

July 21, 1970

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3,521,152

CONSTANT VOLTAGE TRANSFORMER WITH CORE GAP AT PRIMARY END

Filed Aug. 28, 1967

5 Sheets-Sheet 1

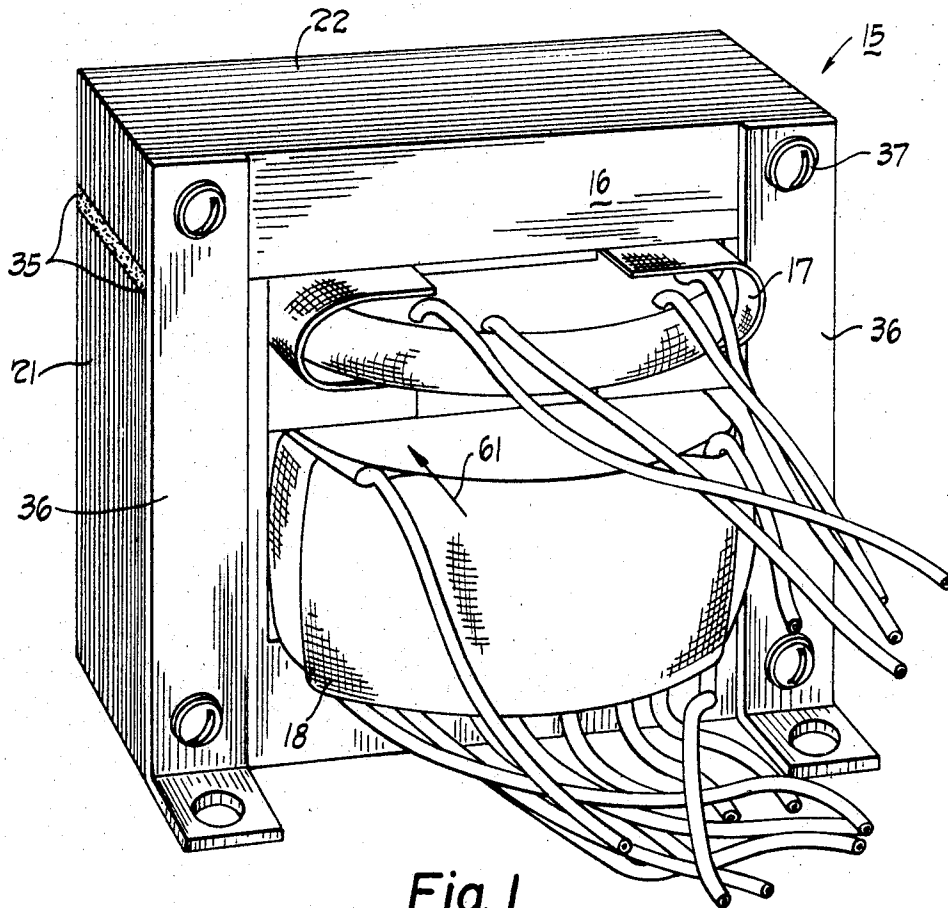


Fig. 1

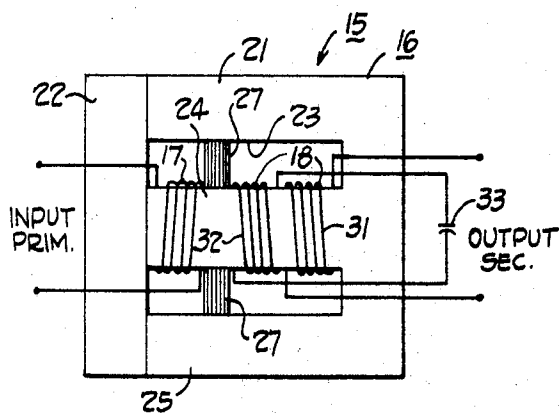


Fig. 2

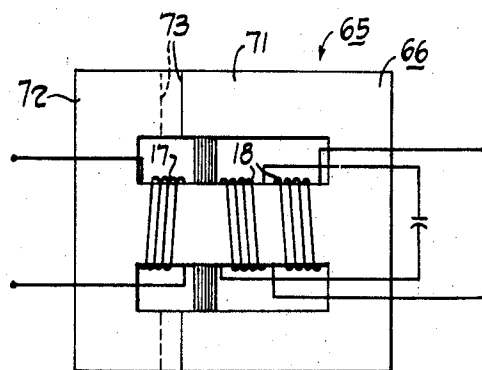


Fig. 3

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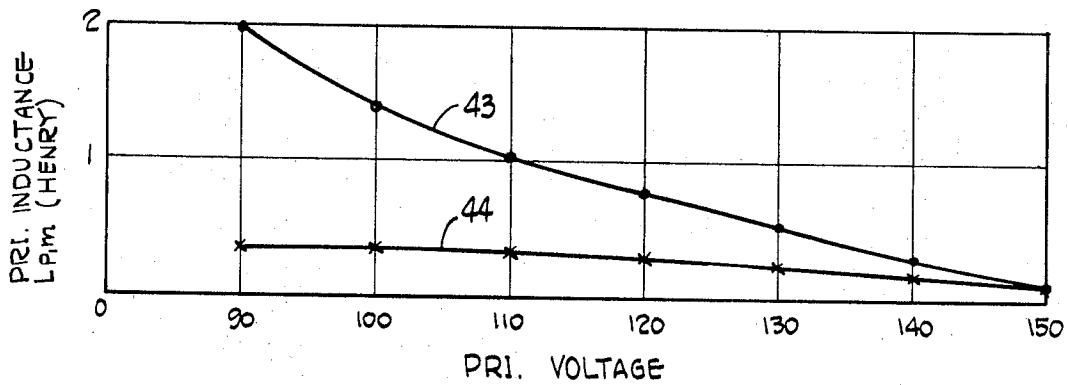
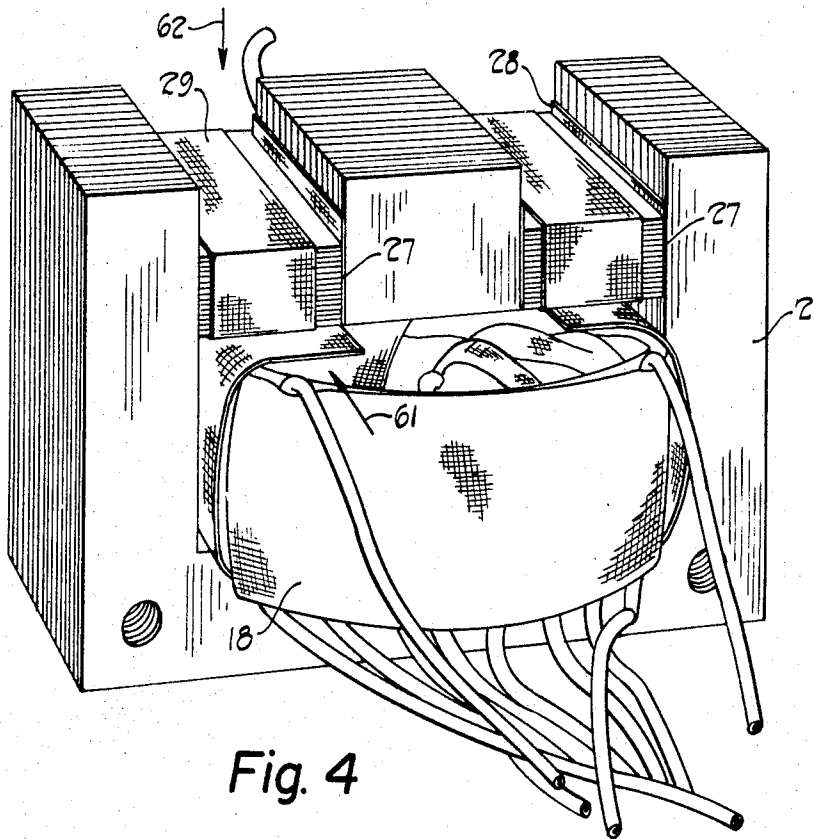
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5 Sheets-Sheet 2



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CONSTANT VOLTAGE TRANSFORMER WITH CORE GAP AT PRIMARY END

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5 Sheets-Sheet 3

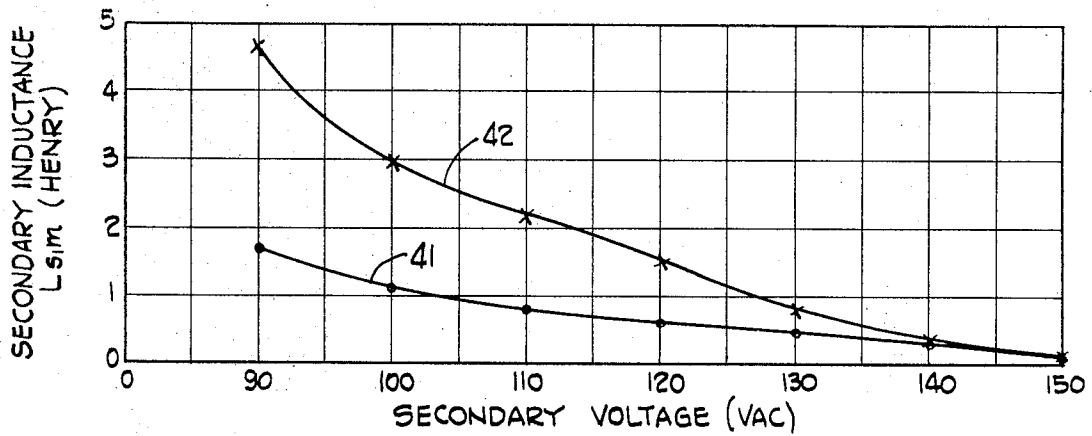


Fig. 6

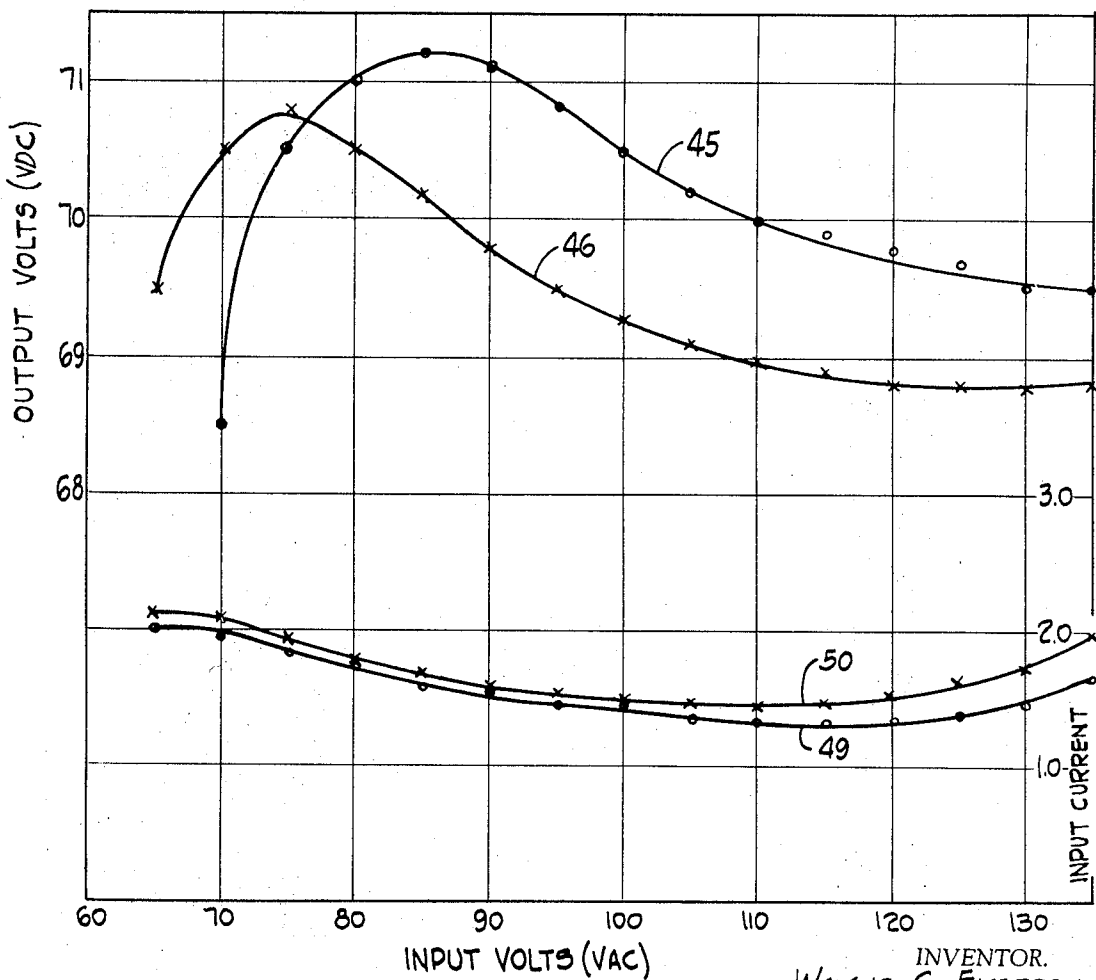


Fig. 7

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5 Sheets-Sheet 4

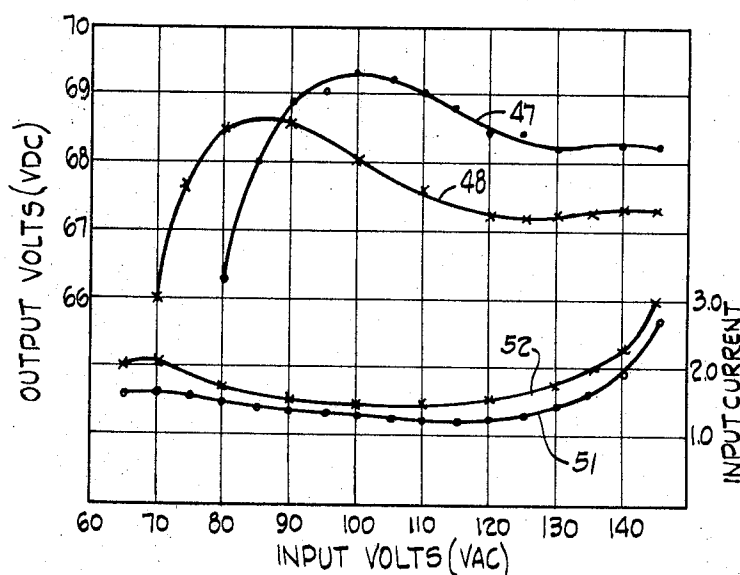


Fig. 8

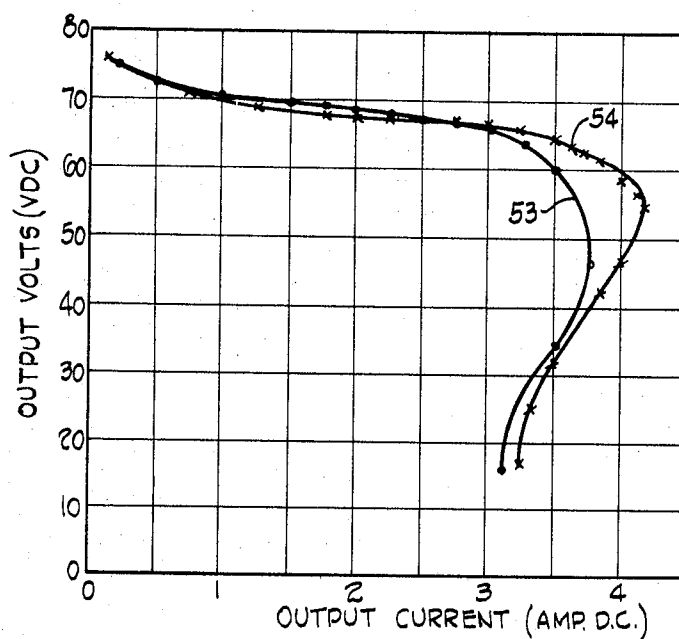


Fig. 9

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5 Sheets-Sheet 5

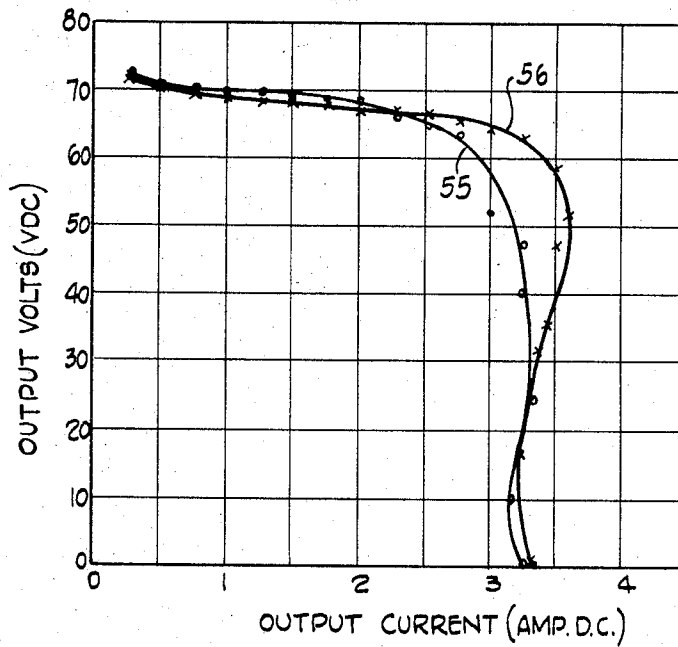


Fig. 10

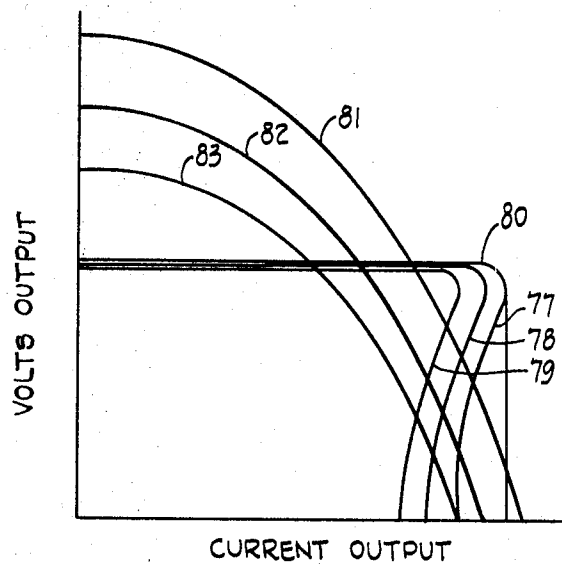


Fig. 11

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CONSTANT VOLTAGE TRANSFORMER WITH CORE GAP AT PRIMARY END

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Int. Cl. G05f 3/06, 5/00

U.S. Cl. 323—60

10 Claims

ABSTRACT OF THE DISCLOSURE

The invention relates to a substantially constant voltage transformer with a core having E and I laminations and a butt joint or lap joint of these laminations all at the primary end of the core. A magnetic shunt is positioned on the core between a primary and a secondary winding to shunt some of the secondary flux. This flux is greater than the primary flux because the secondary winding or a part thereof is connected to a resonating capacitor resonant at the fundamental frequency to establish a ferroresonant transformer wherein the central leg of the secondary core portions is operated above saturation and the primary portion of the core is operated below the knee of the B-H curve. The joint in the core permits the entire transformer to be assembled with the coils on the core and the fact that the secondary core portion has no joint whatever, increases the range of operation by about 20%. This 20% increase is true for regulated output current versus output volts and also for the operating range of input voltage over which the output voltage remains substantially constant. This is in comparison with the prior art form of constant voltage transformer which used E and I laminations interleaved so that the butt joints were interleaved and staggered, alternating on the primary and secondary ends of the core. Accordingly, instead of having the 20% increase in input voltage range and regulated voltage range, one may alternatively provide less volt-ampere capacity in the capacitor and capacitor coil combination, and still achieve a constant voltage transformer meeting the same specifications as the prior art devices.

BACKGROUND OF THE INVENTION

For decades the prior art construction of transformers has been to use E-I laminations with the direction of the legs of the E-shaped pieces alternating so that the butt joints interleaved and were staggered, first on one end and next on the other end core. This achieved a staggered joint construction which had a minimum of magnetic reluctance in the magnetic core circuit.

Constant voltage transformers or voltage stabilizers, as they are sometimes called, are forms of a ferroresonant transformer and are devices to maintain a substantially constant output voltage despite fluctuations in the incoming line voltage. Accordingly these devices are precision devices meeting rather rigid specifications, and it has been the prior art practice to interleave each individual lamination, as in ordinary transformers, in order to achieve the lowest possible reluctance in the core and hence the highest possible inductance in the windings. For example, if one is stacking a 4 inch high stack of E-I laminations completely interleaved using 2973 transformer steel, then this is about 280 laminations. 2973 steel is a grain oriented steel which is 29 gauge and has a 0.73 watt core loss per pound at 15,000 gauss. 29 gauge steel is 0.014 inch thick or about 70 laminations per inch for a total of 280 laminations in a 4 inch high stack. This is 280 separate interleaving operations for an operator assembling the core through the window of the coil or coils, and accordingly it is a time consuming, painstaking job. Also

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after the core was assembled onto the winding means then magnetic shunts had to be driven in place between the primary and secondary windings and had to be driven in a direction perpendicular to the plane of each lamination. Next, because this is a precision device there was 100% testing of the manufactured product, namely each device had to be tested. The laminations of the core had to be clamped together, a nominal input voltage applied to the winding in order to see if the standard output voltage was developed on the secondary. If the voltage was low, then lamination steel had to be added, or if the voltage was high, lamination steel had to be removed in order to achieve the standard output voltage desired.

In ferroresonant devices, the secondary winding or a part thereof or a separate secondary coil is connected in parallel with a capacitor to be resonant at the fundamental frequency of the device. In these constant voltage transformers the capacitor is approximately 25 or 30% of the total cost of the constant voltage transformer. Accordingly this is a large factor in the manufactured cost of the entire item.

The prior art has also attempted to use gaps only in the primary end of the core on ballasts used with neon lamps or fluorescent lamps. Such devices have a different construction and for a different purpose. Such ballasts are essentially constant output current devices whereas the present invention is for a constant output voltage device. In such prior art ballast the gap in the core portion was selected of a certain value in order to establish the desired power factor, instead of having the gap minimized for a maximum primary inductance. Also, such devices achieved regulation by reducing the core area in only one portion as by a hole or a slot cut in the core. Additionally such ballasts used a capacitor in series in order to limit the current and a parallel capacitor was generally used in order to resonate with the third harmonic of the supply voltage rather than resonating with the fundamental of this supply voltage. Such ballasts are well known in the art and establish a high voltage to start or ionize the neon or fluorescent lamp and then after ignition the ballast produces a low voltage to operate the lamp at a lower voltage and a substantially constant output current.

Voltage stabilizers or constant voltage transformers of the present invention are of the ferroresonant type wherein a core has a shunt between a primary and a secondary winding. The secondary winding may be one or more coils with a capacitor connected across the capacitor coil or capacitor coil portion of the secondary winding. The capacitor has a value selected so that it will be substantially resonant at the fundamental frequency with that portion of the secondary winding with which it is in parallel. As the input voltage on the primary winding is increased from zero toward the nominal operating voltage level, the flux threading through the secondary winding tends to increase nearly in direct proportion to the primary flux, due to the reluctance of the extra gaps at the shunts. As the induced EMF of the secondary winding reaches a higher value, approaching the nominal operating voltage, a critical point is reached wherein resonance takes place because at that point the capacitive reactance of the capacitor substantially equals the inductive reactance of the capacitor coil portion of the secondary winding. Under this resonant condition, a fairly large current will flow in the resonant circuit, setting up a relatively high flux in the secondary winding portion of the core. This resonant circuit has many times more volt-ampere capacity than the magnetizing volt-amperes supplied to the primary winding. This is why the device is called a ferroresonant type of transformer and is why the center leg at least of the secondary winding portion of the core is driven into saturation, well above the knee of the B-H curve. At the same

time, the primary winding portion of the core is operating close to but below the knee of the B-H curve, because the flux in the primary winding portion is lower, only enough to drive the secondary winding portion of the core into the resonant and saturated condition.

Under such conditions changes in the input voltage have substantially no effect on the output voltage, because such changes merely change the position of operation of the primary winding portion below the knee of the curve whereas the secondary winding portion of the core remains saturated so that the output voltage therefrom remains substantially constant.

Accordingly an object of the invention is to provide a ferroresonant transformer which obviates the above mentioned disadvantages.

Another object of the invention is to provide a constant voltage transformer which has a greater input voltage range over which the output voltage range is maintained substantially constant.

Another object of the invention is to provide a constant voltage transformer which will support a greater load current in the regulated voltage range.

Another object of the invention is to provide a constant voltage transformer wherein a smaller capacitor or capacitor coil may be used, establishing a smaller volt-ampere capacity rating with the capacitor coil, for the same input voltage range and regulated voltage range.

Another object of the invention is to provide a constant voltage transformer with an increased harmonic content in the output and a lower peak output voltage which will permit use of a smaller filter capacitor where the output voltage is delivered to a rectifier.

Another object of the invention is to provide a constant voltage transformer which has easier assembly and testing.

Another object of the invention is to provide a constant voltage transformer wherein the cost of stacking the core laminations is drastically reduced.

Another object of the invention is to provide a constant voltage transformer wherein there is no joint in the core at the secondary end of the core, the only joint being at the primary end.

SUMMARY OF THE INVENTION

The invention may be incorporated in a transformer having substantially constant output voltage, comprising, in combination, a core and primary and secondary winding means thereon, a magnetic shunt in said core between the primary and secondary winding means to provide a shunt for primary or secondary flux, a capacitor connected to said secondary winding means to increase the flux density in the secondary winding portion of the core to stabilize the output voltage relative to a variable input voltage, and said core being constructed with an absence of joints at said secondary winding end of the core except for said shunt to thus improve the input voltage range of operation of the transformer for a given amount of resonating volt-ampere capacity in the capacitor and secondary winding combination.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims, taken in conjunction with the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a perspective view of a constant voltage transformer made in accordance with the invention;

FIG. 2 is a schematic view of the core and winding of the preferred embodiment of FIG. 1;

FIG. 3 is a schematic view of the core and winding construction of a modification of the invention;

FIG. 4 is a perspective view of the transformer of FIG. 1 in a partly assembled condition, and

FIGS. 5 through 11 are graphs of voltage, current and inductance showing operation characteristics of the device of the invention.

FIGS. 1, 2 and 4 show the construction of the preferred embodiment of the invention, however many changes may be incorporated and still be within the scope of the hereinafter appended claims, as will become more evident from the following specification. The FIGS. 1, 2 and 4 show a constant voltage transformer 15 constructed according to the invention. This transformer 15 includes generally a core 16, a primary winding means 17 and secondary winding means 18. The core is constructed from first and second groups of laminations 21 and 22 respectively, with the first group 21 being E-shaped laminations and the second group 22 being I-shaped laminations. The E-shaped group of laminations 21 has legs 23, 24 and 25, and the ends of these legs make a butt joint with the second group of I-shaped laminations 22. All of the laminations are in the plane of the paper of FIG. 2 and all of the butt joints between the first and second groups of laminations 21 and 22 are stacked one above the other, as opposed to being interleaved for lap joints, and these butt joints are all at the primary winding end of the core 16. The core also includes magnetic shunts 27 tightly disposed in the windows between the legs 23, 24 and 25 and longitudinally disposed between the primary and secondary winding means 17 and 18. Insulating sheets 28 may be wedged between the ends of the laminated magnetic shunts and the legs 23-25 in order to make these shunts fit tightly and still have a specified air gap for proper operation of these magnetic shunts. A layer of tape 29 may be placed around these shunts in order to hold them in place for ready handling and assembly.

The primary winding means may include only a single coil 17 having two terminals adapted to be connected to an AC supply source; for example, 115 volt, 60 hertz for an input voltage to this constant voltage transformer 15. Additionally there may be a tickler winding, either a buck or boost winding, in this same winding space with the primary winding 17 and connected in series with the secondary winding in order to give the proper rising or drooping characteristic to the output voltage.

The secondary winding means is shown as including a secondary coil 31 and a capacitor coil 32. A capacitor 33 is connected in parallel with the capacitor coil 32. As is well known in this art, the capacitor 33 is connected to at least a part of the secondary winding means 18 so as to be resonant therewith at the fundamental frequency of the input voltage. The capacitor 33 may be connected across only a portion of the secondary coil 31, it may be connected across the entire secondary coil 31, with the actual secondary output tapped off this secondary coil 31, or as shown in this FIG. 2 the capacitor 33 may be connected to an entirely separate capacitor coil 32. In each of these cases the capacitor 33 is connected to some portion of the secondary winding means 18 which is on the secondary winding end of the core 16.

The FIG. 4 shows the constant voltage transformer 15 as partially assembled with the secondary winding means 18 in place and the magnetic shunts 27 in place, however the primary winding means 17 and the first group of laminations 21 are not in place, in order to show the sequence of assembling the transformer 15. FIG. 1 shows the transformer 15 as completed except for dipping and baking in a varnish or the like. In this FIG. 1 the first group of laminations 21 has been put in place and fastened by any suitable means such as a clamp or in this case by the weld line 35 in two places on the outside periphery on each end of the lamination group 21. Such welding is done after the first and second groups 21 and 22 are tightly compressed together to minimize any air gap at the butt joint between the groups 21 and 22. Also FIG. 1 shows L-shaped mounting brackets 36 having bolts or rivets 37 extending through holes in the core groups 21 or 22 in order to help hold

these groups together and to provide a support for the entire transformer 15.

OPERATION

For decades transformer type devices have utilized E-I laminations. The laminations are to reduce eddy current losses and these laminations for decades were interleaved, with legs of the E extending first to the right and then to the left in the next level of laminations, in order to achieve staggered butt joints and hence achieve a minimum reluctance and a maximum inductance. This conventional manner of stacking E-I laminations in transformers has also been followed in the prior art for decades in constant voltage transformers. This has resulted in half of the joints being in the primary winding end of the core and the other half of the joints being in the secondary winding end of the core.

The present invention relates to the fact that it has been discovered that if there are no joints in the secondary winding end of the core of this constant voltage transformer, then surprisingly beneficial results are obtained. FIG. 6 shows a curve 41 of secondary magnetizing inductance versus secondary voltage for the prior art construction of interleaved joints, with half the joints in the primary end and half the joints in the secondary end of the core. This same FIG. 6 shows a curve 42 of secondary magnetizing inductance versus secondary voltage for the butt joint construction with the joints all at the primary end of the core, as taught by the present invention. These two curves 41 and 42 illustrate that the magnetizing inductance of the secondary winding is considerably higher when there is no joint in the secondary end of the core, instead all of the joints are at the primary end of the core. FIG. 5 illustrates a curve 43 of the primary magnetizing inductance versus the primary voltage for the interleaved joint construction of the prior art. FIG. 5 also shows a curve 44 of the primary magnetizing inductance versus primary voltage for the butt joint construction in the primary end only of the core, as disclosed in the present invention. These curves 41-44 of FIGS. 5 and 6 were taken by utilizing the very same parts and merely restacking the laminations. The curves 41 and 43 were taken with the unit stacked in the conventional prior art manner of the laminations interleaved so that the joints are staggered and alternately in the primary and secondary end of the core. Next the unit was disassembled and the very same laminations were restacked so that all of the E-shaped laminations of the first group 21 were oriented in the same direction and hence there was a butt joint only at the primary end of the core. The unit was again tested with the identical windings and the curves 42 and 44 were obtained. As shown in the comparison of the curves 43 and 44, the primary inductance is greater for the interleaved construction than for the butt joint construction, however, the butt joint results in a greater magnetizing current. A comparison of curves 41 and 42 show that in all cases the secondary inductance is greater in the butt joint configuration than in the interleaved configuration. The particular lamination steel used was No. 2973 transformer steel which is 29 gauge and has .73 watt core loss per pound at 15,000 gauss. This is a grain oriented steel, oriented in the direction of the legs 23-25 of the E-shaped laminations. Accordingly there is a small portion of the core where the legs are joined which consists of steel which is grain oriented generally perpendicular to the direction of flux flow. This disadvantage has been found to be insignificant compared to the advantage of eliminating all air gaps in the secondary circuit, since the net result of the butt joint stacking is a considerably higher secondary inductance.

FIG. 7 shows a curve 45 of secondary output volts versus primary input volts for the prior art interleaved lamination construction. This same FIG. 7 shows a curve 46 again of output volts versus input volts for the butt joint at the primary end construction of the present in-

vention. This test was again a comparison using the very same parts and merely restacking the laminations from an interleaved construction to one with all the butt joints at the primary end of the core; nothing else was changed. The particular constant voltage transformer tested had a three to one stack; namely, the stack three times as thick as the width of the center leg. Also the particular constant voltage transformer tested was one having a nominal or rated output voltage of 56 volts and 1.5 amperes rated output current. The capacitor was 2.5 microfarads. The input was 115 volts, AC 60 hertz as the nominal input voltage and this particular unit was one supplying an output voltage to a rectifier, the rectifier in turn supplying a nominal 70 volts DC output at 1.5 amps DC output. Accordingly, the ordinate has a scale of DC volts. This particular unit was rated to maintain constant output volts within plus or minus 2% throughout an input voltage range of 50 volts; namely, 115 volts nominal and plus or minus 25 volts AC. It will be noted that from the curve 46 that the butt joint construction of the present invention has a much greater regulating range extending from 140 volts down to at least 75 volts input whereas the curve 45 shows that the prior art construction has a regulating voltage range from 140 volts down to only about 85 volts input, with the same amount of safety factor. Since the curve 46 of the constant voltage transformer of the present invention shows that this transformer has more than ample input voltage range, it also shows that the transformer 15 has more volt ampere capacity in the capacitor and capacitor coil combination than is necessary. These curves 45 and 46 were run with a 2.5 microfarad capacitor and accordingly this was reduced 20% to a 2.0 microfarad capacitor and the unit again retested. The curves 47 and 48 in FIG. 8 are for the interleaved and butt joint configuration, respectively, with the 2.0 microfarad capacitor, and whereas curve 48 shows that the regulating voltage range will extend down to 85 volts, the interleaved construction would extend down to only 100 volts input, for the same amount of safety factor. The 85 volt input minimum voltage on curve 48 shows that this butt joint configuration of the present invention is just as satisfactory as the curve 45; namely, the interleaved prior art construction with a larger capacitor. Further this shows that with the butt joint configuration of the present invention it is not necessary to have as large a volt-ampere capacity in the capacitor and capacitor coil combination. The curves 45-48 show that in all cases of the butt joint configuration the output voltage tends to be slightly lower, about 1%. This may easily be compensated for by adding one extra piece of lamination, for example.

The curves 45-48 also show that the stabilizer or constant voltage transformer with the butt joint configuration goes into the ferroresonant condition at a lower input voltage than the interleaved unit. This ferroresonant condition is where the hump occurs at the lower input voltage of curves 45-48 and from there on up to the higher input voltages, the secondary core portion of the second leg 24 is saturated, that is, operated beyond the knee of the B-H curve.

The FIGS. 7 and 8 also show curves of input current versus input volt. Curves 49 and 51 in FIGS. 7 and 8, respectively, are curves of the input current versus input volts for the interleaved construction. Curves 50 and 52 are input current versus input volts for the butt joint configuration of the present invention. Again curves 49 and 50 are for a 2.5 microfarad capacitor and curves 51 and 52 in FIG. 8 are for the unit connected to a 2.0 microfarad capacitor. Comparing these curves it shows that the butt joint and interleaved devices have fairly similarly shaped curves, with the butt joint curves 50 and 52 showing that the butt joint condition has a slightly higher input current than for the interleaved units. This is due to the air gaps in the primary portion of the magnetic circuit. The input current curves have their minimum at or near

the valve of nominal line voltage where the unit would be operating most of the time. Also the input current curve is much more symmetrical about this point for the butt joint case than for the interleaved joint case.

FIGS. 9 and 10 show curves 53, 54, 55 and 56 of DC output volts versus DC output current. FIG. 9 shows curves 53 and 54 for the interleaved joint of the prior art and the butt joint of the present invention, respectively, for a 3 to 1 stack of a constant voltage transformer connected to a 2.5 microfarad capacitor. Again the core laminations are merely restacked with all other elements remaining the same. FIG. 10 shows the curves 55 and 56 for the interleaved and butt joint units, respectively, with the capacitor coil connected to a 2.0 microfarad capacitor. The curves 53-56 show load regulation, illustrating how well the output voltage remains constant or nearly so for changing output current. The curve 54 of the present invention shows that with a 2.5 microfarad capacitor connected to the capacitor coil, there is a considerably greater load regulation into overload currents than for the prior art interleaved core laminations shown in curve 53. This particular unit had the 1.5 ampere output as the nominal rated output current, at 70 volts output. With overload currents the output voltage droops slightly but it will be noted from curve 54 that the butt joint unit of the present invention sustains a much greater overload current before going into an unstable operating condition. Just as FIGS. 7 and 8 show that one could reduce the size of the capacitor from 2.5 to 2.0 microfarads, a comparison of FIGS. 9 and 10 show that one can also change from a 2.5 microfarad to a 2.0 microfarad capacitor and still have the same overload current carrying capabilities. One may compare the prior art curve 53 with the present invention curve 56 and note that they are particularly the same in overload capabilities yet the curve 56 is with a 20% smaller capacitor. Thus a higher load current is capable of being supported before the unit drops out of the ferroresonance.

Another favorable feature of the present unit of butt joint construction is that it has a higher harmonic content. In other words the wave form is more closely a square wave and hence there is a higher proportion of odd harmonics in the output voltage wave. This fact has advantages for DC applications, wherein the output of the constant voltage transformer is fed into a rectifier. Since the wave is not as peaked, the peak reverse voltage on the rectifier diodes will be lower, permitting lower cost diodes to be used. In addition the ripple factor of the rectified voltage will be lower so that less filtering is needed to reduce ripple voltage to a specified amount. Since a filter capacitor tends to charge to a peak value of voltage, the output voltage is found to be slightly lower for the butt joint unit.

Another advantage of the present invention is the ease of assembly. If one is utilizing 2973 lamination steel which has 29 gauge or .014 inch thick lamination, then a 4 inch high stack of laminations would be about 280 laminations. This would be 280 E pieces and 280 I pieces, and constitutes considerable time and handling to assemble the core. It will be recalled that to assemble the conventional E-I lamination with interleaved joints, the coils must first be wound and then the middle leg of the E pieces inserted through the window of the coils alternately from opposite ends. I pieces are alternately laid on the rising stack to make the interleaved joints. This is what takes considerable time in the assembly of the prior art conventional core. However, viewing FIG. 4, it will be noted that all of the E-shaped laminations of the first group 21 are oriented in the same direction. It is extremely easy to take a group of 280 laminations, for example, either by gauging the height or by weighing, in order to establish the first group of laminations as shown in FIG. 2. This is especially true since all E-shaped laminations are oriented in the same direction as they come from the stamping press which stamps these laminations from a strip of transformer steel.

Accordingly the labor time for stacking is materially reduced.

Another advantage of the present invention is the easier assembly of the shunts 27 into the E-shaped lamination group 21. In the prior art construction of the interleaved joints, one would have a core unit which looked similar to that in FIG. 1, namely with the E-I laminations in place with the middle leg of the E laminations inserted oppositely through the windows of the primary and secondary windings. The unit would then look like FIG. 1 except for the L shaped brackets and except for lack of shunts. Accordingly the only way to get the shunts in place was to drive them in along a direction of the arrow 61 in FIG. 1 or FIG. 4. In the present invention the shunts may be put in place as shown in FIG. 4 merely by setting or pushing them in along the line of the arrow 62. This is not only a shorter path through which they must be moved but it also is one parallel to the plane of the laminations in the group 21 rather than being at right angles thereto. In the prior art construction of driving them in parallel to the arrow 61, they were being driven in across the rough edges of these laminations of the group 21 and accordingly this often posed problems in getting the shunts properly in place.

In most cases with the old method, shunts were driven in with force or some type of tapping. Experience with the method of the present invention shows that the shunts can be set in place with bare hands requiring no tools, or tapping or pounding. In addition, if necessary or helpful, the laminations can be aligned on either side of the middle leg 24 of the E group 21 with a flat tool or flat surface prior to installing the shunt. With the old method only the outer surface of the core was accessible to be squared or tapped with a flat object to align the laminations. Any error in a lamination stamping operation such as die shift, die tolerance, die wear, die clearance and so on could appear double in magnitude along interior surfaces of the middle leg 24. When the laminations are punched using a scrapless pattern, the E pieces alternate in direction, and alternate ones need to be turned around to be grouped as in FIG. 4. Accordingly any error would be seen in double along the side of the middle leg. Another advantage is that a more uniform shunt air gap would result with internal alignment.

Still another advantage of the present invention is that the units are easier to test. In most cases every unit coming off the assembly line is tested. FIG. 4 shows the unit as ready for the primary winding 17. With this primary winding in place, it may be tested to determine if it has the proper output voltage for a given nominal input voltage. To do this the unit may be placed in a fixture against a stack of I-laminations of the second group 22. In fact, for easier testing, the group 22 may be a test group attached to the fixture and used to test successive units. The fixture will tightly clamp the E and I group laminations together at which time the rated input voltage may be applied to the primary winding 17 and the proper size capacitor connected to the capacitor coil 32 in order to determine if the rated output voltage is delivered from the secondary coil 31. If the voltage is low, one or two additional lamination pieces may easily be added and the unit quickly retested. Also if the voltage is high one or two extra pieces of laminations may be removed simply and again the unit easily retested. This is in contradistinction to the considerably more difficult procedure of adding or removing laminations from the prior art interleaved core structure in order to achieve the rated voltage on the unit on test. After testing the proper number of laminations in the I group 22 may be fixed in any desired manner, for example, by L brackets, half shells, the weld line 35 or U frames. With the welds 35 to hold the core 16 together, the unit is complete and may then be impregnated with varnish or the like without the core bolts 37 being in place. This saves time and material in later cleaning of the L brackets.

FIG. 3 shows a modification of the invention with a constant voltage transformer 65 in which the core 66 includes a first group 71 and a second group 72 of E-shaped laminations. The legs of the E pieces are of different lengths in the two groups and they are interleaved a short distance for a lap joint 73 but this lap joint is all at the primary end of the core. The lap joint 73 provides the means to take apart the core 66 and assures an absence of any joint in the secondary winding portion of the core 66. By utilizing the lap joint 73 this will increase the primary magnetizing inductance and hence lower the primary input current. As in the preferred embodiment of FIGS. 1, 2, and 4 it will have the main advantages of a greater input voltage range, as shown in FIGS. 7 and 8, a greater overload current in the regulated voltage range, as shown in FIGS. 9 and 10, a greater secondary inductance as shown in FIG. 6, a larger volt-ampere capacity in the capacitor and capacitor coil combination permitting the use of a smaller capacitor, and it will also have the advantage of a greater content of odd harmonics for a lower peak voltage and use of a smaller filter capacitor when the output voltage is supplied to a rectifier.

FIG. 11 illustrates the curves of output voltage versus output current and shows a family of curves 77, 78 and 79. Curve 77 is for a high input voltage, curve 78 is for a medium or nominal rated input voltage and curve 79 is for a low input voltage. This family of curves shows that the output voltage remains substantially constant throughout the regulated voltage range up to some point 80 for example which would be above rated output current. At overload conditions the curves separate and the device drops out of the ferroresonant condition, showing a separation of the curves at different input voltages. Also shown in FIG. 11 is a family of curves 81, 82, and 83 of output voltage versus output current for transformer type ballasts used for energizing neon or fluorescent lamps. These are prior art devices usually having a shunt in the core between the primary and secondary windings; however, they are considerably different devices in that they are essentially constant output current devices rather than constant output voltage devices. Curve 81 is for a high input voltage, curve 82 is for a medium or nominal rated input voltage, and curve 83 is for a low input voltage. This family of curves 81-83 show that these devices have a relatively high output voltage initially in order to flash or ignite the tube and after ionization of the gas within the tube, the impedance thereof rapidly drops. Also the voltage required to sustain illumination of the lamp is much lower after ignition and accordingly these devices usually incorporated a series capacitor in order to limit the current and to lower the voltage applied to the lamp. In some prior art devices of this type an air gap is provided in the core so that the core may be taken apart to insert the windings. However, the air gap is not made as small as possible, as in the present invention. Instead it is selected to be given dimension in order to control the power factor of the device. Also in such prior art devices regulation is achieved by reducing just one small portion of the core area, as by cutting a slot or a hole in that portion of the core. The reduced core area becomes saturated and tends to limit the amount of flux so that regulation occurs. In the present invention the entire center leg 24 inside the secondary winding means 18 becomes saturated, for example at 20,000 gauss, because of the ferroresonant condition. The secondary winding means is driven into resonance by energization from the primary winding 17 which is on a portion of the core below the knee of the B-H curve. Also in neon or fluorescent lamp transformers, a capacitor is sometimes used in parallel with the secondary winding; however, this is not used to resonate with the secondary at the fundamental frequency, instead it resonates at the third harmonic frequency in order to cause a peaking of the voltage to flash or light the lamp. After ignition or gas ionization, the voltage drops back to the lower fundamental value.

Although this invention has been described in its preferred form and preferred practice with a certain degree of particularity, it is understood that the present disclosure of the preferred form and preferred practice has been made only by way of example and that numerous changes in the details of the circuit and the combination and arrangement of circuit elements and steps may be resorted to without departing from the spirit and scope of the invention as hereinafter claimed.

What is claimed is:

1. A transformer having substantially constant output voltage, comprising, in combination, a core and primary and secondary winding means thereon,
 - a magnetic shunt in said core between the primary and secondary winding means to provide a shunt for primary or secondary flux,
 - said shunt defining an air gap with said core to cause the initial application of voltage to establish the primary flux initially through the secondary winding means portion of the core,
 - a capacitor connected to said secondary winding means to increase the flux density in the secondary winding portion of the core to stabilize the output voltage relative to a variable input voltage,
 - and said core being constructed with an absence of joints at said secondary winding end of the core except for said shunt to thus improve the input voltage range of operation of the transformer for a given amount of resonating volt-ampere capacity in the capacitor and secondary winding combination.
2. A transformer as set forth in claim 1 wherein said capacitor is connected in parallel with at least a part of said secondary winding means to be substantially resonant therewith at the fundamental frequency of the voltage supplied to said primary winding means.
3. A transformer as set forth in claim 1 wherein said capacitor is connected in parallel with a capacitor coil as part of said secondary winding means.
4. A transformer as set forth in claim 3 wherein said capacitor has a value to resonate with said capacitor coil substantially at the fundamental frequency of the voltage supplied to said primary winding means.
5. A transformer as set forth in claim 1 wherein said core comprises first and second groups of laminations, said groups having a joint or joints therebetween only at the primary winding end of said core.
6. A transformer as set forth in claim 5 wherein said joint is a butt joint.
7. A transformer as set forth in claim 5 wherein said joint is a lap joint.
8. A transformer as set forth in claim 7 wherein said first group of laminations is E-shaped and said second group of laminations is I-shaped,
 - said E and I-shaped groups of laminations having three lap joints at the ends of the legs of the E-shaped laminations with all lap joints being at the primary winding end of said core.
9. A transformer as set forth in claim 1 including a first group of laminations,
 - a second group of laminations,
 - said first and second groups of laminations being interengaged with joints only at said primary winding end of said core to establish a greater reluctance in the primary winding end than in said secondary winding end of said core to help establish magnetic flux saturation in a substantial portion of the secondary winding end of the core and to establish operation of the primary winding end of said core close to but below the knee of the B-H curve.
10. A transformer as set forth in claim 1 wherein said capacitor is substantially resonant with at least a part of said secondary winding means at the fundamental frequency of the supply voltage and the absence of a joint at said secondary winding end of said core establishes a

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higher flux density in the secondary winding end than in the primary winding end of said core.

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