thereacross.

The high impedance which the secondary coil S2 now has, causes by far the greater part of flux from primary coil P2 to shunt along high reluctance shunts Sh3 and Sh4 and their associated air-gaps G3, G4, in large measure by-passing secondary coil S2. The design of the shunts is such that only sufficient flux now interlinks secondary coil S2 to induce therein voltage high enough to maintain arc discharge across tube T2.

Shortly after the arc strikes across tube T2, tube T1 likewise becomes energized. These tubes then operate under steady current conditions, and both coils S1 and S2 are of relatively high impedance. The secondary flux developed therein opposes the primary flux, and in each parallel magnetic path, the greater part of the primary flux now seeks the high reluctance shunt paths, which are now of lesser reluctance than are the paths interlinking the secondary coils.

We are enabled, by use of the system and transformer described, to operate banks of fluorescent gas discharge tubes at high system power-factor in the substantial absence of detrimental flicker or stroboscopic effect in the light emission from the tubes. At the same time, by our novel design of the transformer, we are enabled to employ a high leakage reactance type of autotransformer for energizing the system, with all of its attend-

ant advantages of sturdiness, simplicity, compactness, low operating costs, and elimination of delicate and complicated auxiliaries, while maintaining transformer efficiency at an optimum value.

We claim:

1. In combination, a transformer core of substantially rectangular shape, and comprising a central leg, outer legs extending in spaced, parallel relation therewith and on opposite sides thereof, said outer legs each including end legs integral therewith and extending transversely between said outer and central legs, for forming good magnetic butt joints between them, and with magnetic core shunt means extending between central and outer legs intermediate said end legs, said core being built-up of lamina of magnetic metal; and silencing clamps disposed about said transverse legs at each end of the transformer core, each clamp comprising opposed, substantially U-shaped clamping means short of each other, the free ends of said clamping means terminating in outwardly extending wings, with take-up means interconnecting each pair of wings outwardly of the U-shaped portions for drawing the U-shaped members down toward each other and for forcing the wing portions laterally against the lamina of the transformer core.

2. In combination, a transformer core of substantially rectangular shape, and comprising a central leg and outer legs extending in spaced parallel relation relative to each other, with said outer legs including middle and end legs integral therewith and extending transversely between said outer and inner legs for forming good magnetic butt joints between them, the middle transverse legs being very slightly longer than the end legs, said core being built up of lamina of magnetic metal; and silencing clamps disposed about said transverse legs at the middle and each end of the transformer core, each clamp comprising opposed, substantially U-shaped clamping means terminating short of each other, the free ends of said clamping means terminating in outwardly extending wings, with take-up means interconnecting each pair of wings outwardly of the U-shaped portions for drawing the U-shaped members down toward each other and for forcing the wing portions laterally against the lamina of the transformer core, the tightening of said end clamps about the lamina bending the outer legs so that the end legs are in good butting relationship between outer and central legs.

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