June 20, 1944. C. P. BOUCHER ET AL 2,352,073

LUMINESCENT TUBE SYSTEM AND APPARATUS

Filed July 14, 1941 2 Sheets-Sheet 1

FIG. 1.

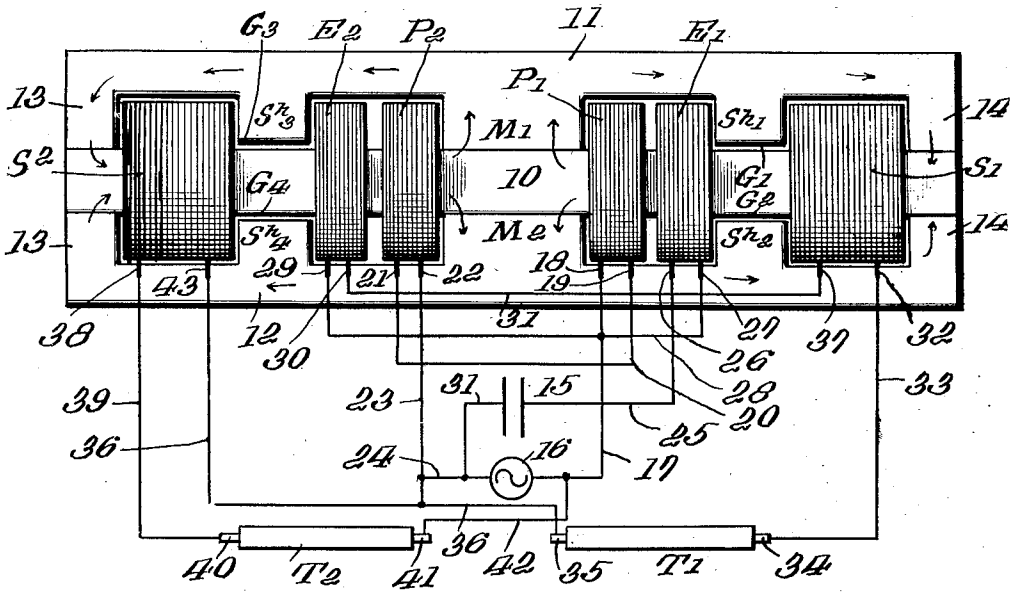
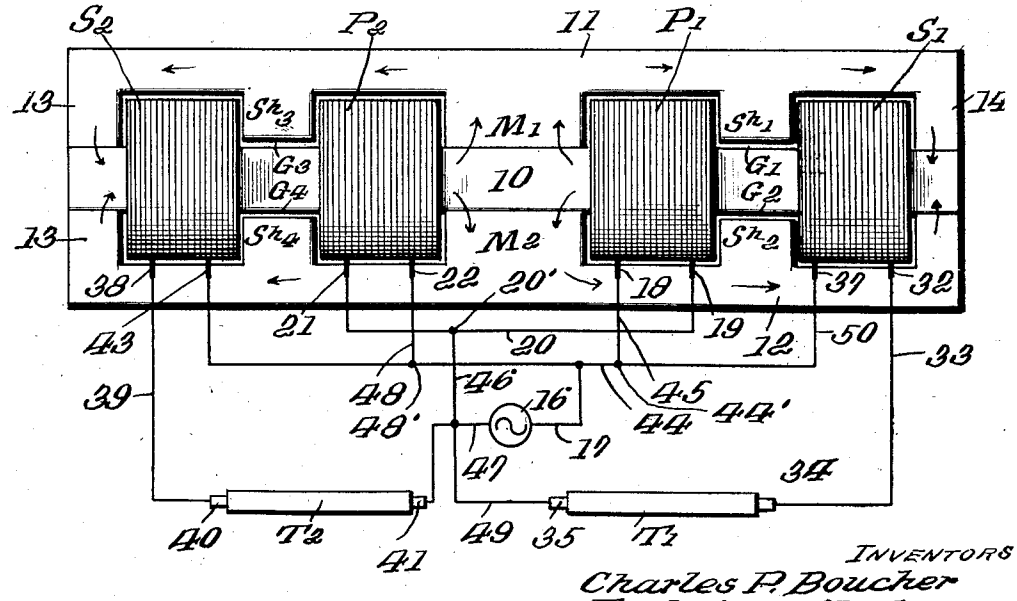


FIG. 2.



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Filed July 14, 1941 2 Sheets-Sheet 2

FIG. 3.

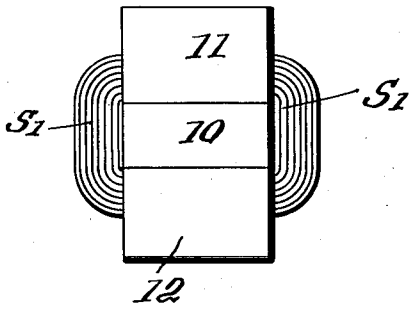


FIG. 4.

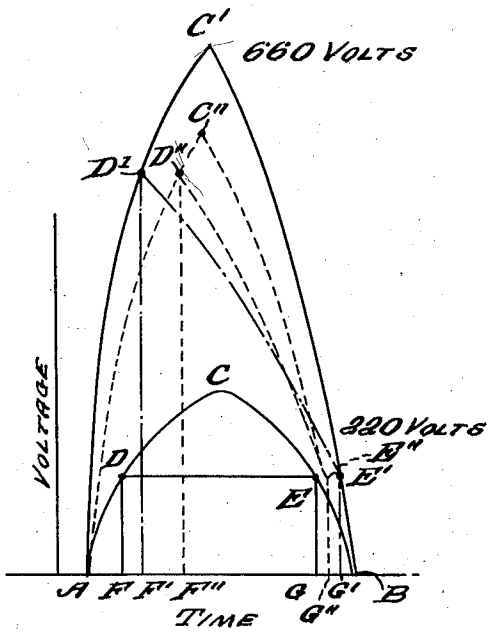
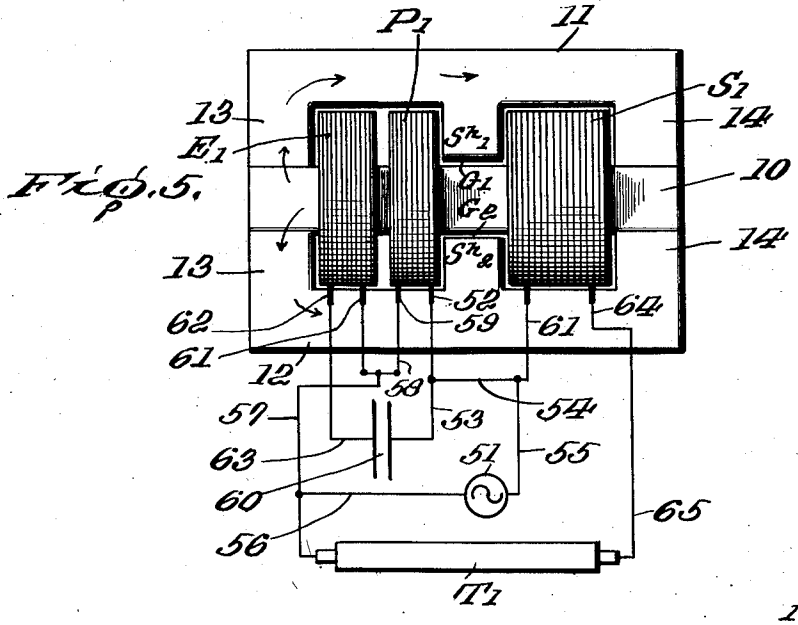


FIG. 5.



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UNITED STATES PATENT OFFICE

2,352,073

LUMINESCENT TUBE SYSTEM AND APPARATUS

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Application July 14, 1941, Serial No. 402,410

6 Claims. (Cl. 315—257)

Our invention relates to fluorescent tube lighting, and more particularly concerns a new autotransformer for use in fluorescent tube illumination, as well as a new system for fluorescent tube lighting.

An object of our invention therefore, is to produce a new autotransformer capable of energizing twin loads, and serving upon energization of one of said loads to provide additional potential across the other load for ensuring prompt energization of the latter.

Another object is to produce a new electrical system for fluorescent tube lighting, which is simple, durable, reliable, involves low cost of fixture manufacture, and low operating costs, and which is characterized by its quick and reliable starting characteristics even in cold weather, its good voltage regulation, the low power demand of the system, and the long life of the tubes, which lighting system has a long duration of light emission during each half-cycle of current supply, and which is capable of operating satisfactorily when desired, at light emissions lower than the rated light emission of the tube.

Still another object is to produce a fluorescent tube lighting unit employing simple, sturdy and dependable means for energizing the tubes, which system employs a transformer for supplying the required system potential, which transformer serves both to restrict the current through the system within safe limits and to supply sufficient potential to ensure proper starting and operation of the tubes.

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

Our invention accordingly resides in the several elements, features of construction, and operational steps, and in 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 3 are front and end elevations, respectively, of a preferred embodiment of our invention, the associated electrical circuits being illustrated schematically.

Figure 2 is a view similar to Figure 1 but illustrating another embodiment of our invention.

Figure 4 is a graph depicting certain important features of our invention, while Figure 5 illustrates an application of our invention to a load consisting of but a single fluorescent tube.

As conducive to a more thorough comprehension of our invention, attention may here be directed to the present state of the art, and consideration given to the many advantages resulting from the introduction of fluorescent tube lighting, as well as the disadvantages attendant thereupon.

In recent years fluorescent tube lighting has come into greater and greater use, and in many instances has in large measure replaced the more conventional incandescent lamps as sources of illumination. Many factors contribute to the wide-spread acceptance of these tube systems. For example, within wide limits these sources may be produced in a variety of light emission ratings. They may be varied considerably as to predominant color of the light output, the practical importance of which feature may be appreciated when it considered that but one single predominant color is available directly from an incandescent light source. The light efficiency on the basis of wattage input is much greater than with incandescent lighting, so that in many instances a single tube of a 15 watt rating for example, will produce the desired light output. To illustrate the important advantages flowing from this feature, it may be noted that a typical gasoline filling station requires between 3000–4000 watt output for evening illumination, where ordinary incandescent lighting is resorted to. This makes the monthly lighting costs, depending somewhat upon the local rate tariffs, range between $30–$65. Replacing the old-style incandescent systems by the new fluorescent lamp system results in a power demand of only about 2000 watts for the same quantity of illumination of more pleasing color at a monthly tariff of from $18 to $20. Briefly stated, the system is admirably suited for flood light operation, at a watt input of only 50–60 per cent of that required for comparable results where incandescent lighting is employed. Additionally, fluorescent tube lighting is found to be more penetrating, and because of its larger area of source, is less brilliant, and gives a more even distribution of light. Two or three tubes in parallel is found to result in excellent flood lighting.

The tubes are guaranteed for 2500 hours, and hence have an ensured life span of about 2½ times that of filamentary lamps. Because the tubes run cooler, detrimental heating is avoided. Their high efficiency, and the many practical

advantages of such fluorescent tube systems, have caused the arts and sciences, ordinarily so hesitant in adopting new ideas, to endorse openly the new system.

Nevertheless, in the practical operation of such systems, several problems have arisen, so that considerable development work still confronts the art. To illustrate, it may be noted that for many reasons, the present-day practice is to employ fluorescent tubes having coated filamentary cathodes at each terminal, and to rely upon electrons emitted from such coating for supplying, in large measure, the electrons which ionize the gas filling of the tube, and thus to produce the arc-carrying medium. Usually such filling consists of a small drop of mercury together with a small amount of argon gas to serve to initiate and support discharge until the mercury vaporizes. However, as is true of the operation of all arc-discharge devices, some current-limiting means must be provided to prevent the flow of excessive current with consequent danger of burning out either the tube or the auxiliary apparatus, associated therewith. These auxiliary apparatus are usually known simply as auxiliaries.

Additionally, such systems require a starting switch for starting the flow of current through the filamentary cathodes in a metallic series circuit, and to break said circuit in the portion thereof between said filaments after the filaments have reached rated temperature, whereupon in the ordinary course of events, an arc is struck between the spaced filaments. The so-called ballasts (part of the auxiliaries) comprise ordinary iron-core inductive reactors, which of course function best with a large iron content. The switches, which preferably are associated with small capacitors for suppressing radio disturbance, are conventionally of the thermal, magnetic relay, or glow discharge type.

While such systems are in large measure satisfactory, there are certain defects inherent therein. Among these may be cited the fact that a separate ballast must be employed for each tube. When it is considered that these tubes frequently are operated in banks or batteries of two or more tubes, it will be seen that the costs of such ballasts mount quickly. Additionally, a separate starting switch must be employed for each tube. Thus, while these switch and ballast auxiliaries may individually be of comparatively low cost, the total costs of all auxiliary equipment required in a complete lighting system may quickly mount up to an appreciable sum. Additionally, the use of so many auxiliaries increases the complexity of the fixtures for receiving the lamps and auxiliaries, increases the cost of producing them, and adds to the complexity of installing them. In this connection it should be noted that if for any reason the tube system cannot be operated on available service lines, so that transformer equipment is required, such transformer will be apart from and in addition to the conventional auxiliaries, and therefore represents an additional item of cost. The starting switches referred to have the defect in common that they succeed in starting the associated tube only after a time interval of from six to seven seconds or more, following connection across the service mains. This is true particularly of the inexpensive thermal type of switch. The magnetic relay switch is slightly faster in its operation, while the glow discharge switch is slower still, since it must first establish its own discharge before it can complete a heating circuit across the filaments of the associated tube. Finally, the further defect may be noted that upon failure of one of the filaments of the tube during its operation, the emission of electrons from that filament will diminish during the continued energization of the lamp, so that rectifier action may quite possibly be set up, resulting in overheating of the system with probably failure of one of the auxiliaries, usually the switch.

Accordingly, an important object of our invention is to avoid the afore-mentioned defects, and to produce a fluorescent tube lighting system characterized by its simplicity, its sturdiness, the small number of parts involved, the elimination of the use of the conventional auxiliaries, and which system is noteworthy because of its quick starting characteristics by the steady operation of the tubes throughout their entire useful life, and by the fact that the power unit associated therewith can readily be mounted as a unit directly on the fixture forming part of the lamp unit.

It frequently is found necessary to employ the fluorescent tubes in batteries or banks of two or more tubes, to produce concentration of light, to achieve a source of sufficient brilliance. In such cases, the usual practice is to operate the tubes in parallel across the current supply, and to provide a starting compensator in series with one of the lamps for functioning while the lamp is starting. This is required to ensure that sufficient voltage maintains to produce adequate heating of the coiled filaments of the tube. A further and additional piece of auxiliary equipment is thus seen to be required, representing an additional item of cost. Additionally, starting difficulties are encountered when these tubes approach the end of their life, due to the fact that ageing is evidenced by consumption of the greater part of the electron-emitting coating on the filaments. Thus, when this coating is nearly exhausted, then when the starting switch is opened and momentary high voltage surge occurs, there are not present sufficient free electrons to bombard the gas filling to establish the arc.

A further object of our invention, therefore, is to remove these afore-mentioned difficulties and disadvantages, and to produce a fluorescent tube illumination system capable of operation at voltages within safe practical limits, which presents no serious starting problems at any stage during the useful life of the tubes, and which system can be started without resort to starting compensators.

Not only are the systems at present in use slow in starting, but delay is encountered in restarting in those cases where a thermal switch is employed, because the heater for such thermal switch remains in circuit during the energization of the tube, and upon interruption of the tube circuit, may have such residual heat that an appreciable time is required for the heater to cool sufficiently to permit the bi-metallic switch element again to close its circuit. Comparatively poor voltage regulation follows as an incident to the comparatively small iron content of the ballast reactors. A large quantity of power is lost in the auxiliaries employed, a disadvantage which is emphasized when transformer apparatus is also required, since as already pointed out, these ordinary transformers do not serve as current limiters.

Thus a further object of our invention is to produce a fluorescent lighting unit which is free from the defects just set forth, and which unit

requires a minimum expenditure of power other than across the tube, which has extremely rapid action both in initially striking and in restriking the arc, and which has good voltage regulation.

With the known low-voltage units experience has shown that it is necessary that the temperature of the surrounding atmosphere be maintained within certain definite limitations to ensure satisfactory arcing conditions. For example, these tubes cannot be operated where the surrounding temperature is much below 45° F. Additionally, under-voltage impressed across the tubes lowers the electron emission to such an extent that difficulty is encountered in starting, while if the arc is already established, it becomes unstable in its operation. For example, a reduction in voltage of twenty-five per cent below rated voltage is found to result in the arc extinguishing. A further object of our invention accordingly resides in removing the disadvantages resulting from low-voltage operation, in avoiding, to a certain extent at least, unstable operation during cold weather, and in producing a fluorescent tube system having long life, and which gives rise to a comparatively stable arc even during operation under external low temperature conditions.

Lastly, these known tube systems, operating at or about service voltages, have only a comparatively short period of light emission during each half cycle of current supply, and cannot be operated satisfactorily at any appreciably lower luminosities than that for which the tube is rated. The arcs across the tubes strike at about the same point on the up slope of the wave form on the voltage half-cycle as that point on the down slope of the wave at which the tube extinguishes, and since these points are comparatively close to the peak of the half-cycle voltage wave form, then it follows that, if attempt is made to decrease the voltage, thus lowering the amplitude of the wave form, the peak of the wave form will fall so close to the striking point that the arc either cannot be struck, or if struck, cannot be maintained. An important feature of our invention, therefore, is to produce a fluorescent tube lighting system capable of efficient operation at both heated lighting emission and on dimmer operation.

Our new system may be considered as comprising primarily of a new autotransformer adapted for its particular purpose and its associated tube system. Turning now more particularly to the autotransformer shown in Figures 1 and 3, the transformer core, rectangular in shape, comprises a central leg 10 extending lengthwise thereof, outer core legs 11 and 12 disposed in spaced parallel relation to said central leg and end pieces 13, 13 and 14, 14 serving to close the outer legs on the central leg near their respective ends. Mid core portions M1 and M2 close the outer legs 11 and 12 respectively in magnetic circuit on the central leg 10 at approximately the center of the core. These core portions M1 and M2 separate the core into two groups of magnetic flux paths. In the first of these groups a magnetic circuit may be traced from the mid point of leg 10, up through M1, through outer leg 11, end piece 14 and back to M1. Also in this first group of magnetic circuits a like path may be traced from the mid point of leg 10 down through M2, through leg 12, up through end piece 14 and back to M2. There are also two basic magnetic circuits established on the left of mid core portions M1 and M2, the first of these circuits being traced from a point at approximately the center of core portion 10, upwardly through mid core portion M1 across outer leg 11, downwardly through end piece 13 and back to M1. Similarly a like path may be traced from the mid point of leg 10 down through the mid core portion M2, across outer leg 12, upwardly through end piece 13 and back to M2. As will be described in greater detail hereinafter each magnetic circuit in group 1 or group 2 is associated with primary and secondary coils positioned on the transformer core. The manner in which the magnetic flux courses these windings will be developed during the progress of the description which follows hereinafter.

Turning now to the second traced group of magnetic flux paths, primary coil P2 and extension coil E2 are mounted about central leg 10 in the first space adjacent core portions M1 and M2, while secondary coil S2 is mounted in the second space enclosed by the second described group of magnetic flux paths.

Tubes T1 and T2 are provided, associated and in circuit with secondary coils S1, S2, respectively. Tubes T1 and T2 are provided, respectively associated and in circuit with secondary coils S1, S2. These tubes are of the fluorescent gas discharge type. Since in accordance with the practice of our invention, we operate these tubes at higher voltages than has hitherto been the practice, with cold cathode operation, we can employ cold cathode tubes having solid electrodes, and designed especially for such use. An alternative expedient is to employ the conventional hot cathode tube, short-circuiting the filamentary terminals thereof to adapt it for cold cathode operation. This alternative expedient is preferable, inasmuch as such cold cathode tubes usually have to be made up on special order.

Extension coils E1, E2 are associated in autotransformer connection across the primary coils P1, P2. The purpose of these extensions E1, E2 may be readily demonstrated. A condenser must be selected of sufficient capacity to bring to approximate power-factor balance, the energizing current of the inductive load on the system. Because of its symmetrical location, this condenser has no effect on the system other than its control on the power-factor. While the use of such power-factor condenser is desirable, it may be omitted where system power-factor may be disregarded. It is also feasible to omit the extensions entirely, and to place the condenser directly in the primary coil, although by so doing, it will be necessary to increase materially the capacity and size, and hence first cost of the condenser employed.

The outer legs 11, 12 and core portions M1, M2 cooperate with the end pieces 13, 13 and 14, 14 respectively, to provide elongated openings or spaces about the central leg 10. Disposed in the spaces thus provided are the primary coils and secondary coils to be described hereinafter, one primary and one secondary coil being mounted in each space. The primary and secondary coils about each flux path are separated by intermediate magnetic shunts extending from the outer legs, through said space, towards but just short of the central leg 10. They thus provide between opposed surfaces of the ends of the shunts and the central legs, air-gaps of high reluctance, calibrated according to the particular loads for which the transformer is designed. Thus, in the group of magnetic flux paths first traced, intermediate shunts Sh1, Sh2, extending respectively from

outer legs 11, 12, toward the central leg 10, provide between them calibrated air-gaps G1, G2. Similarly, in the second traced group of magnetic circuits, intermediate shunts Sh3, Sh4, are provided extending, respectively, from outer legs 11 and 12 towards but just short of central leg 10.

Confining our attention first to the first-traced group of parallel paths, we provide a primary coil P1 in the first space therein, adjacent core portions M1, M2. Assuming now, as will be more fully pointed out hereinafter, that the system with which the transformer is associated is provided with a condenser 15 for improving the system power factor, we provide an extension coil E1 associated with primary coil P1, and also mounted about central leg 10 in said first space. As a possible alternative, the coil E1 is wound on top of coil P1. A secondary coil S1 is mounted about central leg 10, in the other space in the parallel flux path under discussion.

It is interesting at this time to trace the primary circuit through the source of energy 16, keeping in mind that the primary coils are connected in series-opposed relationship. Assuming that for a given half-cycle, the current flows to the right from the source 16, then it will be seen that the current flows through conductor 17, terminal 18, to the right through primary coil P1, terminal 19, lead 20, terminal 21, primary coil P2, terminal 22, lead 23, lead 24, back to the left-hand side of source 16. Of course, during the next half-cycle the direction of flow of current will be reversed.

As has been stated, extension coils E1, E2 serve to energize capacitator 15. These extension coils are connected in autotransformer connection across primary coils P1, P2, and are brought to their high terminal voltage by virtue of their inductive relationship with primary coils P1, P2. The condenser circuit for a given half-cycle may be traced as follows: From right-hand side of condenser 15 in Figure 1, through conductor 25, left-hand terminal 26 of extension coil E1, through extension coil E1, right-hand terminal 27, lead 28, left-hand terminal 29, through extension coil E2, right-hand terminal 30, lead 31, conductor 17, terminal 18, thence through primary coil P1, terminal 19, lead 20, electrode 21, thence through primary coil P2, electrode 22, lead 23, lead 24, and lead 31, back to the left-hand side of condenser 15. During the next subsequent voltage half-cycle, the direction of momentary current flow will be reversed. During each half-cycle, however, a charge is impressed on the condenser 15 with leading current, thus serving to balance the conductive load to be described hereinafter.

Each secondary coil S1, S2 is connected in a separate electrical circuit in adding relation, first with the primary coil of the opposite magnetic path, and then with the primary coil with which it is in direct electro-magnetic circuit. Tubes forming the respective loads for these secondary coils are in direct series-circuit with their corresponding secondary coils.

For example, for any given half-wave of charging current, a circuit may be traced from secondary coil S1, right-hand terminal 32, lead 33, terminal 34, tube T1, terminal 35, lead 36, lead 23, terminal 22, through primary coil P2, terminal 21, lead 20, terminal 19, through primary coil P1, terminal 18, lead 31, and left-hand terminal 37, back to secondary coil S1. During the next half-cycle the direction of current flow through the traced circuit will be reversed.

A similar circuit may be traced for secondary coil S2. Starting with left-hand terminal 38, current passes through conductor 39, terminal 40, tube T2, terminal 41, conductor 42, conductor 17, terminal 18, through primary coil P1, terminal 19, lead 20, terminal 21, primary coil P2, terminal 22, lead 23, conductor 36 and back through right-hand terminal 43 to secondary coil S2.

The tubes employed in our system may be of generally conventional design, having spaced and opposed electrodes for maintaining an arc discharge therebetween, and having a small amount of mercury and a filling of some starting gas such as argon or the like. However, as is conventional with such tubes, the general design is such that the greatest emission from the mercury is around the 2537A line. The argon serves to support the discharge until the mercury is vaporized and comes into operation. A lining of a suitable fluorescent salt is provided on the interior of the tube wall, the combination of which salts is selected in accordance with the color of radiation which is desired. Since the general construction of such lamps is in large measure conventional, and since such construction does not form part of our invention, no further discussion thereof will be made at this time.

It should be kept in mind, however, that in the operation of such arc discharge devices, some current limiting means must be provided. Otherwise the current demand will grow out of all proportion, and either the arc discharge device itself or the equipment in circuit therewith will be destroyed due to overheating. Hitherto, some sort of current limiting ballast means, over and above the current supply source, was required to limit the current through said arc discharge within safe bounds. These ballasts, as they are known to the art, constitute a source of waste energy, and tend towards a lowering of the system efficiency. Our new system provided for current limitation in the arc load by means of the transformer action itself, thus bringing about a material decrease in energy loss, and an attendant rise in system efficiency. This important new action may be attributed to the high leakage reactance in our new transformer.

An understanding of this very important feature can best be had by tracing the electro-magnetic circuit in the transformer itself. We will assume that the momentary direction of current flow is such that the primary coils develop flux in the parallel magnetic paths, coursing in the directions shown by the arrows. Thus directing attention for the moment to primary coil P1, flux courses as a single stream toward the left along central leg 10. When it reaches the mid portion of the transformer core it bucks the stream of flux in the opposite direction from primary coil P2. The flux from primary coil P1 therefore splits into two streams, and since the two halves of each parallel flux path are symmetrical and of the same physical and magnetic characteristics, these two streams are substantially equal. Now, since the flux seeks the path of least reluctance, and since no current as yet flows through secondary coil S1, since the arc in tube T1 has not yet struck, and consequently no back magnetomotive force has been generated in the associated secondary coil S1, the streams of flux shun the high reluctance magnetic shunts Sh1, Sh2, and flowing thru end pieces 14, 14 from opposite directions, meet at central leg 10, there reuniting, the stream of flux courses central leg 10 to the left, interlink-

ing secondary coil S1 and building up an induced voltage therein. The flux flows back to the left in Figure 1, thus completing the magnetic path.

During the same half-cycle, the flux generated by primary coil P2 courses to the right in Figure 1, along central leg 10, to core portions M1, M2. There, bucking the stream of flux from primary coil P1, the flux from primary coil P2 chooses the path of least reluctance, splits into two streams which for reasons of symmetry pointed out hereinbefore with respect to primary coil P1, are substantially equal. These two streams course through outer legs 11, and 12, respectively, shunning the shunt paths Sh3, Sh4 of high reluctance, and course through end piece 13, 13 from opposite directions. The two streams re-uniting at central leg 10, the flux courses through this leg to the right in Figure 1, back to primary coil P2, thus completing the magnetic circuit. The flux coursing through secondary coil S2 induces a voltage therein which is impressed across the tube T2, in a manner pointed out hereinafter. During the next half-cycle of current flow, of course, the direction of coursing of flux is reversed.

While tubes T1 and T2 are supposedly of the same physical and electrical characteristics, small variance or deviations from the normal almost invariably occur. As a result of such variations, one tube is usually found to have slightly less impedance than the other, so that as the voltage thereacross from its corresponding secondary coil builds up toward its peak value, the gas therein is brought to such a degree of excitation that an arc is struck across that tube, while the other tube remains inactive. Let us assume for purposes of discussion that it is the tube T2 which, being of lower impedance, is the one in which the arc strikes first. Immediately, a back magnetomotive force is induced by the flow of current in the associated secondary coil S2, this back m. m. f. opposing the main body of flux from primary coil P2. Thus, the magnetic path through the ends of legs 11 and 12 and end pieces 13, which prior to energization of tube T2 was of low reluctance, now becomes a path of extremely high reluctance. The main body of flux of course seeks the path of least reluctance, and accordingly, no longer flows through the path interlinking secondary coil S2. Inasmuch as the shunts Sh_3, Sh_4, and their associated air-gaps G_3, G_4 now have a reluctance which is less than that of the path through secondary coil S2, some part of the primary flux from primary coil P2 is shunted through these elements and courses back to the primary coil. Primary flux flows through the secondary coil path only in such amount as to induce in secondary coil S2 a voltage sufficient to maintain the arc across tube T2.

Since current traverses secondary coil S2 upon and following the striking of tube T2, and since both primary coils P1 and P2 are electrically in series with that secondary coil, the same current circulates through these two primary coils. Accordingly, the current flowing through coil P1 from S2, adds to the current in P1 coming directly from source 16. When it is recalled that the magnetomotive force set up by a coil is a function of current and number of turns, it will be seen that as soon as tube T2 strikes, the quantity of flux linking primary coil P1 and secondary coil S1 is increased by the additional current in P1 coming from secondary coil S2. The increased flux linking secondary coil S1 builds up the voltage therein so rapidly that the tube T1 strikes substantially simultaneously with tube T2.

As soon as T2 and T1 both strike, steady current flow conditions maintain, and the bodies of flux from primary coils P1 and P2 choose the paths of least reluctance. Only enough flux courses the two secondary coils to induce the voltage required to maintain the arcs across tubes T1, T2. The main bodies of flux are shunted around the shunt path containing the air-gaps G1—G4, which paths are now of least reluctance. Flux from primary coil P1 for example, may be assumed to flow to the left in central leg 10 during a given half-cycle of current flow. Splitting into two substantial streams when confronted by the flux from primary coil P2 which courses in the opposite direction, one stream of flux from primary coil P1 courses upwardly through core portion M1, to the right through leg 11, down through shunt Sh1, across air-gap G1. The other stream of flux from primary coil P2 flows downwardly through core portion M2, through the right along leg 12, up through shunt Sh2, across air-gap G2, to central leg 10. The two streams of flux there re-uniting, a single flux stream courses back to primary coil P1.

Simultaneously, the flux from primary coil P2 splits into two parallel streams, one of which courses upwardly through core portion M1, to the left across leg 11, down through shunt Sh3, across air-gap G3 and back through central leg 10 to the right, to the primary coil P2. The other flux stream courses down through core portion M2, to the left across leg 12, up through shunt Sh4, across air-gap G4, and back to the right along leg 10 to the primary coil P2. In the next subsequent half-cycle of current flow the path which the flux traverses is reversed. During this half-cycle the flux courses to the right along leg 10 from primary coil P1. Only so much flux links secondary coil S1 as is required to maintain the arc across the tube T1. The stream of flux which does traverse secondary coil S1 splits at the end pieces 14, and approximately half thereof courses upwardly to the left along leg 11, while the other stream courses downwardly along leg 12. By far the larger stream of the flux splits off just to the right of the primary coil, and one part courses upwardly across air-gap G1 and shunt Sh1 to leg 11, where it re-unites with the flux coursing through leg 11 from secondary coil S1. Flowing to the left across leg 11, this stream of flux courses down through core portion M1 to leg 10 and back to primary coil P1. Similarly, the other stream of this flux traverses air-gap G2 and flows downwardly through shunts Sh2, and re-uniting at leg 12 with the flux coursing the leg from secondary coil S1, passes as a single stream to the left along leg 12 to core portion M2 and thence through leg 10, back to the primary coil P1.

At the same time, flux passes to the left through leg 10 from primary coil P2. A small amount of the flux, sufficient to induce in secondary coil S2 a voltage high enough to maintain the arc across tube T2, links secondary coil S2, and splitting at end pieces 13, 13, courses back, one stream to the right along leg 11 to core position M1 and leg 10 to primary coil P2, and the other stream to the right along leg 12 to core position M2 and thence through leg 10 to the primary coil P2. The major part of the flux however, splits just short of the secondary coil S2, and courses in two streams, one stream across air-gap G3, up through shunt Sh3, to the right along leg 11, down through fore

position M1, and back through leg 10 to primary coil P2. The other stream courses down across air-gap G4, through shunt Sh4, to the right along leg 12, up through core position M2, and back through leg 10 to primary coil P2.

It is of course to be understood that extension coils E1, E2 are in the nature of a second auto-transformer and are in connection with primary coils sections P1, P2. Thus they build up a counter-magnetomotive force when a current flows in condenser 15, in a manner similar to that described with reference to secondary coils S1, S2 when they become energized. To a certain extent, therefore, these extension coils E1, E2 serve to oppose the flow of the principal bodies of flux through central leg 10. Their locations so close to their respective primary coils P1, P2, however, in the absence of neighboring and advantageously disposed leakage paths, prevents their exerting any undue influence on the passage of flux.

It has been stated hereinbefore that a tube operated according to our new system has a greater luminous efficiency for rated power input than does the conventional hot cathode fluorescent tube when operated under its usual operating conditions. The validity of this assertion can readily be demonstrated having reference to Figure 4. Therein, the sine wave ACB represents the curve of a half-cycle of supply voltage for energizing the ordinary hot cathode tube from a 220 volt service. Similarly, curve AC'B, is a corresponding curve of the wave form of the 660 volt secondary for energizing a tube according to our present invention. With the hot cathode tube prepared for striking by the warming effect of its incandescent electrodes, thus exciting the molecules of gas therein and vaporizing the mercury, and by the flow of electrons emitted from said electrodes, the arc is caused to strike at a point D along the wave ACB. This point D is earlier in the voltage half-cycle than is the point D' at which the tube operating according to our invention strikes. According to our new invention it will be seen, however, that the tube operating on the wave form ACB extinguishes at the point E, which is a point considerably earlier in the voltage half-cycle than is the point E' in the voltage half-cycle AC'B for our new system. Thus, although in the conventional operation the arc strikes earlier than it does in our case, it extinguishes much sooner, so that the total portion of the voltage half-cycle during which the arc remains struck is greater according to our new practice than is true of the prior art systems. Thus it will be seen that not only does the light emission endure longer during each half-cycle according to our new system, but that as well, the quantity of light for rated power input is materially greater.

Consideration of the curve according to Figure 4 will show that a further very important advantage residing in our invention flows from the use of the higher voltages. It may be stated at this point that the use of higher voltages has hitherto been avoided by the workers in this art simply because those workers failed to appreciate the advantages which could be achieved upon the use of such high voltages. It is impossible with these known low voltage tube systems to produce a dimming action such as is desirable for night display in store windows or storerooms, or for decreased illumination in the household.

Such dimming action is quite possible, however, with our new construction, as can be demonstrated from Figure 4. Dimming is brought about simply by decreasing the supply voltage as by shifting to a new service, by connecting the secondary coils of the transformer along a smaller number of turns of the primary coils (decreasing the transformer ratio), or by inserting a voltage-consuming impedance in circuit with the tubes. Such a decreased voltage is shown at C'' on the curve AC''B, illustrated in dotted lines. The significant feature about this curve is that the point C'' is substantially above the point D'' at which the arc can be struck. Thus striking of the arc is ensured. Dimming action is brought about now due to the fact that in the wave form AF''D''E''G''B, the total light emission F''D''E''G'' is substantially reduced from the case previously discussed, and additionally, the fraction F''G'' of each half-cycle during which the arc remains ignited is appreciably less than in the case previously discussed. Desired dimming action follows as a matter of course.

For example, with a mean effective secondary voltage of 660 volts from a 118 volt service, the peak voltage in each voltage half-cycle will be found to be about 900 volts. So long as this peak ranges from 660 volts or up, however, the tubes in our system will strike and remain energized with stable arc discharge.

The system according to Figure 2 differs from that of Figure 1 primarily in that the condenser for power-factor regulation purposes is omitted, and with it the extension coils E1, E2 of the primary winding, and that while in that embodiment the primary cores were connected series-opposed they are here connected, for illustration, in parallel-opposed relation. With these differences in mind, it will be seen that just as in Figure 1, the transformer consists of a central leg 10, outer legs 11 and 12 disposed in parallel-spaced relation on opposite sides of central leg 10, providing for the same functions as in the construction according to Figure 1, and end pieces 13, 13 and 14, 14 together with mid core portions M1, M2. Similar to the construction shown in Figure 1, elongated spaces are provided between central leg 10 and outer legs 11, 12, respectively, on each side of mid core portions M1, M2, which spaces receive the associated primary and secondary coils. In magnetic circuit with each other in that group of parallel magnetic paths extending to the left of core portions M1, M2 are primary coil P2 and secondary coil S2, while disposed in magnetic circuit in the group of parallel flux paths extending to the right of core portions M1, M2 are the primary coil P1 and secondary coil S1. In each instance the coils are wound about central leg 10 in the elongated spaces previously referred to, while the primary coils are each disposed more closely adjacent to core portions M1, M2, the secondary coils being disposed adjacent end pieces 13, 13 and 14, 14 respectively. Still following the construction according to Figure 1, intermediate shunts of high reluctance are provided between the primary and secondary coils. Thus shunts Sh1 and Sh2 extend respectively from leg 11 and 12 towards but just short of central leg 10, between primary coil P1 and secondary coil S1, providing air-gaps G1, G2, of calibrated high reluctance. Similarly, high reluctance intermediate shunts Sh3 and Sh4, disposed between primary coil P2 and secondary coil S2, extend from outer legs 11 and 12 respectively, towards but

short of central leg 10, providing therebetween air-gaps G3, G4 of high reluctance calibrated according to the particular load to be energized by the transformer.

Parallel magnetic paths may be traced, one from leg 10, splitting and passing through core portion M1, to the right along leg 11, end piece 14 and back through leg 10; and through core portion M2, to the right along leg 12, end piece 14 and back, through leg 10. The other path may be traced from leg 10, splitting and passing through core portion M1, to the left along leg 11, end piece 13, and back through leg 10; and through core portion M2, to the left along leg 12, end piece 13, and back through leg 10.

As in the case of Figure 1, primary coils P1, P2 are connected in opposed relation across a source 16 of alternating current energy. Thus the streams of flux generated by these primary coils and coursing through the said parallel magnetic paths tend to buck each other. Current accordingly flows from the right-hand side of source 16 through conductor 17, through lead 44, lead 45, terminal 18, through primary coil P1 to the right in Figure 2, thence through terminal 19, conductor 20, lead 46 and lead 47, back to the left-hand side of current source 16. A parallel path may be traced from the right side of current source 16, through leads 17, 44 and 48, to terminal 22, thence through primary coil P2 to the left in Figure 2, terminal 21, and thence through conductors 20, 46, and 47 back to the left-hand side of the source of energy 16. The primary coils are seen to be connected in bucking relationship with each other.

In this embodiment, each secondary coil is connected across the net work consisting of the parallel-connected 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. This current necessarily courses the net work electrically connected therewith, and splits thereacross in accordance with the relative impedance of the branches of that net work. 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 instantly induced in the associated secondary coil. This increased potential, impressed across the terminals of the tube in circuit with that secondary coil, causes rapid striking of the arc across that tube.

A fluorescent gas discharge tube T1 is associated in series with and comprises the load of secondary coil S1, while similarly, a fluorescent gas discharge tube T2 is in series with and constitutes the load of secondary coil S2. The electrical connections for secondary coil S1 may be traced as follows: From right hand terminal 32, lead 33, socket 34, tube T1, thence through conductors 49 and 46 to junction 20'. The other leg of the secondary coil circuit is from terminal 37 and lead 50 to junction 44'. One branch circuit then can be traced from junction 20' lead 20, terminal 21, to the right in Figure 2 through coil P2, terminal 22, and leads 48 and 44 to junction 44'. The other branch circuit can be traced from junction 20', lead 20, terminal 19, primary coil P1, terminal 18, and lead 45 to terminal 44'. During the next circuit half-cycle, of course, the direction of current flow is the reverse of that described.

Similarly, a like circuit may be traced from secondary coil S2. One leg includes terminal 38, lead 39, socket 40, tube T2, socket 41, leads 47 and 46 to junction 20'. The other leg includes terminal 43 and lead 44 to junction 48'. One branch of the parallel network across which the secondary circuit just traced is connected as follows: From junction 48', lead 48, terminal 22, to the left in Figure 1 through primary coil P2, down terminal 21 and lead 20 to junction 20'. The other branch may be traced from junction 48', leads 44 and 45, terminal 18 through primary coil P1 to the right, terminal 19, and lead 20 back to junction 20'. It is of course to be understood that the circuits just traced assume momentary current flow in given direction and that upon reversal of the current half-cycle, the direction of current flow will be precisely opposite to that indicated.

It will be noted that while in Fig. 1 the primary coils are series-connected across the source of current supply, in the embodiment under discussion, the primary coils are connected in parallel. With parallel connection each primary coil carries the full potential of the service. For a certain number of turns in the secondary winding, parallel connected primary coils must contain twice as many turns as the number of turns in series connected primaries so that the volt per turn will be equal in either hook-up.

Assuming now that the direction of the impressed current is the same as the maintaining in the construction according to Figure 1 during the discussion thereof, it will readily be appreciated that flux passing to the left in Figure 1 from primary coil P1 will buck the body of flux from primary coil P2, and splitting, will course upwardly and downwardly, about legs 11, 12, and following the paths of minimum reluctance, course through secondary coil S1. At the same time, flux from primary coil P2 will course to the left through legs 11 and 12 and link secondary coil S2. In the alternate half-cycle, of course, the directions of the passage of flux are reversed, and the flux from primary coil P1 passes to the right through secondary coil S1, thence through end piece 14, to the left through legs 11, 12 to core portions M1, M2, and thence back through leg 10 to primary coil P1. In like manner, flux from primary coil P2, passing to the left through leg 10, traverses secondary coil S2 and passes in two paths through end pieces 13, 13 and to the right through legs 11, 12, to core portions M1, M2, and thence to primary coil P2.

In operating our system, one or the other of tubes T1, T2 is first brought to a condition where the arc can be established thereacross. Let us assume that it is tube T1 which strikes first. Accordingly, when the arc strikes, a large current is induced in secondary coil S1. This current of course flows through the primary coil P2 electrically connected with secondary coil S1. Because of the higher impedance which primary coil P1 in the same magnetic circuit now has, however, it is only the smaller part of the current which courses the branch circuit including coil P1. The larger part of the current flows through coil P2. Now, since the flux gen-

erated is a function of the number of turns and of the current flowing through these turns, the quantity of flux generated by primary coil P2 promptly increases to a considerable extent. This increased quantity of flux so materially increases the voltage induced in secondary coil S2 that an arc is immediately struck across the tube T2.

It will be seen that the total time consumed between closing of the primary coils on the service mains until the arcs have been struck in both tubes is a matter of but a fraction of a second, as contrasted with a period of from six to seven seconds or more, as is required in the case of the other present-day fluorescent tube systems.

As soon as both tubes have been energized, steady flow conditions obtain; and the loads of the two tubes being approximately equal, the flux from the two primary coils, always selecting the paths of least reluctance, now follow the comparatively low reluctance parallel paths through the associated intermediate shunts and air-gaps, while but a small portion of the flux courses through the secondary coils. Thus, having attention to the primary coil P1, and assuming a current half-cycle giving rise to a coursing of the flux in the direction opposite to that indicated by the arrows, the flux courses to the right from primary coil P1 along central leg 10, and splitting, flows in part through air-gap G1, shunt Sh1, leg 11, core portion M1 and leg 10 back to coil P1, and in part through air-gap G2, shunt Sh2, leg 12, core portion M2, leg 10, back to coil P1. In like manner, and making the same assumption, then during the same half-cycle of current flow, only a small part of the flux from primary coil P2 courses through secondary coil S2. The major part of the body of flux, going from the left of coil, P2, splits, and part goes through air-gap G2, shunt Sh3, leg 11, core portion M1, leg 10 and back to coil P2, while the other part courses through air-gap G4, shunt Sh4, leg 12, core portion M2 and leg 10 back to coil P2. Of course, during the next half-cycle, the direction of coursing of flux is reversed.

Our new transformer and system can also be adapted to single circuit operation if desired. An embodiment of such construction is illustrated in Figure 5.

Therein, the transformer core consists of central leg 20, outer legs 11, 12, in spaced, parallel relation with respect thereto, end pieces 13, 13 and 14, 14 magnetically forming the adjacent ends of said outer and inner legs, and high leakage reactance shunts Sh1, Sh2 extending from legs 11, 12 respectively, towards but short of leg 10, forming air-gaps G1—G2, of reluctance calibrated in accordance with the particular load for which the transformer is adapted.

A primary coil P1 and an extension coil E are disposed about central leg 10 on one side of the shunts, with the primary coil disposed next to them. On the opposite side of the shunts, secondary coil S1 is disposed about the leg 10. Alternating-current source 51 is connected across primary coil P1 by means of terminal 52, leads 53, 54, to source 51, and thence back through leads 56, 57, 58 to terminal 59.

To maintain the capacity and size of condenser 60 down to practical proportions, the extension coil E, which serves to energize the condenser, is associated in auto-transformer connection with the primary coil P1. Thus terminal 61 of extension coil E1 is connected by lead 58 to terminal 59 of primary coil P1, the other terminals 62 and 52 of extension coil E1, and primary coil P1, respectively, being connected by leads 63, 53 to opposite sides of condenser 60. This condenser is designed to provide nearly unity system power factor.

Secondary coil S1 is likewise connected in autotransformer connection across the primary coil P1, and the secondary terminals of this transformer are connected across the load, comprised of fluorescent gas discharge tube T1. Thus circuit may be traced from terminal 64 of coil S1, through lead 65 to tube T1, thence through leads 57 and 58 to terminal 59 of coil P1, through primary coil P1, thence through terminal 52 and lead 54 to terminal 61 of coil S1.

During the next subsequent half-cycle of charging current, of course, the directions of current flow are the reverse of those traced.

At all times during the energization of primary coil P1, all the primary flux generated thereby interlinks the extension coil E1, because of its close association with the primary coil, so that condenser 60 is energized.

Similarly, when primary coil P1 is first closed on the service mains, the primary flux chooses the path of least reluctance, and assuming a momentary condition where it flows in the direction of the arrows in Figure 5, it flows from the left of coil P1 along leg 10, interlinking extension coil E1, and splitting, flows in two substantially equal parallel streams. One stream courses upwardly along end piece 13 to the right along leg 11, down end piece 14, to leg 10. The other stream may be traced down end piece 13, to the right along leg 12, and up end piece 14 to leg 10. The two streams there reuniting the combined stream course; to the left along leg 10, interlinking coil S2. During the next half-cycle of charging current, of course, the direction of these two streams is reversed. Secondary voltage is induced in coil S2, quickly resulting in energization of tube T1.

When this happens, secondary flux tends to flow counter to the primary flux. Accordingly, just sufficient primary flux continues to traverse secondary coil S1 as is necessary to induce therein the voltage sufficient to maintain the arc across tube T1. This involves a proper design of the shunt paths. By far the greater part of the primary flux now courses down shunts Sh1, Sh2 and their associated air-gaps G1, G2, shunting out the secondary coil S2.

During the next subsequent half-cycle of charging current flow, the direction of coursing of the flux is reversed. At this time, flux will flow to the right from primary coil P1 along leg 10. A small part of the flux will continue on to the right along leg 10, interlinking secondary coil S1, and splitting, flows part up through end piece and to the left along leg 11, and part down end piece 14 and to the left along leg 12. The major portion of the primary flux is, however, split into two streams, one of which courses up across air-gap G1 and shunt Sh1 to leg 11. There uniting with the flux which has coursed upwardly from coil S1, the combined flux streams to the left along leg 11 and down end piece 13. The other major stream of flux courses across air-gap G2 and down through shunt Sh2 where it unites with the stream of flux which courses downwardly from the coil S1, passing to the left along leg 12, the combined streams of flux passing upwardly through end piece 13. The two streams uniting in central leg 10, they pass to the right

therealong to the primary coil P1, interlinking extension coil E1 during such passage.

While the assembly according to this embodiment is characterized by its sturdiness, reliability, high efficiency and long life with low operating costs, nevertheless, since according to this embodiment there must be a complete transformer for each tube, the construction does not represent quite as much advance as do the double circuit transformers according to the embodiments of Figures 1 and 3.

It will readily be appreciated from the foregoing that by the use of our new system the necessity for complicated, delicate and wasteful auxiliaries is completely avoided, and that one transformer is capable of operating two or more lamps. Thus a sturdier unit can be produced, characterized by its long life and low operating costs. The transformer itself serves as a current-limiting means for the tubes.

Combined with the comparative simplicity of our new system are the advantages that the tubes will both start and restart quickly, and will operate satisfactorily even under cold weather conditions. To illustrate, whereas in conventional systems the arc will extinguish at ambient temperatures of about 50° F., tubes operated in accordance with our new invention will remain energized with temperatures as low as 0° F.

Because of the large iron content of the transformer as contrasted with the iron-core ballast hitherto in use, the voltage regulation is better, and there is but little variation in the voltage drop across the tubes upon variation of the potential across the service mains. Thus the light output changes linearly or even to a lesser degree with change of voltage, rather than as a power function of the impressed potential across the service mains. Thus the light output changes linearly or even to a lesser degree with change of potential, as has hitherto been the case.

Finally, our new system makes possible for the first time to employ fluorescent tubes satisfactorily with dimmer operation, wherein the tubes are operated at lower than rated light output, for producing pleasing soft light in the evenings or periods of quiet.

Inasmuch as autotransformer operation at secondary voltages of 600 volts or less, with primary grounded to earth if desired, is permitted by the Fire Underwriters, it will be understood that our new system satisfies all practical requirements.

We claim:

1. An electrical system for producing illumination, comprising a high leakage reactance, double-section autotransformer, each said section having a primary coil and a secondary coil mounted individually thereof the primary coils being connected with a source of power in bucking relationship to each other; fluorescent gas-discharge tubes individually connected with and energized by said secondary coils, the secondary coils being individually connected in circuits with both said primary coils whereby when one said tube strikes, the quantity of flux coursing through the other of said sections increases, due to increased current flow in its primary coil, thereby increasing the voltage induced in the other secondary coil, so that the associated tube strikes almost instantaneously.

2. A system of illumination comprising a high leakage reactance, autotransformer having two main magnetic core portions, each having a primary coil, an extension coil, and a secondary coil mounted individually thereof a source of electrical energy; said primary coils being connected across said source of energy in series, and in series with said extensions coils having autotransformer connection in series-aiding relationship with said primary coils; a condenser across the terminals of said extension coils for power-factor correction; fluorescent gas discharge tubes individually connected with the secondary coils, each said secondary coil being connected in series-aiding relationship, with the primary coil of the opposite core portion and with the primary coil of its own core portion.

3. A tube lighting system, comprising a high leakage reactance transformer comprising two main magnetic core portions each having a primary coil and a secondary coil mounted individually thereof said paths, the primary coils being located closer to the junction of said paths; a source of electrical energy supply, said primary coils being connected in parallel-opposed relationship across said source; and fluorescent tubes individually connected across the secondary coils, each secondary coil being electrically connected in series with the network consisting of the parallel-connected primary coils.

4. A system for energizing fluorescent gas discharge tubes, comprising a high leakage reactance autotransformer having two main magnetic core portions each having a primary coil and a secondary coil mounted individually thereof and a shunt core portion magnetically between the coils; a source of alternating-current electrical energy, said primary coils being connected in parallel across said source; each secondary coil being in circuit with a fluorescent gas-discharge tube, and series-connected with the network consisting of the parallel-connected primary coils.

5. A fluorescent gas discharge tube lighting system comprising in combination, a high leakage reactance autotransformer which consists of a core divided magnetically into two parts by high leakage reactance shunt means including air-gaps calibrated according to the secondary load for which the transformer is designed, a primary coil and an extension coil disposed on one said part and a secondary coil disposed on the other said part; a source of alternating-current energy across which said primary coil is connected, the said primary coil additionally being connected in series with an extension coil and a power-factor-improving condenser, in a separate autotransformer circuit with the secondary coil; and a fluorescent gas discharge tube connected across the secondary terminals of the said primary and secondary coils, the high leakage reaction shunts serving to by-pass the greater part of the primary flux about said secondary coil upon increase in the load across said coil.

6. A system for energizing fluorescent gas-discharge tubes, comprising a high leakage reactance autotransformer having two main magnetic core portions, each having a primary coil and a secondary coil mounted individually thereof and a shunt core portion magnetically between the coils; a source of alternating current electrical energy, said primary coils being connected in series across said source; and fluorescent gas-discharge tubes individually connected across the secondary coils, each secondary coil being individually connected in series with the primary coils.

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