March 19, 1968 A. Y. BROVERMAN ET AL 3,374,453

ELECTRICAL INDUCTIVE APPARATUS

Filed Dec. 27, 1966 2 Sheets-Sheet 1

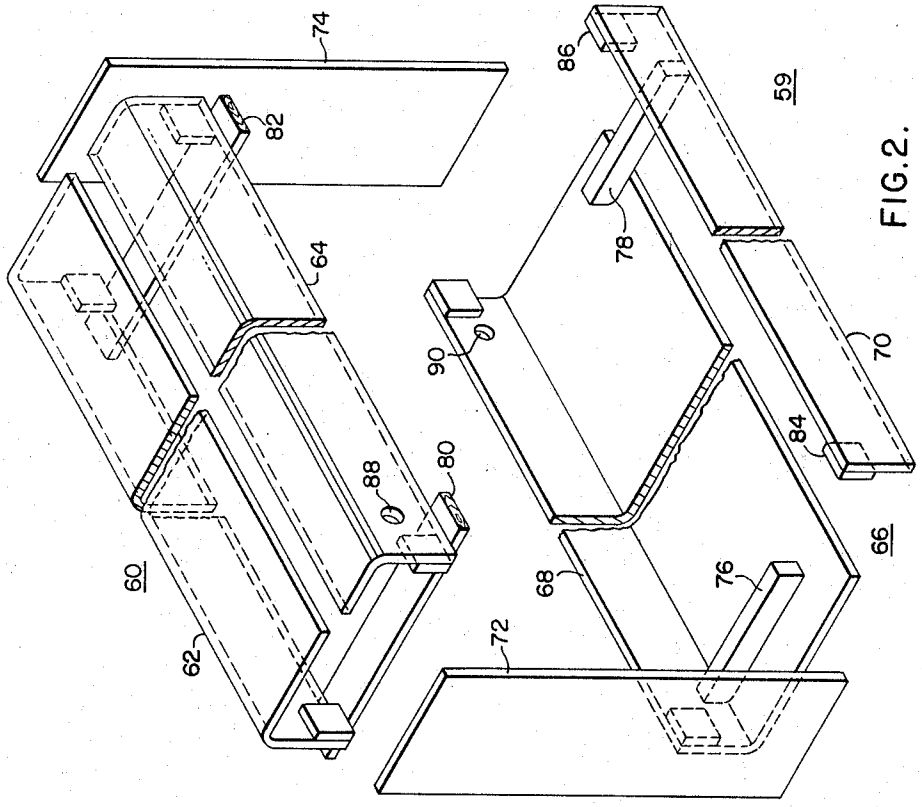


FIG. 2.

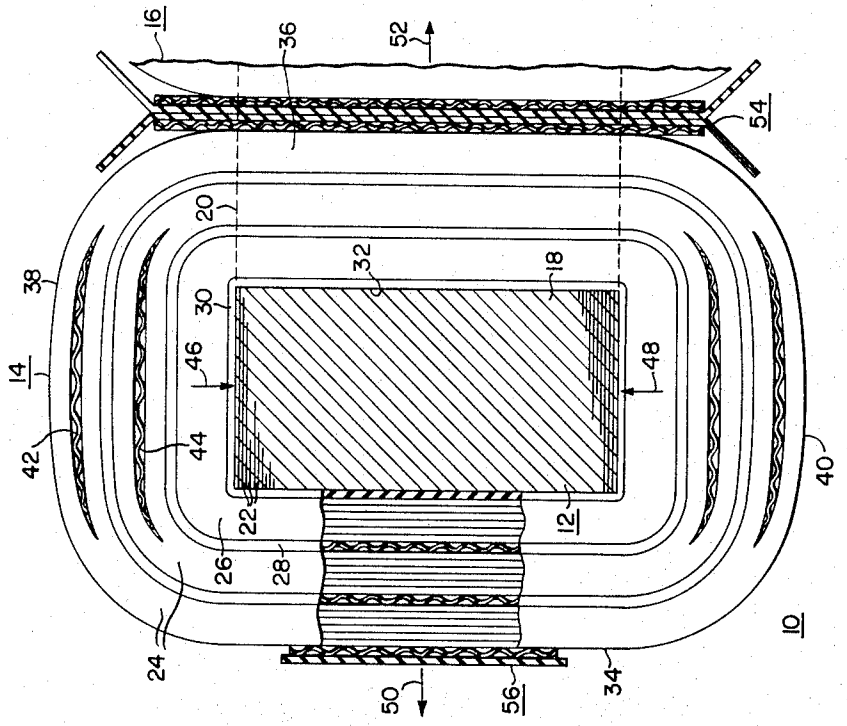


FIG. 1.

March 19, 1968 A. Y. BROVERMAN ET AL 3,374,453

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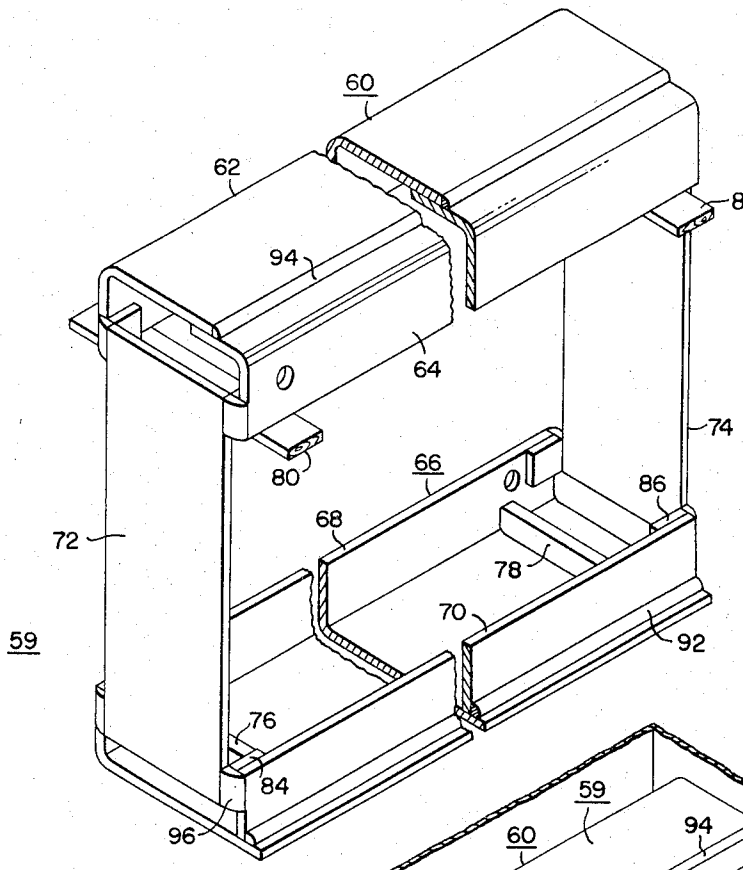


FIG. 3.

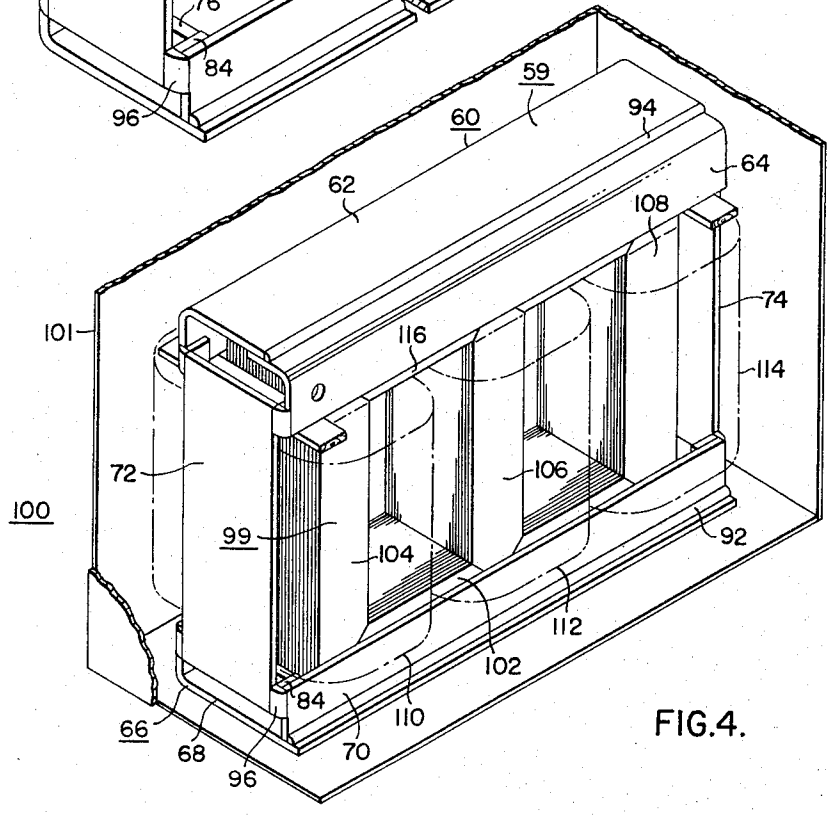


FIG. 4.

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3,374,453

ELECTRICAL INDUCTIVE APPARATUS

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ABSTRACT OF THE DISCLOSURE

A transformer of the core-form type, and methods for constructing same, having concentric high and low voltage coils disposed on the leg portions of a stacked type magnetic core assembly. The yoke portions of the magnetic core assembly are compressed uniformly across their longitudinal length by metallic end frame members which are in continuous fixed engagement with one another across the complete longitudinal length of the yoke portions. Metallic plate members connect adjacent ends of the end frame members to brace the transformer during short circuit conditions, and to allow the transformer to be lifted without stressing the magnetic core assembly.

Electrical inductive apparatus of the core-form type, such as transformers and reactors, conventionally include magnetic core assemblies in which the plurality of leg portions, and connecting yoke portions, are formed of stacks of metallic laminations. The yoke portions are compressed and held in assembled relation by end frames, which include members disposed on opposite sides of each yoke portion, wtih the members being bolted at the ends of the yoke portions. Boxed channel members are disposed to connect adjacent ends of the end frames, to brace the transformer against short circuit forces, and to facilitate the lifting of the completed magnetic core-winding assembly. This construction requires a large plurality of core parts, and hardware, such as nuts and bolts, which are costly to fabricate and assemble, and which contribute to other undesirable factors. For example, the sound level of the transformer depends to a large extent upon the clamping pressure exerted on the laminations by the end frames, and its uniformity. Bolting the two major portions of the end frames adjacent the ends of the yoke portions provides a large pressure near the bolts, and progressively less pressure towards the center of the yoke portions, where the inner leg of the magnetic core assembly is disposed, in a three-phase magnetic core assembly. The laminations have a tendency to bow in the area of this inner leg joint. Thus, not only is it difficult to obtain an optimum pressure or compression of the yoke portions, but the pressure is non-uniform across the longitudinal length of the yoke portions. In applications where the noise or sound level is a definite limitation, the iron of the magnetic core may have to be worked at lower levels of induction, which increases the size, weight and cost of the magnetic core and adversely affects the size of the windings, the size of the tank, the amount of the fluid dielectric, and thus the total cost and weight of the transformer.

The boxed channel members which are bolted to the end frames are costly to fabricate, and they adversely affect the overall length of the completed magnetic core-winding assembly. This, in turn increases the tank length, and the amount of insulating fluid required, and thus, the total weight of the transformer.

Accordingly, it is an object of the invention to provide new and improved electrical inductive apparatus which is less costly to manufacture and assemble, than similar apparatus of the prior art.

Another object of the invention is to provide a new and improved transformer in which the yoke portions of the magnetic core are compressed uniformly across their longitudinal length, to a predetermined optimum pressure.

Still another object of the invention is to provide a new and improved transformer construction of the core-form type which reduces the overall length of the transformer.

A further object of the invention is to provide a new and improved method of constructing electrical inductive apparatus of the core-form type, which reduces the size and cost of the apparatus.

Another object of the invention is to provide a new and improved method of constructing electrical transformers of the core-form type, which enables the yoke portions of the magnetic core to be uniformly compressed to a predetermined pressure across their longitudinal length.

Briefly, the present invention accomplishes the above cited objects by a new transformer construction, and methods of constructing same, which substantially reduces the number of core parts required to hold the magnetic core in assembled relation and brace the magnetic core-winding assembly, eliminates hardware, such as nuts and bolts from the core parts, reduces the overall length of the transformer, and uniformly compresses the yoke portions across their longitudinal length.

More specifically, the end frames which clamp the yoke portions of the magnetic core each include two metallic yoke pieces which, in addition to contacting opposite sides of the yoke portion, also contact one another in a continuous, fixed engagement, for at least the complete longitudinal length of the yoke portions. The two yoke pieces compress the stack of metallic laminations which form its associated yoke portion, and these yoke pieces are continuously welded together while compressing the yoke portion, to maintain the desired predetermined pressure. The bracing of the transformer against movement of the windings during short circuit stresses, and the consolidation of the magnetic core which allows the magnetic core-winding assembly to be lifted without stressing the core, is provided by flat metallic plate members, instead of boxed channels. The flat metallic plate members are welded to adjacent ends of the upper and lower end frames. The overall length of the magnetic core assembly, and thus the overall length of the completed transformer, is reduced, compared to transformers of the prior art which utilize fabricated boxed channel members to provide these functions.

Further objects and advantages of the invention will become apparent from the following detailed description, taken in connection with the accompanying drawings, in which:

FIGURE 1 is a fragmentary, cross-sectional plan view of a transformer of the core-form type which may utilize the teachings of the invention;

FIG. 2 is an exploded perspective view showing the core parts required to construct a transformer according to the teachings of the invention;

FIG. 3 is a perspective view which illustrates the core parts of FIG. 2 in assembled relation; and

FIG. 4 is a perspective view, partially cut away, and partially in phantom, which illustrates a transformer constructed according to the teachings of the invention.

FIG. 1 illustrates a fragmentary, cross-sectional plan view of a transformer **10** of the core-form type, which

may advantageously use the teachings of the invention. Transformer **10** includes a magnetic core assembly **12**, and a plurality of electrical winding assemblies, such as those shown at **14** and **16**. The magnetic core assembly **12** is of the type which includes a plurality of leg portions, such as leg portion **18**, which are disposed in spaced parallel relation, and they have a substantially rectangular cross-section. FIG. 1 illustrates only one complete winding assembly and leg portion of the magnetic core, as the additional winding assemblies and leg portions would be similar. Any number of winding leg portions and electrical winding assemblies may be utilized, depending upon the particular application. The leg portions of the magnetic core assembly are joined by upper and lower yoke portions, shown generally by dotted line **20**. The various leg and yoke portions are each formed of a stack of metallic laminations, such as laminations **22**, which are usually formed of a grain oriented silicon steel, with the leg laminations making a joint with a yoke lamination in the same plane. The joints between successive layers of laminations may be offset from one another, in any predetermined pattern, to reduce the core losses and to lower the noise level of the core when excited. Transformer **10** may be single or poly-phase, having two or more leg portions.

The winding assemblies, such as winding assembly **14**, include high and low voltage coils **24** and **26**, respectively, concentrically disposed about one of the leg portions of magnetic core **12**, such as leg portion **18**, with the high and low voltage coils being separated by suitable high-low insulation **28**, and with the complete winding structure being insulated from the magnetic core leg by winding tube **30**. Winding assembly **14** has a rectangular opening **32** therein for closely coupling the winding assembly with its associated leg portion of the magnetic core, and the winding assembly has a substantially rectangular outer configuration. As will be noted from FIG. 1, while the outer configuration is referred to in the art as being rectangular, it actually has two substantially straight outer side portions **34** and **36**, joined at each end by curved or rounded side portions **38** and **40**, which approach a circular configuration. The substantialy flat side wall portions of the winding assembly are perpendicular to the major planes of the individual laminations **22** which make up the magnetic core leg portions. The rounded side portions **38** and **40** of the winding assemblies are disposed outside of the main magnetic core configuration, and thus permit the most efficient use of cooling ducts, such as ducts **42** and **44**, for cooling the winding assembly.

The type of construction shown in FIG. 1 presents a problem which is universal to stacked type magnetic cores for core-form transformers, and a problem unique to the specific core-form construction shown. The universal problem is the one of clamping the metallic laminations which make up the magnetic core. The noise level of stacked magnetic core assemblies, and to a lesser extent the core losses, depends upon the magnitude of the clamping pressure, and its uniformity. There is an optimum clamping pressure at which the noise level of the magnetic core will be a minimum, and to be effective, this clamping pressure should be uniformly applied across the longitudinal length of the laminations. The core losses are not substantially affected by the clamping pressure per se, but a non-uniformly applied pressure which results in bowing and/or separation of the laminations, will increase the losses of the magnetic core. In the prior art, it is common to dispose a metallic channel or angle member against the outer laminations of the stack of laminations which make up the yoke portions, and apply pressure to the laminations in the direction of arrows **46** and **48**, by nut and bolt combinations disposed through the angle members just beyond the ends of the yoke portions. The discrete pressure points provided by the nut and bolt combinations at the ends of the yoke portions distribute the compressive forces applied to the yoke portions non-uniformly along its longitudinal length. In other words, the channel members bow slightly outward, with the magnitude of the deflection increasing with the distance from the pressure points. This causes bowing of the laminations, particularly in the area of the inner leg joints on three-legged core structures, which substantially increases the sound level of the magnetic core, and also the losses of the core.

The problem unique to the specific core-form construction shown in FIG. 1, is the tendency of the straight side portions of the winding assemblies to assume a rounded configuration under short circuit stresses. Thus, winding assembly **14**, under short circuit conditions, exerts a very substantial force in the direction of arrows **50** and **52**. The various winding assemblies which make up transformer **10** are disposed in spaced side-by-side relation, with the space between the winding assemblies, such as assemblies **14** and **16**, being filled with solid insulating means **54**, such as layers of corrugated and sheet pressboard, which provide the electrical insulating strength necessary between the winding assemblies, ducts for circulating cooling fluid between the winding assemblies, and also the mechanical strength necessary to withstand the forces provided by the windings. The winding assemblies disposed on the outer leg portions, such as winding assembly **14**, include solid insulating means **56**, which may also be formed of layers of corrugated and sheet pressboard, and in the prior art, a metallic boxed channel member is disposed against insulating means **56**, at each external end of the completed winding assemblies disposed on the outer leg portions. The boxed channel members are bolted to the upper and lower end frames, and provide the bracing necessary to withstand the tremendous short circuit forces generated in the windings. The boxed channel members, along with the upper and lower end frames, form an integral support for the completed core-winding assembly, which enables the completed assembly to be picked up during the various manufacturing steps without stressing the magnetic core and winding assemblies. The boxed channel members add several inches to the overall length of the magnetic core-winding assembly, and thus add to the tank length and tank volume. The additional tank volume requires additional insulating fluid, such as oil, which adds to the manufacturing cost, weight and shipping charges.

This invention teaches a transformer construction, and method of constructing transformers, which solves these problems, and at the same time simplifies the assembly and reduces its cost. FIGURES 2, 3, and 4 illustrate the invention, with like reference numerals in the figures indicating like components. FIG. 2 is an exploded perspective view illustrating the individual core parts which are used to hold the magnetic core assembly and brace the electrical winding assemblies, according to the teachings of the invention. FIG. 3 illustrates the core parts of FIG. 2 in assembled relation, and FIG. 4 illustrates the core parts of FIGS. 2 and 3 used in one of the embodiments of the invention.

As shown in FIG. 2, the core parts **59** comprise a first end frame **60**, which includes metallic yoke pieces **62** and **64**, a second end frame **66** which includes metallic yoke pieces **68** and **70**, and bracing members **72** and **74**, which are substantially flat metallic plate members. The metallic material of which the core parts are constructed may be any suitable material, such as hot rolled steel.

The second end frame **66** may include a metallic bracing member **76**, which is welded to yoke piece **68**, and a metallic bracing member **78**, which is welded to yoke piece **70**. The function of these bracing members **76** and **78** is to box the ends of the yoke portions, and prevent the end leg laminations from being forced out of position by the windings under short circuit conditions. Magnetic core bracing members **80** and **82** form similar functions at the top of the magnetic core-winding assembly. Brac-

ing members **80** and **82** may be formed of wood, and wedged or driven into position after the core-winding assembly has been completed.

Each end of the yoke pieces **62**, **64**, **66** and **70** may have an additional block of metal welded thereto, such as metallic blocks **84** and **86** associated with yoke piece **70**, in order to provide sufficient area for obtaining a high strength welded joint, which will be hereinafter explained. Suitable openings may be disposed in the yoke pieces for enabling the completed assembly to be handled, such as openings **88** and **90**.

As illustrated in FIG. 3, core parts **59** may be completely assembled, without hardware. Yoke pieces **68** and **70** are disposed in contacting relation and welded with a continuous bead **92**, yoke pieces **62** and **64** are disposed in contacting relationship and welded with a continuous bead **94**, bracing member **72** is welded to adjacent ends of the first and second end frame members **60** and **66**, and bracing member **74** is welded to the remaining adjacent ends of the first and second end frame members. As shown in FIG. 3, the weld bead which welds the bracing members to the end frame members is disposed to cover both the metallic block and the yoke piece. For example, welding bead **96** extends across both metallic member **84** and the end of yoke piece **70**.

The assembly of core parts **59** relative to a three-phase transformer **100** is shown in FIG. 4. In general, transformer **100** includes a magnetic core assembly **99**, and winding assemblies **110**, **112** and **114**, disposed within a tank or casing **101** which is shown partially cut-away. Tank **101** may be filled to a suitable level with an insulating fluid, such as oil or SF_6. Transformer **100** may be constructed by stacking a plurality of metallic laminations on yoke piece **66**, to form yoke portion **102**. Yoke piece **66** has a substantially L-shaped configuration, to allow the laminations to be stacked against the back portion of the L-shape. The ends of the laminations may be snugged against bracing member **76**. As described in U.S. Patent 3,153,215, issued Oct. 13, 1964, which is assigned to the same assignee as the present application, if a stepped-lap type joint between the leg and yoke portions is desired, the ends of the yoke laminations may be incrementally clipped, and the stacking of the laminations against bracing member **76** will then automatically establish the desired stepped relationship. The next manufacturing step is to stack laminations against the ends and the inner cut of the laminations which form yoke portion **102**, to form leg portions **104**, **106** and **108**. The assembly of the various leg and yoke portions may be facilitated by placing yoke piece **68** on a suitable holding fixture, which has three upstanding locating members strategically disposed to allow the various leg laminations to be vertically stacked against the locating members. This holding fixture may also have wheels thereon which facilitate an assembly line type production of the transformer. After the yoke portion **102** and leg portions **104**, **106** and **108** have been stacked in assembled relation, yoke piece **70** may then be placed against the outer lamination of yoke portion **102**, and means, such as a plurality of spaced hydraulic cylinders may compress the yoke laminations to a predetermined optimum pressure. Yoke pieces **68** and **70** may then be welded together with a continuous welding bead **92**, while the laminations are being compressed, in order to maintain the desired compressive force. Since yoke pieces **68** and **70** are in continuous, fixed engagement along the complete longitudinal length of yoke portion **102**, the compressive pressure will be uniform throughout the length of the yoke portion.

The upstanding leg support members on the holding fixture may then be removed, or pivoted out of position, and winding assemblies **110**, **112** and **114** telescoped over leg portions **104**, **106** and **108**, respectively. The insulating barrier between the winding assemblies, such as barrier **54** shown in FIG. 1, may then be placed between the winding assemblies. The winding assemblies are shown in FIG. 4 in phantom, to more clearly illustrate the location of the core parts **59** relative to the magnetic core assembly **99** and to the winding assemblies.

The upper yoke portion **116** may then be stacked, with its laminations being aligned with the end laminations of the various leg portions. Yoke portion **116** may be clamped by disposing yoke piece **62** against one side of the yoke portion, and yoke piece **64** against the opposite side. These yoke pieces are constructed with a configuration which allows them to clamp the yoke portion, and also to provide continuous contact between them. The yoke pieces, may then be compressed, to compress the laminations of yoke portion **116** as described relative to the lower yoke laminations, and yoke pieces **62** and **64** may then be welded with a continuous bead **94** to maintain the predetermined optimum compressive pressure. Like end frame **66**, end frame **60** provides a uniform compressive pressure across the complete longitudinal length of its associated yoke portion **116**.

The particular shape and design of the yoke pieces is not critical; it is only necessary to have a yoke piece disposed on each major face of the end laminations which make up its associated yoke portion, with the two yoke pieces contacting one another continuously across the longitudinal length of the yoke portions to allow them to be welded together. For example, as shown in FIG. 4, the bottom yoke pieces **68** and **70** may have different configurations than the top yoke pieces **62** and **64**, in order to position the welding beads **92** and **94** above their respective joints.

The next manufacturing step is to place the outer insulating barriers, such as barrier **56** shown in FIG. 1, adjacent each of the outer winding assemblies, and to weld the bracing members **72** and **74** between the adjacent ends of end frame assemblies **60** and **66**. The metallic bracing members have a thickness dimension selected to withstand the short circuit forces which will be provided by the winding assemblies under short circuit conditions, a length dimension sufficient to extend at least to substantially the end of the metallic blocks which have been welded to the yoke pieces, such as metallic block **84** on yoke piece **70**, and a width dimension substantially equal to the distance between the metallic blocks on the same end of one of the end frames. Thus, the bracing members may be snugged up against the insulating barrier members, without regard to small manufacturing tolerances, as the bracing members may be extended slightly inward past the start of the metallic blocks, without detriment. The metallic bracing members are welded to the metallic blocks and to the ends of the yoke pieces, with the filler metal or bead preferably covering both the metallic block and end of the associated yoke piece, to obtain the high mechanical strength necessary to withstand short circuit forces. It will be noted that the bracing members brace the windings against short circuit forces in the winding assemblies, and they also consolidate the core pieces into a single integral assembly, which enables the completed magnetic core-winding assembly to be handled without stressing the magnetic core and windings. Also, the bracing members add very little to the overall length of the winding assembly. The bracing members, being a flat metallic plate welded to the end frames, instead of the fabricated boxed frame which is bolted to the end frames, reduces the overall length of the magnetic core winding assembly by four to five inches on a 1000 kva. transformer. Each inch that the length of the magnetic core-winding assembly is reduced, results in substantial savings in tank steel, liquid dielectric, and shipping charges.

In summary, there has been disclosed new and improved inductive apparatus, and methods of constructing said inductive apparatus, which provides many advantages over similar apparatus and methods of the prior art. The methods disclosed lend themselves to production line techniques, as the number of core parts has been substan-

tially reduced, and core parts hardware has been completely eliminated. For example, on a 1000 kva. transformer, the number of core parts required to be assembled according to the teachings of the invention is less than half of the number of core parts required in prior art bolted assemblies.

The inductive apparatus disclosed, in addition to being less costly to manufacture, has a lower sound level than similar apparatus of the prior art, as the clamping pressure exerted by the end frames may be selected to be an optimum value, and the optimum pressure is exterted uniformly across the longitudinal length of the yoke portions.

Further, the disclosed apparatus in addition to being less costly to manufacture due to its simplicity, requires a smaller tank than similar apparatus of the prior art, which results in still greater savings in steel, liquid dielectric and shipping costs.

While the inductive apparatus has been shown and described as being disposed in a tank **101** such that the leg portions are vertical, it will be understood that the teachings disclosed in co-pending application Ser. No. 556,207, filed June 8, 1966, which is assigned to the same assignee as the present application, may be used to enable the magnetic core-winding assembly to be disposed on one end, such that the yoke portions are vertical, and the leg portions horizontal. The disclosed magnetic core-winding structure would enable the height of the transformer casing to be reduced in this embodiment. Also, the disclosed construction may be used in reactors, and in applications where all of the leg portions do not contain electrical windings, such as the two-phase to three-phase constructions disclosed in U.S. Patent 3,129,377, issued Apr. 14, 1964, and co-pending application Ser. No. 450,411, filed Apr. 23, 1965, now patent 3,328,738, both of which are assigned to the same assignee as the present invention.

Since numerous changes may be made in the above-described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings, shall be interpreted as illustrative, and not in a limiting sense.

We claim as our invention:

1. An electrical transformer comprising a magnetic core assembly having a plurality of leg portions connected by first and second yoke portions, said leg and yoke portions being formed of a plurality of stacked metallic laminations; first and second end frame members having first and second ends, associated with said first and second yoke portions, respectively; said first and second end frame members each including first and second separate metallic yoke pieces which compress the laminations which form their associated yoke portions; said first and second yoke pieces extending across the longitudinal length of their associated yoke portions, and means joining said first and second yoke pieces in continuous fixed engagement with one another, to uniformly compress their associated yoke portion; and electrical winding assemblies telescoped over at least certain of said plurality of leg portions.

2. The electrical transformer of claim **1** including first and second substantially flat, metallic plate members, said first metallic plate member being fixedly attached to the first ends of said first and second end frame members, and said second metallic plate member being fixedly attached to the second ends of said first and second end frame members.

3. The electrical transformer of claim **1** wherein said electrical winding assemblies have a substantially rectangular cross-section.

4. The electrical transformer of claim **1** wherein said plurality of leg members and said electrical winding assemblies have a substantially rectangular cross-section.

5. The electrical transformer of claim **2** wherein said electrical winding essemblies have a substantially rectangular cross-section, and including insulating means disposed between said electrical winding assemblies and between said electrical winding assemblies and said first and second metallic plate members to form a continuous, substantially solid structure between said first and second metallic plate members, said first and second metallic plate members bracing the electrical transformer to maintain the substantially rectangular cross-section of said winding assemblies during short circuit conditions.

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