BALLAST TRANSFORMERS HAVING BRIDGED AIR GAP

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ABSTRACT OF THE DISCLOSURE

A transformer suitable as a ballast for an electric discharge lamp, the transformer having two magnetic cores, one having a full air gap and one a bridged air gap, a primary coil encircling both cores, a secondary coil encircling only the core with the bridged gap and being connected in series with part of the primary winding series-aiding, to act as an auto-transformer. The air gaps are under the windings, the bridged air gap being under the secondary winding; another bridged gap may be used in the same core under the primary winding. Two oppositely disposed plates, held together by a bolt passing through the space between cores, clamp the transformer together.

This application is a continuation of my copending patent application Ser. No. 546,416, filed Apr. 29, 1966, the specification, claims and first sheet of drawings hereinafter, the second sheet of drawings conforming to the description of FIGS. 4 and 5 in said copending application.

This invention relates to transformers for operating electric discharge lamps and other devices requiring a different voltage for starting than for subsequent operation. The starting voltage is generally higher than the operating voltage, and the transformer is generally called a ballast.

Transformers with long, narrow cores have been commonly used as ballasts for many years, but they are bulky and expensive, with large stray fields, the latter producing heavy losses and considerable noise when placed in metal containers or near metal parts. Ballast transformers having external magnetic shunts across the middle of the core between the coils have also been used, but with similar disadvantages.

Suggestions have been made to use two cores, each shaped like a squared O, with one leg of each O in proximity to one leg of the other, to form a sort of squared figure 8, with one winding encircling both of the legs which are in proximity to each other at the middle of the 8, and another winding encircling only one core. Such constructions have, in U.S. Patent 2,792,556, issued May 14, 1957, to W. Ogleboe. In this patent, however, each core has two air gaps which would cause large stray fields and considerable noise, without giving the high peak voltage desired.

Instead of having both cores of substantially the same magnetic characteristics, I discovered that it was necessary to have one core of a different magnetic characteristic from the other. Dissimilar cores had previously been used in voltage regulators for vacuum tube lamp filaments, as shown in U.S. Patent 1,654,097, issued Dec. 27, 1927, to W. J. Shackleton. However, in this a secondary coil was present on each outside leg of the core and connected in series opposition to get voltage regulation; moreover, although an air gap was used in one core, there were no gaps at all in the other core, and of course there is no mention of the problems of ballasts for electric discharge lamps.

But so far as I am aware, none of the devices in the aforementioned patents have been used commercially as ballasts for electric discharge lamps. They were all unsuitable for one reason or another. I have discovered, however, that a remarkably effective ballast can be made with a magnetic circuit composed of two cores, each closed except for air gaps, and each having four legs in series with the center leg of the combined core including two legs in parallel, one leg from each core. A full air gap is used in one of the parallel legs, at least one bridged air gap in the other. The magnetic circuit having a full air gap in its parallel leg has no other air gaps; the other magnetic circuit can have an additional bridged air gap in the opposite leg. If a single bridged gap is used it should be on the leg containing the secondary coil.

The parallel legs are spaced apart by air or other nonmagnetic material to prevent the bridged gap in one parallel leg short circuiting the full air gap in the other. The magnetic circuits of the two cores are substantially separate except for interaction through the coils. The primary coil links both cores, being wound around their parallel legs, and the secondary links only the core with the bridged gap and is wound on the leg opposite the leg in the primary coil. The primary and secondary can be connected as an auto-transformer. Each gap, bridged or otherwise, is under a coil.

The above device provides a peaked pulse for starting the lamp during part of each half cycle, provides the proper reactance for ballasting, gives some degree of independence of fluctuation in line voltage, keeps stray fields at a minimum, reduces noise and lowers manufacturing costs. In addition it enables a flexibility in design for controlling open circuit voltage and waveform and results in a ballast of minimum size, even allowing the use of a smaller condenser.

I have discovered that the number of air gaps and type and position of each is very important.

The leakage flux in the core having a full air gap is greatly reduced by using only a single air gap in that core and having it under the coil for there is then very little magnetomotive force drop around the rest of the core, the drop being nearly all in the air gap. Having the air gap under the coil also reduces the noise level by reducing the stray field, and also by keeping the open ends of the gaps where they can be held securely in place. The core is made up of two U-shaped stacks of laminations, joined facing each other. At one end of each U, the laminations can be arranged to stack even with each other, to form an air gap; at the other ends, they can be staggered so that they will interleave. This further reduces noise from the laminations. In the other leg, the use of bridged gaps on opposite legs not only reduces noise by helping to confine the possible movement of the ends of the laminations but also aids in providing a high peak voltage and a good lamp current waveform. The unbridged air gap can be adjusted to give a desired power factor.

In addition the bridged gaps provide a high voltage peak during each half cycle for starting the lamp. The air gap core has such a high reluctance that nearly all the flux goes through the bridged gap core until the latter saturates, thus providing a high voltage up to that time in the cycle. Once the bridges saturate, the flux is forced into the air spaces between the bridges, resulting in operation like an air gap, thereby increasing the reluctance so that the flux is shared with the air gap core, and the voltage induced in the secondary is reduced. The time-width of the pulse increases with the amount of bridging.

When only one bridged gap is present in the core carrying the secondary winding and it is in the leg carrying the primary coil, there will be considerable stray field and leakage flux between the two connecting legs, that is,
between the legs which do not carry the coil. The full magnetomotive force of one coil will exist between the legs whether the bridged gap is in the primary or secondary leg. If two bridged gaps are used, one in each leg bearing a coil, then I find that the major portion of the magnetomotive force of each coil occurs across the gap that it overlies, and the magnetomotive force across the connecting legs is small, the stray field and loss of flux between these legs being accordingly small.

A bridged gap in the secondary leg, with air gaps in the primary leg, is also very effective. In this case, the flux in the core which links only the primary causes, in fact, a drop in the magnetomotive force in the primary leg of the secondary core while the bridged gap causes a magnetomotive force in the secondary leg. But when only one bridged gap in the secondary core is used, it will produce a large stray field if it is placed in the primary leg of the secondary core.

The core can be held together most effectively by using a channel fitting over the laminations on one side of the core, a metal piece fitting against the laminations on the other side, with a bolt passing through, extending down the space between the two cores at the middle of the 8, and passing through the channel and the other metal piece, the bolt having a head at one end and a bolt at the other, the nut being tightened to hold the assembly together. Thus the whole unit is held together by a single bolt, the whole unit being very quiet and free from noise.

Other objects, features and advantages of the invention will be apparent from the following specification, taken in connection with the accompanying drawings in which:

FIGURE 1 is a perspective view of a transformer according to the invention.

FIGURE 2 is a profile section of the same transformer.

FIGURE 3 is a circuit showing the transformer connected to a lamp.

FIGURE 4 is a view showing the arrangement for holding the transformer together.

FIGURE 5 shows the wavefront of the secondary voltage.

In FIGURE 1 the two cores 1, 2 are shown carrying the two coils 3 and 4. Coil 3 is the primary coil and encircles a leg of each core; coil 4 is the secondary coil and encircles a leg of core 2 only. Coil 4 has the connecting wires 5 and 6 at its ends, the latter wire being connected to a connecting wire 7 from a tap on the primary coil, there being also two other lead-in wires 8 and 9, each from coil 4. Each coil has a covering 10, 11 of insulating tape wound around it in the usual manner. A mounting plate 12 has its middle portion 13 bent into a channel which engages the bottom leg of the core 1, 2 holding them firmly to prevent vibration. The mounting holes 14, 15, 16, 17, 18 and 19 (the latter two being shown only in FIGURE 4) are useful as holes through which screws can be passed for mounting the transformer on a support. At the top of the transformer the channel 20 is held in reverse fashion, that is with its side walls 21, 22 pointing upwardly, bolt 23 having a nut 24 affixed thereto as seen at the top of said channel 20 and passes in the space 37 between the two cores to engage the mounting plate 12 and hold the assembly together, as shown more fully in FIG. 2.

The air gap 25 in core 1, and the bridged air gaps 26, 27 in core 2 are shown in FIGURE 2. Although two bridged air gaps 26, 27 are shown, the air gap 26 can be omitted. In core 1 the laminations 28 are staggered at the joint 29, opposite the air gap 25, in order to prevent good magnetic contact there and to confine any air gap to the other side of the coil, that is to gap 25. In core 2 the bridging pieces are staggered, with the bridging pieces under the primary coil 3 extending oppositely to the direction in which the bridged pieces on the opposite air gap 27 extend; that is, the bridging pieces under the primary coil extend upwardly as the bridging pieces under the coil 4 extend downwardly. The bolt 23 has its head 33 against the bottom of the middle portion of channel 12, the bolt extending upwardly in the space between the cores and terminating in a threaded portion which passes through the channel 20 into the washer 35, which is held against channel 20 by a nut 24 screwed onto the thread of bolt 23.

A diagram of the electrical circuit of the transformer and lamp is shown in FIG. 3. The primary coil 3 has the intermediate tap 7, which divides it into coil 36, which is in the primary circuit only, and coil 38 which is common to both primary and secondary, in the autotransformer manner. Coil 4 is in the secondary circuit only, and generally referred to herein as the secondary coil, coil 4 as a whole being generally referred to as the primary coil.

A condenser 39 and electric discharge lamp 40 are connected in series between an end 5 of the secondary coil and end 9 of the primary 3, the end 9 also being connected to the line, as in the other end 8 of the primary 3. The tap 7 is connected to the end 6 of the secondary coil in autotransformer fashion. To prevent circuлатion, the ends of the coils are referred to above by the reference numbers of the connections made to the end.

The manner of holding the transformer parts together will be further apparent from FIG. 4 in which the cores 1, 2 are shown in phantom, so that the mechanical features of the holding assembly can be shown clearly. The mounting plate 12 had its middle portion bent upwardly to form side walls 42 which tightly grip the sides of the legs 43, 44 of the cores 1, 2 forming a channel and having tabs which fit into the space 37 between the cores 1, 2. The otherwise flat bottom 45 of mounting plate 12 has the longitudinal parallel ribs 46 extending up out of the bottom 45 to keep the plate 45 rigid and on which the cores 1, 2 rest. A bolt 23, having its head 33 on the bottom of the plate 12 extends through the space between the cores, through the reversely-placed channel 20, and through a square washer 34, a nut 24 being screwed onto the threaded top portion of bolt 23 to hold the assembly together. The square washer 34 is held from turning by the upwardly-extending walls 21, 22 of channel 20, the walls also serving to make channel 20 more rigid.

The above construction holds the transformer together with only a single bolt, and holds it so well as to reduce the noise level over customary methods of assembly and clamping of transformers.

Before the lamp starts, the reluctance of the air gap 25 will be much greater than that of the bridged gaps 26, 27 because the flux in the bridging pieces has not yet become saturated. Nearly all the flux produced appears in the secondary core 2, and very little in the other core 1. The voltage across the secondary will thus be the turns-ratio voltage, and rise to a sharp maximum. As the secondary flux nears the saturation value, the rate of change of flux with time decreases, and with it the induced voltage. The flux in the primary core thus becomes a larger part of the total flux, and a larger reactance drop appears in the primary circuit. The secondary, since the voltage induced in it by the primary is now smaller, acts mainly as a reactance in series with the primary and with the oil of the current producing a large back magnetomotive force, opposite to that in the primary. However, this magnetomotive force does not appear across the two legs because of the drop in the bridged gap 27. Similarly, the opposing primary magnetomotive force will be reduced by the gap 26 so the two, although equal and opposite, except for the magnetizing magnetomotive force which is out of phase, are small. There is very little magnetomotive force between the legs—hence the stray field.

When the bridged gap 27 is omitted, the full back magnetomotive force of the secondary appears between the opposite side legs of core 2 with a large stray field and leakage flux between them. The arrangement is therefore ineffective. When bridged gap 26 is omitted instead,
the same result might be expected, but the stray field and leakage is actually discovered to be smaller than with both bridged gaps 26, 27. The reason appears to be that a large part of the magneto motive force of the primary is present in core 1, and hence across the air gap 25, which reduces the magneto motive force available in core 2 from the primary coil 3.

The presence of an air gap 25 in core 1 and of at least one bridged gap in core 2 allows the power factor to be adjusted by a gap different from that which sets the peak of the voltage wave. The power factor can be set by adjusting the primary gap 25.

In the ballast transformer for the 400-watt high pressure mercury lamp, especially for a mercury lamp of the type containing iodine vapor and added metals such as thorium, sodium and scandium, the overall dimensions outside are 4% inches high by 5% inches long by 3% inches wide, of about 9% inch stock. The overall height of the sidewalks is about 3% inch.

The bolt 23 is a 1/4–20 carriage bolt in size, made of aluminum.

The cores 1, 2 are each about 2% wide, that is, 2 inches viewed from an end of the transformer. The outside dimensions of the core, looked at from the side, are 2 inches by 3% inches for core 1, the thickness of the stack of laminations being about 5% inch by 9% inch. The other core is of about the same dimensions except that the 2-inch dimension in core 1 becomes about 2% inches in core 2.

The primary coil 3 has 530 turns on an insulating tube having a hole 0.763 inch by 2.25 inches, which is filled by a leg of the core. The coil is about 2.11 inches long. The secondary 4 is of 200 turns with a hole of 1.656 inches by 2.25 inches, and is about 2% inches long. The primary 3 is of insulated wire of No. 17 A.W.G. and the secondary of 16 A.W.G.

The air gap 25 in core 1 is about 3% inch long, the two bridged gaps 26, 27 in core 2 being each about 7% inch long, each with three bridging strips, each bridging strip being of the same thickness as the other laminations, that is about 0.0187 inch. The interleaved portion is about 3% inch long.

In this transformer, if used on a 110-volt line, there will be no intermediate tap on the primary coil and the wire 7 will go directly to connecting wire 8, so that the secondary 4 will be in series with the whole primary coil 3.

The condenser 39 is of 12.7 microfarads, capable of withstanding 475 volts, and the lamp 40 is a 400-watt high pressure mercury iodine lamp with added metals, as explained above. The transformer can also be used with a 400-watt high pressure mercury lamp which has no iodine or added metals, and the interchangeability of the lamps is an added advantage obtained by my invention.

If the transformer is for operation from a 220-volt line then the primary will have about double the number of turns, with a tap near its middle as in Fig. 3. The wire size in the primary will be reduced because of the smaller current carried.

The core is made of steel strips bent to the desired shape and stacked, as shown in U.S. Patent to Biggs et al., issued July 9, 1963, Patent No. 3,096,805. Other types of core can be used but will be less effective, and, of course, far less flexible in design possibilities.

Fig. 5 shows the waveform of the voltage across the terminals of the transformer; the voltage across the lamp will be somewhat different, because of the series condenser. The sharp pulse 43 will not be at the middle of the voltage wave across the lamp, but will be nearer to its beginning, and may even be negative across the lamp, that is, may extend below the zero line of the waveform curve. Since the pulse occurs at substantially open circuit, it will be always in the same phase with the induced transformer voltage, whereas the phase of the voltage across the lamp will change with the values of capacitive and inductive reactance used. The height of the voltage peaks is not as important once the lamp starts, but is very important in starting. In most cases, the lamps do not need to be restarted, each half-cycle, but only during the first few starting cycles.

Although a particular embodiment has been described, many modifications will be apparent to a person skilled in the art, without departing from the spirit and scope of the invention, as set forth in the claims.

What I claim is:

1. A ballast transformer for electric discharge lamps, comprising a first magnetic core, closed except for an air gap, a second magnetic core, closed except for at least one bridged air gap, a portion of one core being close to but spaced from a portion of said other core, a primary coil encircling each of said portions of said core and overlying the air gap in said first magnetic core, and a secondary coil encircling a portion of said second magnetic core only and overlying a bridged air gap therein.

2. The transformer of claim 1, in which the secondary coil is connected in series aiding with at least a portion of said primary coil to form an autotransformer.

3. The transformer of claim 1, in which the primary coil also overlies a bridged air gap in the second magnetic core.

4. A ballast transformer for electric discharge lamps, comprising a first magnetic core having four legs in series, a second magnetic core having four legs in series, one leg of said first magnetic core being placed close to but spaced from a leg of said second magnetic core, a primary coil encircling both said legs, an air gap in said first magnetic core, the primary overlying said air gap, a secondary coil on another leg of said second magnetic core, said leg being opposite the leg encircled by the primary coil and having one of the other legs joining one end of it to one end of the leg encircled by the primary coil, and the fourth leg joining the other end of the leg encircled by the secondary coil to the other end of the leg encircled by the primary coil, said joining legs being substantially free of air gaps and the leg encircled by the secondary coil having a partially-bridged air gap which the secondary coil overlies.

5. The transformer of claim 4, in which the core leg of the second magnetic core carrying the primary coil also has a bridged air gap.

6. The transformer of claim 4, in which at least a portion of the primary coil is connected in series aiding to the secondary coil.

7. The combination of claim 1, a mounting plate against corresponding sides of each core, a channel member bearing against the opposite sides of each core, and a bolt passing through both channel members in the space between the cores, to urge the channel members toward each other to hold the cores rigidly in place.

8. The combination of claim 7, in which the mounting plate has upwardly turned sidewalks which grip the core and tabs extending from said sidewalks into the space between the cores.

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