

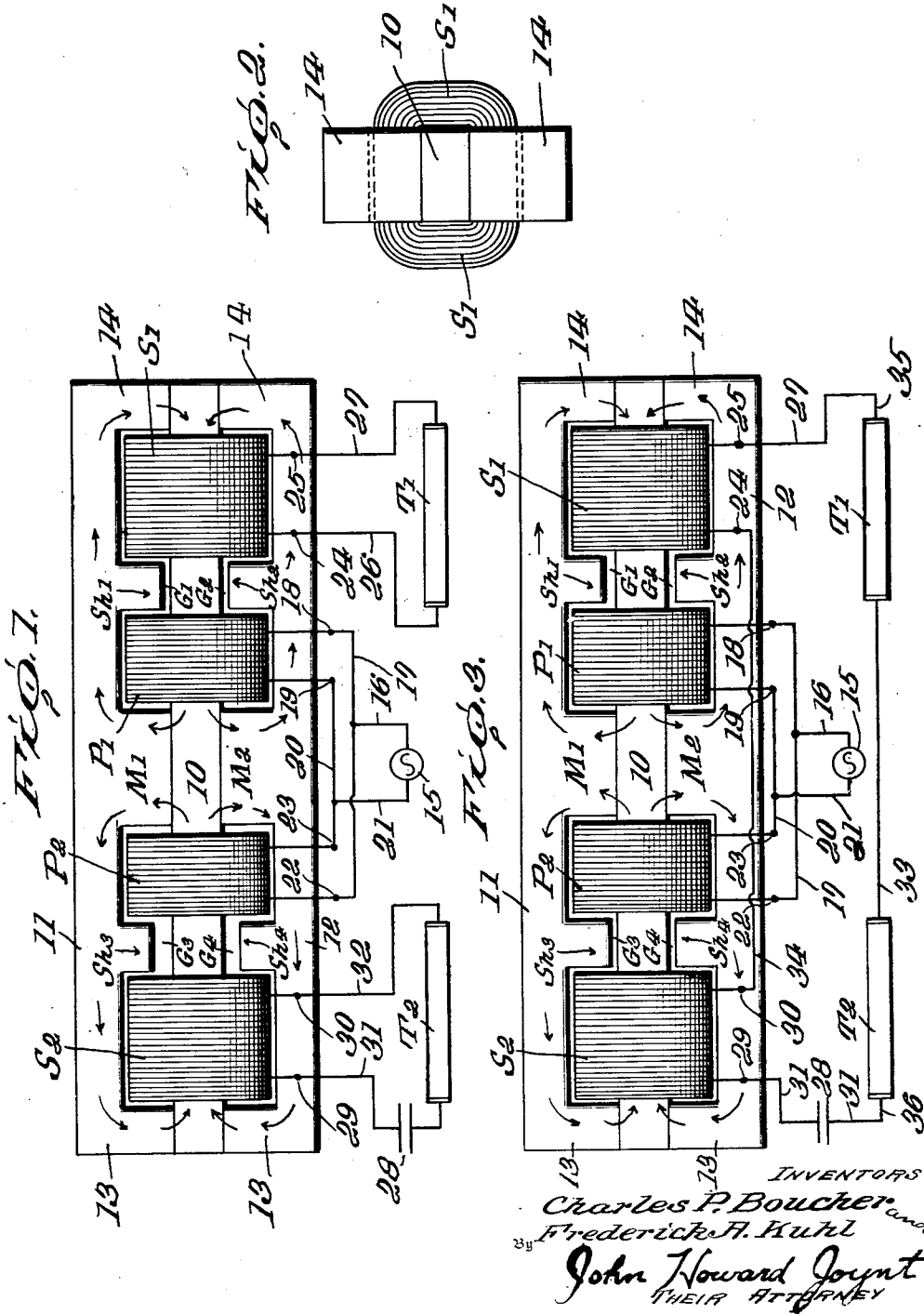
March 6, 1945.

C. P. BOUCHER ET AL

2,370,633

LUMINESCENT TUBE SYSTEM AND APPARATUS

Filed Oct. 21, 1941



UNITED STATES PATENT OFFICE

2,370,633

LUMINESCENT TUBE SYSTEM AND APPARATUS

Charles Philippe Boucher, Paterson, and Frederick August Kuhl, Ridgewood, N. J., assignors to Boucher Inventions, Ltd., a corporation of Delaware

Application October 21, 1941, Serial No. 415,964

11 Claims. (Cl. 315—257)

Our invention relates to fluorescent gas discharge tube lighting, and more specifically concerns a new high voltage fluorescent lighting system, together with a new form of high leakage reactance transformer for energizing the same.

An object of our invention therefore is to produce a new form of high leakage reactance transformer for operating high voltage fluorescent lighting equipment at high efficiency, which is characterized by its compactness, small size, reliability, simplicity, low first cost, and low cost of operation.

Another object is to produce an electrical system capable of operating fluorescent tube lighting at high potentials with steady light emission having only slight flicker, if any, all with a maximum of simplicity and with the substantial absence of fragile auxiliaries, which system is characterized by its high efficiency and low operating costs.

Other objects and advantages will in part be obvious and in part pointed out hereinafter.

Our invention accordingly resides in the several elements and features of construction and operational steps, and the relation of each of the same with one or more of the others, all as described herein, the scope of the application of which is developed in the accompanying claims, forming part of this specification.

In the attached drawing,

Figure 1 is a front, and

Figure 2 a side elevation of one embodiment of our invention, the electrical circuits being indicated diagrammatically.

Figure 3 is a view similar to Figure 1, but illustrating a second embodiment of our invention.

To facilitate thorough understanding of our invention, it may be noted at this point that during the past several years, fluorescent tube lighting has come more and more to replace the known incandescent lighting. Such replacement may be attributed to a variety of causes, among some of the more important of which may be included the large number of pleasing colors which can be obtained, the pleasing flood lighting effects which can be obtained by the effective use of fluorescent tubes, the high efficiency, low operating costs, cool operation and long life as compared with filamentary bulb lighting. Upon the solution of several existing technical problems in a manner acceptable to the art, it may safely be assumed that a more complete realization can be obtained of the widespread possibilities of this style of lighting.

Despite its present-day use in the industries,

in commerce, and in household lighting, however, it soon developed that known fluorescent tube lighting systems were unduly encumbered by the use of many fragile, somewhat complicated auxiliaries, including among them the familiar iron-core ballast, the starting switch and the starting compensator. Fixture manufacture was complicated and costly. These constructions, employing hot cathode fluorescent tubes, were subject to short tube life, unexpected failures of the auxiliaries, and being fragile, required careful handling. Additionally, these known systems were open to the objection that they could not be operated satisfactorily at light intensities lower than those for which the tubes were rated, and that operation under cold weather conditions was unsatisfactory.

In our prior applications, Serial No. 402,410 filed July 14, 1941, and Serial No. 402,411, filed July 14, 1941, we disclosed a new autotransformer construction, and a new electrical system embodying that transformer, which admirably solved many of the problems which hitherto had been considered as somewhat inherent in the art, applicable, however, to those cases when peak voltages of not in excess of about 600 volts were impressed across the tubes which were connected in the secondaries of the new transformers. Long tube life, high operating efficiencies, sturdiness, compactness, high power factor regulation in the absence of noticeable tube flicker, all were obtained. The tubes functioned satisfactorily on dimmer operation, and the arc would maintain under cold weather conditions.

While these autotransformers, because of their simplicity, compactness, low first cost, high efficiency and low operating costs, are admirably suited for operation under those low-voltage requirements which are approved by the Fire Underwriters, practical objections are encountered in their use for energizing high voltage equipment where the tubes require an energizing potential of say 1000 volts or more. Where voltages of such values are involved, or in fact, in excess of 600 volts, the requirements of the Fire Underwriters are more stringent. Transformers producing such secondary voltages must have completely insulated primary coils, i. e., they must be electrically independent of each other. The primary winding cannot be grounded. No electrical connection is permitted between the primary coils and the secondary coils.

Our present invention is directed to the satisfaction of all of the foregoing requirements. A further object of our invention is, therefore, to

produce a thoroughly practical transformer producing high potential at its secondary terminals, and having high leakage reactance characteristics and high efficiency under all operating conditions for which the transformer is designed, which transformer has primary and secondary coils which are electrically separate from and independent of each other, and which are only in inductive association, one with the other. Another object is to produce a high potential fluorescent tube lighting system incorporating such a transformer and being energized thereby, which system is noteworthy because of its safe operating characteristics under prevailing high voltages, which has high power-factor and high efficiency, and which gives satisfactory performance on dimmer operation, and which will both start readily and maintain a steady arc under cold weather operation, and in which detrimental stroboscopic effect or flicker is reduced to a minimum.

According to our new system, the primary coils may be connected either in parallel or series connection, and in either bucking or adding relationship. Parallel connection possesses the advantage that full primary voltage is impressed across each primary coil, so that the secondary output voltage is practically doubled for given transformation ratio. 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 windings must be double the number of turns in two series connected primaries, in order to maintain a constant volt per turn relationship. We have also found it preferable to connect the primary coils in opposed or bucking relationship, such connection resulting in slightly higher efficiencies since when the arc strikes in the load across one secondary coil, assuming that one tube becomes energized before the other, the flux shifts from one side of the transformer core to the other, and aiding the flux already coursing through that side of the transformer core, induces in the corresponding secondary coil a voltage of such magnitude that any load thereacross, separate and apart from the load across the first secondary coil, is immediately energized. Thus with separate or what may properly be termed parallel-connected secondary coils, both tubes constituting the separate loads across the secondaries, even though striking separately, are energized within but a few cycles of current flow, as contrasted with the minimum striking period of 6 to 7 seconds in the case of present-day low-voltage hot cathode systems.

Having reference to the embodiment according to Figs. 1 and 2, this will be seen to comprise a new transformer according to our invention, together with the associated tube lighting system.

The double circuit parallel magnetic path high potential transformer, possessing high leakage reactance illustratively comprises a central leg 10, and outer legs 11, 12 extending in spaced parallel relation to said central leg, on opposite sides thereof. These legs extend longitudinally of the core, and are closed at their ends on each other by end pieces 13, 13 and 14, 14. Mid-core portions M1, M2 serve to interconnect said outer and central legs near their mid-points, thus dividing the transformer core into two groups of parallel magnetic paths, of which the abutting portion of central leg 10 forms a leg common to each path in either of the groups. In the first

group, one such magnetic path may be traced from core portion M1 to the right along leg 11 down end piece 14, across leg 10, and a second parallel path may be traced down the core portion M2, right along leg 12, and thence up core portion 14 and across leg 10. Similarly, in the second group, a magnetic path may be traced up core portion M1, to the left along leg 11, down end piece 13, across leg 10, and a second parallel path may be traced down the core portion M2, to the left along leg 12, up core portion 13 and back to M2 along leg 10.

The end pieces 13, 13 and 14, 14 and the mid-core portions M1, M2 serve to provide pairs of spaces between the central and outer legs, one said pair of spaces being on each side of the mid-core portions M1, M2. Thus there are a pair of spaces for each group of parallel magnetic paths, the spaces of each pair being on opposite sides of the central leg 10. A primary coil and a secondary coil are mounted in said spaces, positioned about central leg 10, with the primary coil adjacent the mid-core portions M1, M2. These primary and secondary coils are electrically independent of each other, and have only inductive association. Intermediate shunts of high leakage reactance extend between each primary coil and its associated secondary coil, from legs 11 and 12 respectively, towards but short of central leg 10. Air-gaps comprising part of the shunt paths thus are formed, having high reluctances calibrated in accordance with the loads for which the transformer is designed. More specifically, in the first group of parallel magnetic paths, primary coil P1 and secondary coil S1 are positioned about central leg 10, with primary coil P1 adjacent mid-core portions M1, M2. Intermediate shunts Sh1, Sh2 extend between said primary and secondary coils, which are electrically independent of each other, from outer legs 11 and 12, respectively. They extend towards but short of central leg 10, providing high reluctance air-gaps G1, G2, respectively, calibrated as aforesaid.

In like manner, primary coil P2 and secondary coil S2 are similarly disposed in the second group of magnetic paths, with the primary coil adjacent mid-core portions M1, M2. Shunts Sh3, Sh4 extend between the primary and secondary coils, from legs 11 and 12, respectively. They terminate short of central leg 10, providing air-gaps G3, G4, of high leakage reactance calibrated according to the load for which the associated secondary is designed.

A source of alternating current supply 15, which may constitute the ordinary service mains, serves to energize the primary coils P1, P2. While as has been suggested hereinbefore, these primary coils may be connected in either series or parallel connection and in adding or opposed relation, we here connect them in parallel-opposed relation. As a result of this connection, the full service potential is impressed across each secondary coil. Additionally with the primary coils opposed or bucking each other, and assuming parallel secondary connections, each with separate load, then when the load increases across one secondary coil, there is a shift of flux from that magnetic circuit to the other, aiding the primary flux therein, and increasing the voltage induced in its associated secondary coil.

Thus the primary coils are branched across the source 15, and parallel energizing circuits may be traced as follows: from the right side of source 15, through leads 16 and 17 to terminal

18, thence to the left through primary coil P1, terminal 19 and leads 20 and 21, back to the left side of source 15. The second circuit may be traced from right side of source 15, leads 16 and 17, to terminal 22, thence to the right through primary coil P2, terminal 23, and through leads 20 and 21 back to the left side of source 15. Of course during the next subsequent half-cycle of current flow, the direction by which the charging current traverses the primary circuits is exactly the reverse of the paths just traced.

While as has been set forth, either series or parallel (electrically independent) secondary circuits can be employed. In this present described embodiment we employ separate secondary circuits, each circuit being electrically independent of the other and each energizing a separate load.

Because of the inductive nature of the load across the service mains represented by the transformer and system, a lagging current is drawn, reducing the load power factor appreciably. This requires considerable investment on the part of a utility company. Equipment of increased wire sizes and larger dimensions are required, and since while the company charges only for the actual wattage consumed by the user, such company in reality operates on the basis of current demand. It will be seen that low system power factor quickly results in a substantial increase in cost to the utility. Similarly, and since in many industrial and commercial installations, the rates assessed by the utilities are dependent upon the power factor drawn by the particular consumer, and additionally, since low power factor requires increased investment on the part of the consumer from the service connections into his lines, power factor correction is to be resorted to whenever possible.

Accordingly, we employ a power-factor regulating condenser of capacity sufficient to restore the system power factor to approximately unity, and while the desired power factor correction can be obtained by placing the condenser at any point in the primary or secondary leads, we find that by disposing the condenser in one parallel secondary circuit, an additional valuable result is obtained. By so locating the condenser, the circuit in which it is connected draws a leading current, and hence is appreciably out of phase with the neighboring parallel secondary circuit.

Now, each time that the energizing alternating current rises from zero value during one-half cycle of current flow, up to its peak value, and then falls back again to zero, before duplicating that phenomenon in the opposite direction, the arc across the tube strikes as the voltage reaches its striking potential, and then extinguishes, when the voltage falls through its extinguishing potential. Thus the arc strikes and extinguishes during each half-cycle, or 120 times per second for 60-cycle energizing current.

A somewhat similar phenomenon is also experienced in the case of the conventional filamentary lamp, when used on alternating current supply. Here the voltage rises and falls through zero 120 times per second on 60-cycle supply. However, the temperature inertia of the filament is such that it remains incandescent during the no-voltage periods of the supply source. Thus there is no appreciable change in the light emission, and it remains relatively constant.

In the case of the arc discharge tubes, however, there is no heat or temperature retentivity across the medium of the arc. As soon as the energizing voltage falls below the extinguishing po-

tential, therefore, the tube becomes dark, and remains so until the arc is again struck during the next half-cycle. It is only the inertia of the human vision that gives the illusion of persistence of illumination, and there is sensed by the eye an objectionable flicker, known as stroboscopic effect.

By placing one secondary circuit out of phase with the other, we are enabled to reduce this stroboscopic flicker to a minimum because at such times as the tube in one secondary circuit is dark, the tube in the other circuit will be energized, and vice versa. Substantially constant light emission results.

Again having reference to Fig. 1, therefore, it will be seen that the tube T1 is series-connected directly across secondary coil S1. Tube T1 may be considered to be a high voltage fluorescent gas discharge tube, containing a suitable filling of inert gas such as argon, neon or the like, together with a measured small quantity of mercury, and being interiorly coated with a suitable light-emitting fluorescent salt. While the gas pressure of conventional hot-cathode tubes may be at about 4 mm. of mercury, requiring an energizing potential of about 14 volts per inch of length, we prefer to operate our tube at a pressure of from about 6 to 10 mm. of mercury. The tube may, for example, have a length of say 6 feet, a diameter not over 25 millimeters, and require a terminal potential of about 1000 volts. Tube T1 is connected by leads 26, 27 directly across terminals 24, 25 of secondary coil S1.

Similarly, a tube T2 of like characteristics as tube T1, may be connected in series with condenser 28, across terminals 29, 30 of secondary coil S2, by means of leads 31, 32.

Condenser 28 is of capacity sufficient to restore the system power factor to approximately unity value. The comparatively high voltage of the secondary circuit makes it possible to achieve this result while retaining the size of the condenser within practical limits.

Condenser 28 giving rise to a leading current in secondary coil S2, the back magnetomotive force from secondary coil S2 is out of phase with that from secondary coil S1, assuming the loads across each said coil to be energized. By consequence, the primary flux from coil P2 is not weakened to the same extent as is that from primary coil P1. Accordingly, since not so much primary flux is required, primary coil P2 can be wound of smaller diameter wire than otherwise would be the case, accomplishing a saving both in initial investment and in dimensions of the transformer.

Additionally, since the condenser causes increase in voltage in the corresponding secondary coil S2, then to achieve the same open circuit voltage across both secondary circuits, we wind the secondary coil S2 of a few less turns of wire than we do secondary coil S1.

It will be interesting to develop at this point, the manner in which the primary or energizing flux courses the magnetic core, in response to closure of primary coils P1, P2 on energy source 15. Because of leading current required by condenser 28, flux will course first from primary coil P2, and we will assume that during the half-cycle under discussion, the flux courses in the direction of the arrows to the right of the coil, along leg 10. There splitting into two streams, one stream of flux courses up along core portion M1, to the left along leg 11, and choosing the path of minimum reluctance, passes down end piece 13 to central leg 10. At the same time, the other

stream of flux courses down mid-core portion M2, to the left along leg 12, and choosing the path of least reluctance, passes up along end piece 13 to leg 10. The two streams reuniting at leg 10, course together to the right along leg 10, to primary coil P2. During this passage, the entire body of flux interlinks the secondary coil S2, inducing full secondary voltage therein. During the next subsequent half-cycle, of course, the direction of coursing of flux is reversed, and in such case the flux courses to the left along central leg 10, interlinking secondary coil S2, and then splits into two streams. One stream courses up along end piece 13, to the right along leg 11, and down core portion M1, where it joins at leg 10 with the other flux stream and courses back to the primary coil P2. The other stream likewise flows in a direction opposite to the arrows, down end piece 13, to the right along leg 12, up mid-core portion M2, to primary coil P2.

About 90 to 115 electrical degrees later, flux starts to flow from primary coil P1. Passing to the left during the assumed half-cycle, along 10, it splits into two streams when it meets the body of primary flux from coil P2. One stream courses up through core portion M1, to the right along leg 11, and selecting the path of minimum reluctance, courses down end piece 14 to central leg 10. The other stream courses down mid-core portion M2, to the right along leg 12, and choosing the path of least reluctance, courses up end piece 14 to central leg 10. The two streams of flux there uniting, courses as a single stream, back along leg 10 to the primary coil P1. During its passage along leg 10, the flux interlinks secondary coil S1, inducing therein the required high voltage.

During the next subsequent half-cycle, the direction of coursing of flux is, of course, just the reverse of that traced. The path of the flux at such times, contra to that shown by the arrows, can be traced just as in the case of the magnetic circuit embracing primary coil P2 and secondary coil S2.

Were the primary coils to be connected in aiding rather than bucking, relationship, then the legs 10, 11, 13 would have to be formed of larger cross-sectional area; and since the mid-core portions M1, M2 would be traversed only by out-of-phase flux from the primary coils, their cross-sectional area would be appreciably reduced.

Despite the fact that the tubes are conventionally selected of like electrical rating, almost invariably it will be found that one parallel secondary circuit and its associated tube will have an impedance slightly less than that of the other. In this instance, it may reasonably be expected that the tube T1, in the inductive side of the transformer, will be of lesser impedance. Because of its lower impedance, the impressed voltage will be sufficient to strike the arc across this tube first, the tube being energized in but a fraction of a second, after the passage of only a comparatively few current cycles.

As soon as this tube strikes, a counter-magnetomotive force, opposing the primary flux, is developed by the secondary coil S1. Since the primary flux seeks the path of least reluctance, and splits in proportion to the admittance of the several available paths, then with proper design of intermediate shunts Sh1, Sh2 and associated air-gaps G1, G2, only so much primary flux interlinks secondary coil S1 as is required to induce therein a voltage sufficient to maintain the arc discharge across tube T1. The remainder of the

primary flux courses the paths of lesser reluctance. Part will flow across shunts Sh1, Sh2 and air-gaps G1, G2, but by far the major part of this primary flux makes what we term a flux shift, and courses over to the other magnetic path, and joins with the flux from primary coil P2. Since the voltage induced in the secondary coil S2 is a function of the number of turns in the secondary coil and the quantity and rate of change of the flux coursing through those turns, the increased primary flux aids in inducing a voltage of such elevated value in the secondary coil S2 that the arc across tube T2 is quickly struck.

As soon as both the tubes strike, then steady current flow conditions maintain, and the primary flux still follows the path of least reluctance. Only so much flux courses the several secondary coils as is required to induce therein the secondary voltages required to maintain the arcs across tubes T1 and T2.

Assuming the momentary half-cycle to be such as to cause primary flux to flow from the primary coils in the direction of the arrows, flux from coil P1 flows to the left along leg 10, splits into two streams and courses, one stream up mid-core portion M1 and to the right along leg 11, and the other stream down mid-core portion M2 and to the right along leg 12. Part of the first stream continues on down end piece 14 and back to the left along leg 10, interlinking secondary coil S1. By far the greater part, however, courses down across intermediate shunt Sh1 and air-gap G1, back to primary coil P1, this path now having the least reluctance because of the back secondary flux induced by coil S1. Similarly, part of the second stream of flux courses up end piece 14 and back along leg 10 to coil P1, interlinking secondary coil S1 during its passage. The greater part of this primary flux, however, choosing the path of least reluctance, courses up through shunt Sh2, across air-gap G2, and through leg 10 back to primary coil P1. Thus most of the primary flux is shunted around secondary coil S1, and only the quantity of flux interlinks that coil which is necessary to induce therein the required secondary voltage.

At the same time, the flux from primary coil P2 flows to the right along leg 10, and splitting, flows one stream up mid-core portion M1 and to the left along leg 11, and the other stream down mid-core portion M2 and to the left along leg 12. Part of the first stream courses down end piece 13 and back along leg 10 to primary coil P2, interlinking secondary coil S2 during its passage. The greater part, however, choosing the path of least reluctance, courses down through shunt Sh3, across air-gap G3 and back to primary coil P2.

Similarly, part of the other stream courses up through end piece 13 to the right along leg 10 to primary coil P2, interlinking secondary coil S2, during its passage. The greater part of this stream of primary flux, however, chooses the path which now is of least reluctance, and courses up through intermediate shunt Sh4, across air-gap G4, and back to primary coil P2. In this manner, the secondary coil is by-passed, and the greater part of the primary flux is shunted around it. Only sufficient flux courses through the secondary coil to induce therein the voltage required to maintain the arc across tube T2.

The design of the air-gaps G3 and G4 forms an important feature of our invention. The condenser 28 gives rise to high impedance in the secondary circuit including coil S2. Accordingly,

but little flux tends to interlink this coil. If the shunts Sh3 and Sh4 are not constructed of sufficiently high reluctance, therefore, then when the tube T2 strikes, the shunts would by-pass such a large proportion of the primary flux that the remaining primary flux available for interlinking secondary coil S2 would be insufficient to maintain the required energizing potential across the tube load, and the arc would extinguish. Accordingly, these shunts should include long air-gaps, or where desired, the shunts may be substantially or completely omitted.

To permit understanding of the voltage conditions maintaining in the various parts of the system according to the embodiment under discussion, we may say that with a 115 volt source 15, supplying 1.8 amperes, primary coil P1 is found to draw a current of 1.28 amperes, while primary coil P2 draws 0.92 ampere. Secondary coils S1 and S2 are each found to have a terminal voltage of 900 volts induced thereacross, while the voltage across the terminals of condenser 28 is found to be 1250 volts.

The tubes in our new system are found to have better starting characteristics, even in cold weather. For example, hot cathode, low voltage tubes, the mercury condenses out and operation becomes unstable when the surrounding atmosphere falls as low as 52° F., tubes according to our invention will operate at stable arc discharge at atmospheric temperatures which are much lower. We find that at low temperatures the six foot tube draws about 60 milliamperes current, as contrasted with 80 milliamperes for operation at about 70° F. at 1000 volts secondary potential.

In actual practice approximately unity power factor is obtained by balancing condenser 28 against the lengths of shunts Sh1—Sh4. These values are standardized as the result of experiment, so that a satisfactorily operating transformer results.

In this embodiment, with parallel secondary circuits, wherein the condenser is connected in one secondary leg, the objectionable stroboscopic flicker is minimized. The capacity of condenser employed can be used to regulate the tube output. The larger the condenser, the greater will be the tube output. In other words, system impedance decreases with increase in condenser capacity.

In the embodiment according to Figure 3, we disclose a series connection of the transformer secondary circuits. In this embodiment, the several parallel magnetic paths are symmetrical with respect to each other. While with the use of this series connection both tubes strike simultaneously, we find that for some unknown reason, less voltage than usual per tube is required to strike the arc across the tubes. For example, the arcs will be struck across two tubes, each of 6-foot length, connected across secondaries, each developing 900-volt secondary voltage output with 115-volt supply, at but 72-volts primary input. Even less primary voltage is required when the condenser is disposed in the primary circuit.

Somewhat according to the construction illustrated in Figure 1, the transformer core of the embodiment illustrated in Figure 3 consists of a central, longitudinally extending leg 10, together with outer legs 11, 12, extending in parallel, spaced relation to leg 10, one on each side thereof. End pieces 13, 13 and 14, 14 and mid-core portions M1, M2 serve to interconnect said outer and inner legs at their ends and adjacent their centers, respectively. The mid-core por-

tions will be seen to divide the transformer core into two groups of parallel magnetic paths of which the adjacent portion of central leg 10, forms a leg common to each path in either of the groups. In the first of these groups, one magnetic path may be traced from core portion M1, to the right along leg 11, down through first end piece 14, across leg 10, back to M1, and a second parallel path may be traced from M2, through the outer leg 12, up through end piece 14, across central leg 10 and back to M2. Similarly, in the second group a magnetic path may be traced up through core portion M1, to the left along leg 11, down through first end piece 13, across the leg 10, back to core portion M1, and a second parallel path is traced from M2 to the left along leg 12, up through core portion 13, and along leg 10 back to core portion M2.

The end pieces and mid core portions serve to provide a pair of spaces in each said parallel magnetic path, the spaces of each pair being provided on opposed sides of central leg 10.

A primary coil P1 and a secondary coil S1 are disposed about central leg 10 in the spaces provided in the first parallel path, while a primary coil P2 and a secondary coil S2 are similarly disposed in the spaces provided in the second parallel magnetic path. In each instance, the primary coils are disposed adjacent the mid core portions M1, M2.

Intermediate shunts of high leakage reactance are provided in pairs in each magnetic path, disposed between the corresponding primary and secondary coils. These shunts extend from the respective outer legs toward but short of the central leg, thus providing air-gaps of high reluctance calibrated according to the particular load for which the transformer is designed. Thus, intermediate shunts Sh1 and Sh2 extend between primary and secondary coils P1, S1 from outer legs 11, 12 respectively, towards but short of central leg 10. The air-gaps, G1, G2 are thus formed between the corresponding intermediate shunts and the central leg 10. In like manner, shunts Sh3 and Sh4 extend from outer legs 11, 12 respectively, between primary and secondary coils P2, S2, towards but short of central leg 10, providing therebetween high reluctance air-gaps G3, G4, respectively. The primary and secondary coils are electrically independent and are solely in inductive relation with each other.

As has already been developed in connection with the embodiment according to Figure 1, the primary coils may be connected either in parallel or in series across source of energy 15, and may be disposed in either adding relation on the one hand, or opposed or bucking relation, on the other hand. The various advantages attendant upon these several modes of connection have already been discussed in some detail, and need not be repeated here. Suffice it to say that we prefer to connect the primary coils in parallel-opposed relation across the energy source 15. Thus, a charging circuit for primary coil P1 may be traced from the right-hand side of the source 15 of alternating-current energy supply, through leads 16 and 17 to terminal 18, thence to the left through primary coil P1, terminal 19, and leads 20, 21, back to the left-hand side of the energy source 15. A corresponding parallel charging circuit for primary coil P2 may be traced from the right-hand side of source 15, through leads 16 and 17 to terminal 22, thence through the primary coil P2 to the right, terminal 23, and through leads 20 and 21 back to the left-hand

side of energy source 15. It will of course be understood that current flow maintains in the direction described only during the assumed half-cycle of charging current, and that the direction of flow will be just the opposite during the next following half-cycle of current flow.

Across the terminals of the secondary coils S1, S2 are provided in series circuit, fluorescent gas discharge tubes T1, T2, each of which will normally be of such length that voltages are required across their terminals in excess of about 600 volts. For example, the tubes illustrated will normally be about six feet long, requiring about 1000 volts each. It will of course be understood that the selection of tube length is but a matter of routine design, once the fundamental aspects of our invention are disclosed. The tubes may be of somewhat conventional design, containing a filling or argon, neon or similar suitable inert gas, together with a small quantity of mercury. The tubes are lined interiorly with a suitable light-emitting fluorescent salt, as is typical of such tubes. A condenser 28 is a likewise provided in the series-connected secondary circuit of capacity sufficient to correct the system power-factor to approximately unity value.

A second secondary circuit can be traced from right-hand terminal 25 of secondary coil S1, through conductor 27 to tube T1, across lead 33 to tube T2, thence through lead 31 to condenser 28, through lead 31 to terminal 29, thence to the right through secondary coil S2, terminal 30, lead 34, terminal 24, and back to the right through secondary coil S1. The location of condenser 28, of capacity sufficient to correct the system power factor, in series circuit results in its having no influence on the phase relations between the primary and secondary coils. Thus it exercises no effect on any tube flicker which may occur. The loads across the second secondary coils being substantially equal in the present embodiment, both primary coils and both secondary coils are of like characteristics, as are the shunts SH1-SH4 and the air-gaps G1-G4.

In the embodiment under discussion it makes no particular difference whether the primary coils are connected in aiding or opposed relationship, inasmuch as there is no opportunity for flux shift to occur. Since both tubes have to strike before the secondary circuit can become energized, and since the secondary circuit becomes energized as a unit, back magnetomotive forces are created simultaneously in the respective secondary coils, so that a low reluctance path interlinking the energized secondary coil, a condition necessary for flux shift, is not present in the embodiment undergoing discussion.

For an assumed half-cycle of current flow in which the primary magnetic flux flows initially substantially in the direction of the arrows, and as illustrative of the conditions before the arc is struck across the series-connected tubes as shown, let us consider the case of the primary coil P1. Primary flux generated therein may be assumed to flow to the left along leg 10. When it reaches the region of the common leg of the second parallel path previously referred to, the stream of flux here encounters and opposes (in the described embodiment, wherein the primary coils are connected in bucking relationship) the flux from the primary coil P2, which is now in phase with the body of flux from primary coil P1. Splitting into two streams which are of substantially equal value, because of the symmetrical construction of the transformer core

and windings, one stream courses upwardly through core portion M1, to the right along leg 11, and choosing the path of least reluctance, courses down end piece 14 to common leg 10. At the same time, the other stream courses through core portion M2 and to the right along leg 12. Likewise choosing the path of least reluctance, the stream of flux courses up end piece 14 to central leg 10. The two streams of flux reuniting in leg 10 at the right of the secondary coil S1, the combined streams course through the deenergized coil along leg 10, back to primary coil P1.

At the same time, the primary flux from coil P2 passes to the right along leg 10 and splitting into two streams at the common magnetic leg comprised of core portion M1, M2 and the adjacent portion of central leg 10, one stream flows up core portion M1, to the left along leg 11, and choosing the path of least reluctance courses down end piece 13 to central leg 10. The other stream simultaneously courses down core portion M2, to the left along leg 12, and likewise choosing the path of least reluctance, courses up along end piece 13 to central leg 10. The two streams of flux reuniting at leg 10 at the left of secondary coil S2, the combined stream now courses along leg 10 to the right, back to primary coil P2. During such passage, the flux interlinks the deenergized secondary coil S2. At these times a high voltage is induced in the respective secondary coils S1, S2, which is additive in nature. Of course, during the alternate half-cycles of the current flow, the direction of coursing of magnetic flux is exactly the reverse in each parallel magnetic path, of that described.

It may be noted here that were the primary coils to be connected in aiding relationship, the main flux path would be along outer legs 11 and 12, with the combined flux streams flowing through central leg 10. There would be in effect only a single magnetic path, and the core portions M1, M2, since they would be required to accommodate only that flux of one magnetic circuit which is out of phase with the flux in the other magnetic circuit, could be greatly minimized in cross sectional area, or even, for all practical purposes, entirely eliminated.

After the passage of but a few cycles of the charging current, the voltage impressed across the outermost terminals 35, 36 of the tubes T1, T2, representing the summation of the potentials induced in the secondary coils S1, S2, excites the two tubes to such an extent that the arc strikes across each tube, in a matter of but a fraction of a second after closure of the primary coils on the service mains.

A conductive circuit is now completed through the secondary coils and the tubes and condenser in series connection therewith. Back magnetomotive force is immediately developed in each secondary coil, resulting in a secondary flux which opposes the flow of primary flux through the particular magnetic circuit interlinking the secondary coils. The primary flux, seeking the paths of least reluctance, now by-passes in large measure the metallic circuits interlinking the secondary coils, and by far the larger part of the primary flux courses through the high reluctance intermediate shunts SH1 and SH2 and associated air-gaps G1 and G2, on the one hand, and the high reluctance intermediate shunts SH3 and SH4 and the associated air-gaps G3, G4, on the other hand. The reluctance of these intermediate shunts is calibrated to values

whereby, with the exception of just sufficient flux to induce in the secondary coils a potential sufficient to maintain the arc discharge across the tubes in the secondary circuits, they by-pass all the primary flux around the secondary coils. Since the condenser 28 has no effect on the phase relationship of the tubes T1, T2, because of its connection in a single series-connected secondary circuit, and since it is desirable that the secondary coils S1, S2 divide the secondary load equally therebetween, we design the primary coils P1, P2 of the same electrical characteristics, and treat similarly the secondary coils S1, S2. Because of this symmetrical construction and connection, shunts SH1—SH4 are all of the same reluctance as are the air-gaps G1—G4.

As has already been suggested, the series-connection of the tubes as described possesses the advantage that for some unknown reason, less voltage per tube is required to strike the arc thereacross. Thus, in the example under discussion, wherein the induced potential at the terminals of each secondary coil is about 1000 volts for 115 volt primary input, we find that 72 volts impressed, across the primary coils is sufficient to cause two series-connected tubes, each six feet long, to strike with certainty, even less striking voltage across each tube is required where the power-factor correction condenser is disposed in the primary circuit.

Just as in the case of the parallel-connected or separate secondaries, the condenser may be employed in the series connected secondary to regulate the tube output. The differences exist, however, that where in the parallel connection a larger condenser is employed to ensure higher tube output, in the present arrangement herein we employ a smaller condenser to accomplish that end. Where in the parallel connection the system impedance decreases with increase in the size of the condenser disposed in one branch, here where the condenser is disposed in the complete secondary circuit, the system impedance increases with increase in the capacity of the condenser.

Our new invention, of which two preferred embodiments have been described for purely illustrative purposes, and in which the primary and secondary coils are electrically independent of each other, permits the use of a high leakage reactance transformer with comparatively high voltage fluorescent gas discharge tubes. Thus, the advantages attendant upon the elimination of the use of fragile and complicated auxiliary equipment can be obtained even in those cases where the required voltages are such that the Fire Underwriters prohibit the use of autotransformers. Both costs of fixtures and the cost of installing the auxiliary equipment in such fixtures are considerably reduced as compared with known hot cathode equipment.

The system is absolutely safe from the standpoint of electrical installation, and gives rise to high system power-factor, with at least in one embodiment, the reduction to a minimum of detrimental stroboscopic effect. High efficiency of both the system and the transformer are obtained with the life expectancy of both tube and transformer brought to optimum values. In the first described embodiment, upon striking the arc across the tube load in one parallel secondary circuit, the construction of the transformer is such that the flux in the one parallel branch thereof shifts, and aids in the production of a momentarily increased voltage in the second par-

allel circuit, ensuring rapid energization of the tube load therein.

We claim:

1. A high leakage reactance transformer comprising a longitudinally extending central leg; outer legs disposed in spaced parallel relation to said central leg; end pieces and mid core portions interconnecting said outer and central legs at their ends and adjacent their centers, respectively; pairs of intermediate high leakage reactance shunts, each including an air-gap of high reluctance calibrated in accordance with the particular load for which the transformer is designed, disposed on each side of said mid core portions and extending from respective outer legs towards but short of said central legs; a primary coil and a secondary coil disposed around said central leg on each side of said mid core portions, with each primary coil disposed adjacent said mid core portions and with each pair of intermediate shunts separating the corresponding primary and secondary coils, the intermediate shunts by-passing the primary flux around the corresponding secondary coil upon increase of the load energized by said coil, and the air-gaps in a first pair of intermediate shunts being of greater reluctance than the air-gaps in the second pair, to accommodate a secondary load of greater capacitative reactance.

2. A high leakage reactance transformer comprising a longitudinally extending central leg; outer legs disposed in spaced parallel relation to said central leg; end pieces and mid core portions interconnecting said outer and central legs at their ends and adjacent their centers, respectively; pairs of intermediate high leakage reactance shunts, each including an air-gap of high reluctance calibrated in accordance with the particular load for which the transformer is designed, disposed on each side of said mid core portions and extending from respective outer legs towards but short of said central leg; a primary coil and a secondary coil disposed around said central leg on each side of said mid core portions, with each primary coil disposed adjacent said mid core portions and with each pair of intermediate shunts separating the corresponding primary and secondary coils, the intermediate shunts by-passing the primary flux around the corresponding secondary coil upon increase of the load energized by said coil, and the air-gaps in a first pair of intermediate shunts being of greater reluctance than the air-gaps in the second pair, to accommodate a secondary load of greater capacitative reactance, the corresponding secondary coil being wound of a slightly fewer number of turns, while the corresponding primary coil is wound of smaller diameter wire than are the primary and secondary coils, respectively, in the second magnetic circuit.

3. A fluorescent tube lighting system, comprising a high leakage reactance transformer having a primary winding and two secondary windings mounted on a core with the secondary windings independent of the primary winding, a fluorescent gas discharge tube connected in circuit with the first of said secondary windings, another fluorescent gas discharge tube connected in circuit with the second of said secondary windings, shunt core means between the primary winding and said first secondary winding to limit the current therein, shunt core means of higher reluctance than the previous shunt core means between the primary winding and said second secondary winding to limit the current therein

somewhat, and a condenser in circuit with said second secondary winding and the tube connected thereto to further limit the current therein to a value substantially that of the first secondary winding.

4. A fluorescent tube lighting system, comprising a high leakage reactance transformer including a core having two parallel magnetic paths with a leg in common, a primary winding mounted on the core and linking both of said parallel magnetic paths, two secondary windings mounted on the core, one linking each of said parallel magnetic paths, a fluorescent gas discharge tube connected in circuit with one of said secondary windings, a second fluorescent gas discharge tube connected in circuit with the other of said secondary windings, core means shunting one only of said parallel magnetic paths at a point magnetically between the primary winding and one of said secondary windings to limit the current in said winding, with the other secondary winding positioned closely adjacent the primary winding and with no magnetic core shunt therebetween, and a condenser in circuit with said other of said secondary windings and the tube connected thereto to limit the current in that winding to substantially that of the first mentioned secondary winding.

5. A fluorescent tube lighting system, comprising a high leakage reactance transformer including parallel magnetic paths having a leg in common, each said magnetic path having therein high leakage reactance shunts including air-gaps, and interlinking primary and secondary coils electrically independent of each other, disposed, one coil on each side of said magnetic shunts, with the primary coils disposed adjacent and on opposite sides of said common leg, the electrical circuit of each secondary coil being independent of the other; a source of alternating-current electrical supply across which said primary coils are connected; a like fluorescent gas discharge tube in each secondary circuit; and a power-factor regulating condenser disposed in one secondary circuit and producing a phase-unbalance and limitation of current flow, the air-gaps in the path which energizes the secondary coil having the condenser in circuit therewith being of higher reluctance than the air-gaps in the other parallel path.

6. In combination a high leakage reactance transformer including a core providing parallel magnetic paths, high leakage reactance shunts disposed in each said magnetic path, and primary and secondary windings mounted on the core with a primary coil and an electrically independent secondary coil interlinking said magnetic path, one coil being disposed on each side of the magnetic shunt with the reluctance of one shunt substantially exceeding that of the other; a source of alternating-current electrical energy across which said primary coils are connected; and a condenser connected in series with the secondary coil with which the shunt of higher reluctance is associated to limit the current in said winding to substantially the same value as that had in the other secondary winding by reason of the magnetic shunt associated therewith.

7. A high leakage reactance transformer including, in combination, a primary winding and two secondary windings mounted on a core with the secondary windings independent of the primary winding and of each other, shunt core means between primary winding and one of said second secondary windings, shunt core means of higher reluctance than the previous shunt core means between the primary winding and a second secondary winding.

8. In combination, a core providing parallel magnetic paths, high leakage reactance shunts disposed in each said magnetic path, primary and secondary coils mounted on the core with a primary coil and an electrically independent secondary coil interlinking each magnetic path, one coil being disposed on each side of the magnetic shunt with the reluctance of one shunt substantially exceeding that of the other, and a condenser connected in series with said secondary coil associated with the magnetic shunt of greatest reluctance to limit the current therein.

9. In combination, a primary winding and two secondary windings mounted on a core with the secondary windings independent of the primary winding and of each other, shunt core means between primary winding and one of said second secondary windings, shunt core means of higher reluctance than the previous shunt core means between the primary winding and a second secondary winding and a condenser connected in series with said second winding to limit the current therein.

10. In combination, a primary winding and two secondary windings electrically independent of each other mounted on a common core, shunt core means magnetically between the primary winding and one only of said secondary windings to limit the current therein, with the other secondary winding positioned closely adjacent the primary winding and with no magnetic core shunt therebetween, and a condenser of such capacity connected to said other secondary winding as to limit the current therein to substantially the same value.

11. In combination, a core having two parallel magnetic paths with a leg in common, a primary winding mounted on the core and linking both of said parallel magnetic paths, two electrically independent secondary windings also mounted on the core, one linking each of said parallel magnetic paths, core means shunting one only of said parallel magnetic paths at a point magnetically between the primary winding and one of said secondary windings to limit the current in that secondary winding, with the other secondary winding positioned closely adjacent the primary winding and with no magnetic core shunt therebetween, and a condenser of such capacity connected to said other secondary winding as to limit the current in that winding to substantially the same value.

CHARLES PHILIPPE BOUCHER.
FREDERICK AUGUST KUHLE.