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3,289,280

METHOD OF MAKING A SHELL TRANSFORMER

Original Filed Feb. 27, 1961

2 Sheets-Sheet 1

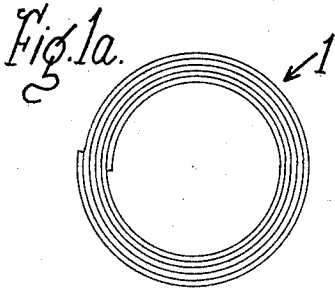
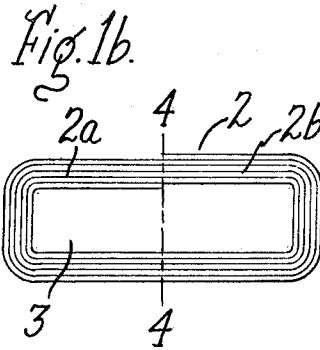


Fig. 4.

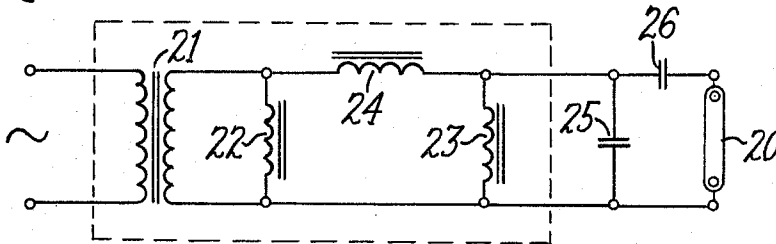
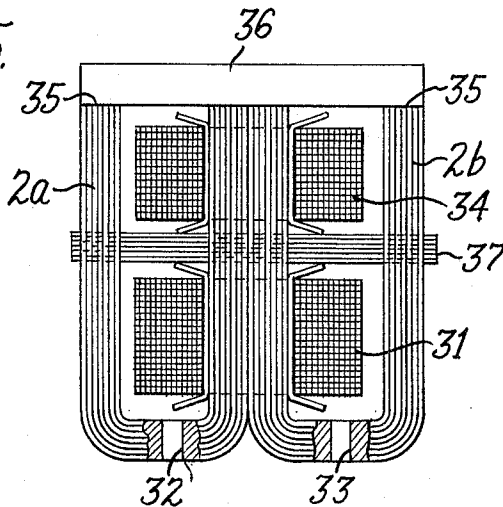


Fig. 5.



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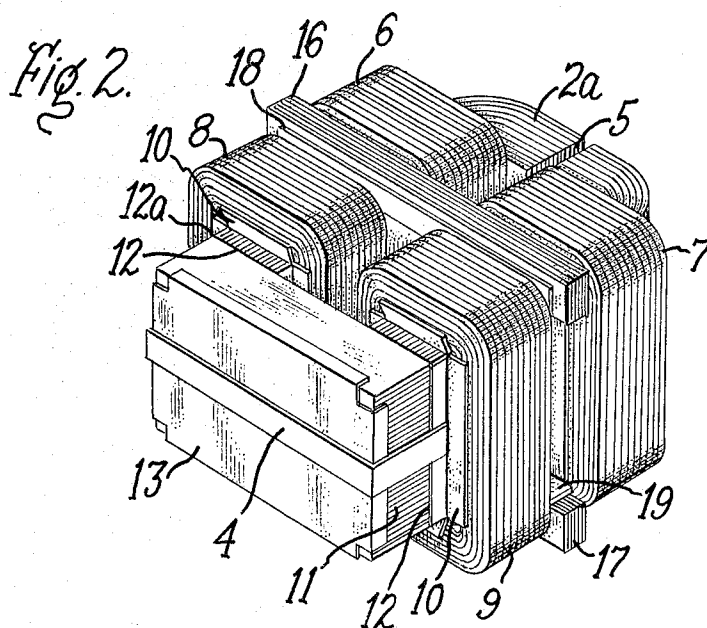
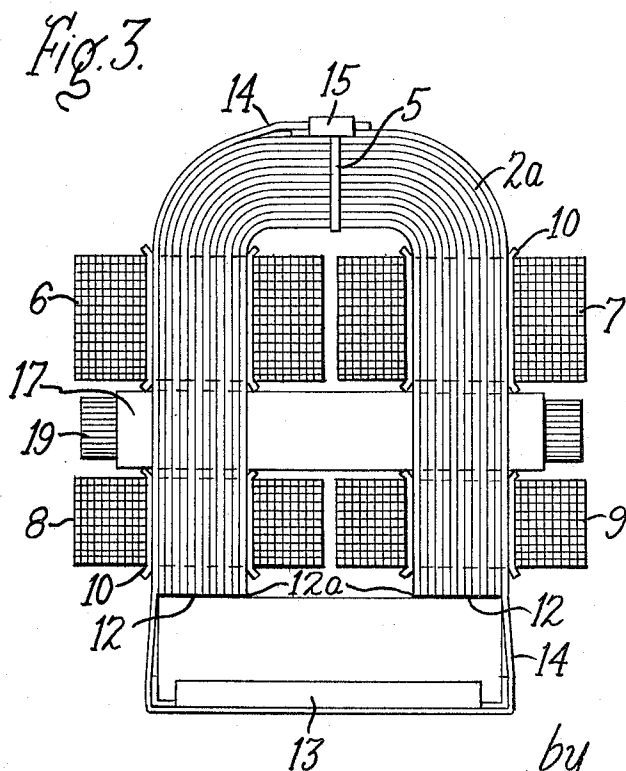
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METHOD OF MAKING A SHELL TRANSFORMER

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2 Sheets-Sheet 2



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METHOD OF MAKING A SHELL TRANSFORMER
Howard T. Jones, Hendersonville, N.C., assignor to General Electric Company, a corporation of New York
Application Jan. 25, 1965, Ser. No. 434,164, which is a division of application Ser. No. 91,730, Feb. 27, 1961. Divided and this application Nov. 19, 1965, Ser. No. 508,764

1 Claim. (Cl. 29—155.57)

This is a division of application Serial Number 434,164, filed January 25, 1965, now Patent 3,248,781 issued May 3, 1966, which in turn is a division of application Serial Number 91,730, filed February 27, 1961, now abandoned both said applications being assigned to the same assignee as the present application.

This invention relates to reactive transformers, also known as ballast transformers, and more particularly to a core and transformer construction useful for regulating the current through arc discharge devices such as mercury vapor lamps.

The small transformer conventionally used to energize discharge lamps serves a dual function. At starting, it provides a sufficiently high voltage to ionize or ignite the lamps; during operation, it limits the current through the lamp. In order to provide the current limiting action, such transformers are conventionally of the high leakage reactance type, that is, they are provided with magnetic shunts providing a low reluctance path for leakage reactance flux. The reactive transformer construction disclosed herein, although intended primarily for ballasting mercury vapor discharge lamps and described principally from the standpoint of such utility, are also useful in related fields like arc welding and voltage regulation wherein it is desired to limit the current through a load.

The transformer portion of a regulator ballast can be made in many conceivable ways. The basic requirements are that independent primary and secondary electrical circuits be mutually linked by a magnetic circuit and that another magnetic circuit be provided to link either the primary or the secondary circuit without necessarily linking the other. In addition, the secondary electrical circuit should be linked by a saturable magnetic circuit wherein the flux linkages are not a linear function of the primary voltage.

In the past, reactive transformers have generally been provided with a magnetic core, formed of a stack of relatively thin flat laminations of magnetic material. The use of grain-oriented magnetic material or transformer iron permits greater flux density with less core loss and lower exciting current. However when grain-oriented sheet magnetic material is used for transformer core lamination, although the flux can be parallel to the grain orientation in the principal direction of the core, it is transverse to the orientation in the transversely arranged portion of the core. Reactive transformers have also been made using wound cores of grain-oriented magnetic material. The problem then arises of making the maximum effective utilization of core winding techniques to reduce the total amount of magnetic material required while maintaining superior electrical characteristics, and of providing in most effective manner the shunts and other features necessary to achieve the desired electrical characteristics.

The object of the invention is to provide a reactive transformer construction and a method of making same wherein the most effective utilization is made of core and coils to reduce the total amount of material and labor or operations required while achieving superior electrical characteristics.

In a particular transformer construction and winding technique according to the present invention, the transformer core is formed by first winding a long strip of magnetic sheet material flatwise layer upon layer to form a laminated ring. The ring is then shaped by flattening to an elongated straight-sided loop, that is a loop forming an elongated generally rectangular window. The core is then annealed for stress relief and grain growth and may at this point be impregnated with a suitable resin or binder whereby it will henceforth maintain its shape. The core is then cut transversely by sawing or otherwise into substantially equal parts, each part having an elongated U-shaped. Each part, which will henceforth be referred to as a wound U-core, is now used as the principal portion of the core of a reactive transformer, so that from the original wound core, two separate transformers will result.

To complete the reactive transformer, the U-core is provided with a saturable area of reduced cross section by sawing a slot partially through the core normal to the edge of the lamination, preferably in the bight or transverse portion of the U. Wound primary and secondary electrical windings are then assembled inductively on the U-core in such a way that the secondary windings are at the closed end of the core loop where the restriction occurs. An end member or yoke is placed across the legs of the U to provide a closed magnetic circuit around a central window in such way that the butt joints occur next to the primary winding and are in the primary portion of the magnetic circuit. Reactive shunts are then introduced between the primary and secondary portions of the core loop by placing a stack of laminations on one or both sides of the core loop spanning the central opening so that the laminations of the reactive shunts are edge to edge with those of the U-core. To prevent magnetic saturation of adjacent laminations, layers of paper or other composition may be inserted between the magnetic shunts and the U-core. The yoke and the reactive shunts may be fastened in place by a suitable strap.

A reactive transformer formed in the foregoing manner makes very efficient use of magnetic material since all stock is initially in the form of strip, no irregular punchings productive of waste are used, and winding and cutting operations are reduced to a minimum. The unique placement of the component parts wherein the air gap inevitably introduced by the yoke is located next to the primary windings and wherein the restriction is located next to the secondary windings, results in superior electrical characteristics under the limitations unavoidably introduced by the winding technique. The invention thus provides a comparatively inexpensive reactive transformer with no sacrifice in performance. In fact, the wound U-core reactive transformers in accordance with the invention achieve a higher efficiency and show lower losses than conventional transformers using a stack of punched laminations.

For further features and advantages and for a better understanding of the invention, attention is now directed to the following description of preferred embodiments and to the accompanying drawings. The features of the invention believed to be novel will be more particularly pointed out in the appended claim.

In the drawings:

FIGS. 1a and 1b illustrate, to a smaller scale than the other figures of the drawings, the core of a transformer made according to the invention at two different stages.

FIG. 2 is an isometric view of a loosely shunted transformer constructed in accordance with the invention.

FIG. 3 is a plan view, with the electrical windings sectioned, of the transformer illustrated in FIG. 2.

FIG. 4 is an equivalent circuit for a regulator ballast for arc discharge lamps illustrating the electrical characteristics of a reactive transformer according to the invention.

FIG. 5 is a plan view similar to FIG. 3 but with the core structure partially cut away and illustrating a variant of the present invention.

Referring to the drawings and more particularly to FIG. 1a, the core structure of a reactive transformer according to the invention is made by winding a long strip of grain-oriented magnetic sheet material flatwise layer upon layer until a sufficient cross-sectional area is built up and a laminated ring 1 is formed as shown. The laminated ring is then reformed, for instance by pressing in a suitable clamping jig or vise, to an elongated loop 2 having parallel sides defining a rectangular window 3 as illustrated in FIG. 1b. Alternatively, the strip of magnetic sheet material may be wound directly on a suitable mandrel to a rectangular loop form. The laminations are next annealed by heat treatment to achieve stress relief and grain growth, the stress relief permitting the shape to be maintained; additionally, to prevent subsequent separation of the laminations, the loop may be impregnated at least in part with a suitable resin or binder which is allowed to set or polymerize. The rectangular loop is then cut along a single plane 4, 4 transverse to the long sides, into two equal U-shaped portions 2a, 2b. The loop may be severed by any suitable means such as a metal saw but, in order to prevent short circuits between laminations, it is preferred to use a milling cutter or a thin abrasive wheel.

In accordance with the invention, where a core type reactive transformer is to be made, one of the U-shaped parts 2a, or 2b illustrated in FIG. 1b is used as the main portion of the core. A transformer so constructed is illustrated in FIGS. 2 and 3. Before assembling the windings on the U-core, a restriction in the cross-sectional area of the core is created in order to provide a saturable area in that portion of the core loop which is to carry the secondary winding. This is most conveniently done in the bight or transverse portion of the U by cutting a narrow slot 5 across one edge of the lamination to a depth of approximately $\frac{1}{3}$ the width of the lamination. Next pre-wound and preformed electrical windings are slipped into place over the legs of the U-core. A pair of secondary windings 6, 7 is slipped on first so as to be at the closed end of the U-core next to the slot 5. Then the primary windings 8, 9 are positioned near the open end of the U-core legs. The windings are preferably insulated from the core by a layer of insulating material such as the paper insulators 10 shown.

The main magnetic circuit linking the primary and secondary winding is completed by means of a yoke 11 which is butted up against the ends of the legs of the U-core so as to bridge the gap. The laminations of the yoke are arranged as illustrated to meet edge to edge with those of the U-core but with the plane of the laminations in the yoke transverse to that of the laminations in the U-core. An insulating layer 12a, suitably a thin sheet of paper, or a resin coating, or the oxide on the laminations is interposed between the core and yoke at the butt joints 12 to prevent a continuous electrical circuit around the core. An advantageous feature in accordance with the invention resides in that the butt joints 12 formed by juxtaposing yoke 11 to the ends of the U-core 2a occur in that part of the main magnetic circuit bearing the primary windings. Butt joints are unavoidably present in the wound core construction adopted and, by placing them in the primary portion of the main magnetic circuit, the losses which they introduce are kept to a minimum. The effective air gap at the butt joints affects the primary magnetizing reactance and the gap may be adjusted, for instance by inserting additional paper separators, to control the input power factor. The laminations of the yoke are held together by means of

frame plate 13 and the yoke is fastened to the U-core 2a by means of a steel strap 14 whose ends are clamped together in conventional fashion by a crimping band 15.

In order to provide a magnetic circuit linking either the primary or the secondary windings without necessarily linking them both together, a magnetic shunt is added to the basic core loop between primary and secondary windings. As illustrated, the reactive shunt consists of a pair of stacks of laminations 16, 17 which are spaced from the laminations of the core by thin insulating spacers 18, 19. The laminations of the reactive shunt are placed against the side of the main magnetic loop in edge to edge relationship with the laminations of the main loop. The reactive shunts span the central opening through the core, thus providing a leakage path for the primary and secondary portions of the core loop. The entire reactive transformer assembly is ordinarily mounted in a suitable container or can and impregnated with a potting compound; prior to such potting, the shunts may be held in place on the core loop by tape (not shown) wound for example about the center or ends of the stacks of laminations 16, 17. By placing the reactive shunts consisting of stacks of laminations beside the wound core loop instead of in the same plane, and by orienting its laminations edge to edge with those of the main core loop, an effective low loss shunt is obtained. The losses with this arrangement are substantially lower than they would be if the shunt were placed in the plane of the main core loop which would entail that most of the shunted flux would necessarily have to pass through several adjacent layers of the laminations in the main core loop in a direction normal to the laminations.

A reactive transformer serving as a regulator ballast for a gaseous discharge device such as a mercury vapor lamp or a fluorescent lamp, is intended to maintain a nearly constant current into the lamp load with variations of supply potential. When the lamp is operated about at its rated power, variations in lamp current are reflected in the energy output of the lamp even though the potential across it remains nearly constant. The regulator ballast performs its function by supplying a substantially constant voltage to the lamp and by limiting the amount of current which the lamp is permitted to draw. The present reactive transformer is intended to provide a non-linear transformer coupling between a source of power and a load circuit including a discharge device such as an arc lamp, and a series capacitor. The series capacitor, in addition to its current limiting function, provides the necessary leading current through the non-linear transformer coupling so that a constant output voltage may be obtained. The factors involved may be explained by reference to the schematic diagram of FIG. 4 showing the equivalent circuit of a reactive transformer according to the invention connected as a regulator ballast for an arc lamp 20. The elements enclosed within the dashline rectangle represent the effective impedance elements resulting from the transformer construction which has been described. These elements include an ideal transformer 21 having a turns ratio of preselected value. Reactance 22 represents the primary magnetizing reactance referred to the secondary circuit. Reactances 23 and 24 represent, respectively, the secondary magnetizing reactance and the total leakage reactance. The output circuit is completed by the connection of a shunt capacitor 25 across the output leads and a series capacitor 26 in series with the load consisting of arc lamp 20.

With the transformer construction which has been described, it is possible to vary each of the effective reactances to obtain optimum characteristics for a given installation. The reactance shunts 16, 17 placed between the primary and secondary core provide the effective leakage reactance 24 which must be proportioned to the series capacitor reactance 26. The value of this leakage reactance may be adjusted without altering the other effective reactances, by varying the cross sectional area of the

laminations in the reactive shunts and the width of the air gap between the edges of the reactive shunts and the edges of the core loop. The effective secondary magnetizing reactance 23 provides a non-linear saturating effect that affects both the regulation of load current with variations in input potential and the crest factor of the load current. This reactance is controlled principally by the core restriction placed on the secondary side of the main core loop. The shape of the restriction, whether hole or slot, and also its dimensions control the actual characteristics of the secondary magnetizing reactance. Normal variations in the primary supply voltage affect only the degree of saturation in the secondary magnetic circuit so that the secondary magnetizing reactance remains substantially constant and thus the voltage output of the ballast likewise remains nearly constant.

By placing the butt joints 12 in the primary portion of the core loop, they affect only the primary magnetizing reactance 22, and the effective gap may be adjusted to control the input power factor. If the butt joints were located in the secondary portion of the core loop, they would affect also the secondary magnetizing reactance, thereby adversely affecting regulation and increasing transformer losses. Shunt capacitor 25, which may also be termed a peaking capacitor, is used to increase the peak open circuit voltage above the turns ratio voltage and should preferably be of a value to resonate with the leakage reactance 24 at slightly above the third harmonic frequency of the supply voltage. Although shown as connected across the entire output of the ballast transformer, the peaking capacitor may also be connected across only a part of the secondary turns to reduce to some extent the open circuit voltage supplied by the ballast.

A variant of the invention is shown in FIG. 5 illustrating a shell type reactive transformer. In this construction, a pair of U-cores 2a, 2b are positioned side by side and the common or center leg of the resulting shell-type core is constituted by two juxtaposed legs, one from each U-core. The single secondary winding 31 is slipped over the center leg so as to be located next the closed or inner end of the U-cores. The core restriction, in this instance is provided by holes 32, 33 drilled through the transverse portions or bights of the U-cores, being thereby located in the secondary portion of the main core loop. A single primary winding 34 is slipped over the center leg so as to be located next to the butt joints 35 where the open ends of the U-cores are bridged by a yoke 36 consisting of a stack of laminations. The plane of the laminations in the yoke 36 is transverse to that of the laminations in the U-cores, in similar fashion to the embodiment of FIGS. 2 and 3, and the laminations are likewise arranged for edge to edge contact. The reactive shunt is provided by two stacks of laminations, only one of which, 37, is shown in the figure, spanning the windows of both core loops and located between the primary and secondary windings. The reactive shunts are arranged in similar fashion to those in FIGS. 2 and 3, being placed edge to edge on the side of the main core loop.

The shell type reactive transformer construction of FIG. 5 makes use of two core loops but only one set of primary and secondary windings. Evidently, for a given trans-

former rating, the cross sectional areas of the two U-cores which make up the complete core will be equal to half that of the core of the transformer in FIGS. 2 and 3. Thus in this construction, both parts 2a, 2b of an elongated rectangular core loop as illustrated in FIG. 1b are used in a single reactive transformer but each core part is of half the cross sectional area. The shell type core construction offers most of the features of the transformer design illustrated in FIGS. 2 and 3 along with the added advantage of an improved outward heat transfer from the core because of a greater exposed core area.

Although certain preferred embodiments have been illustrated and described herein, it is to be understood that these are intended as exemplary and not limitative of the invention. Modifications in construction and method will readily occur within the scope of the present teachings, to competent designers. The appended claim is intended to cover any such modifications falling within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

The method of making a shell-type reactive transformer comprising winding a band of magnetic material flatwise layer upon layer to form an elongated straight-sided core, cutting said core in two on a plane midway through the elongated sides to form a pair of substantially equal sized U-shaped core portions; arranging the two U-shaped core portions side by side to form a double U with a central core leg and opposite side legs having their end edges all substantially in the same plane; placing on the central core leg a secondary winding adjacent the closed end of the core and a primary winding adjacent the open end so that the central core leg projects beyond said windings at the open end, closing the open ends by providing a yoke bridging the end edges of all said core legs to provide closed magnetic loops around a pair of windows, said yoke being formed of a flat stack of laminations placed with their edges abutting the end edges of all said core legs and with their planes at right angles thereto, whereby the junctures of the laminations of the core legs with those of the yoke form butt joints next to said primary winding, and placing on said double U-shaped core a reactive shunt formed of at least one flat stack of laminations of magnetic material against the side of the core so as to span said windows, the laminations of the double U-shaped core and of said reactive shunt being placed in edge-to-edge relationship and with their planes at right angles to each other.

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