

[54] ELECTRICAL WINDINGS

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[51] Int. Cl.H01f 27/08, H01f 15/14

[58] Field of Search.....336/60, 69, 70, 187, 57, 150,
336/186, 185

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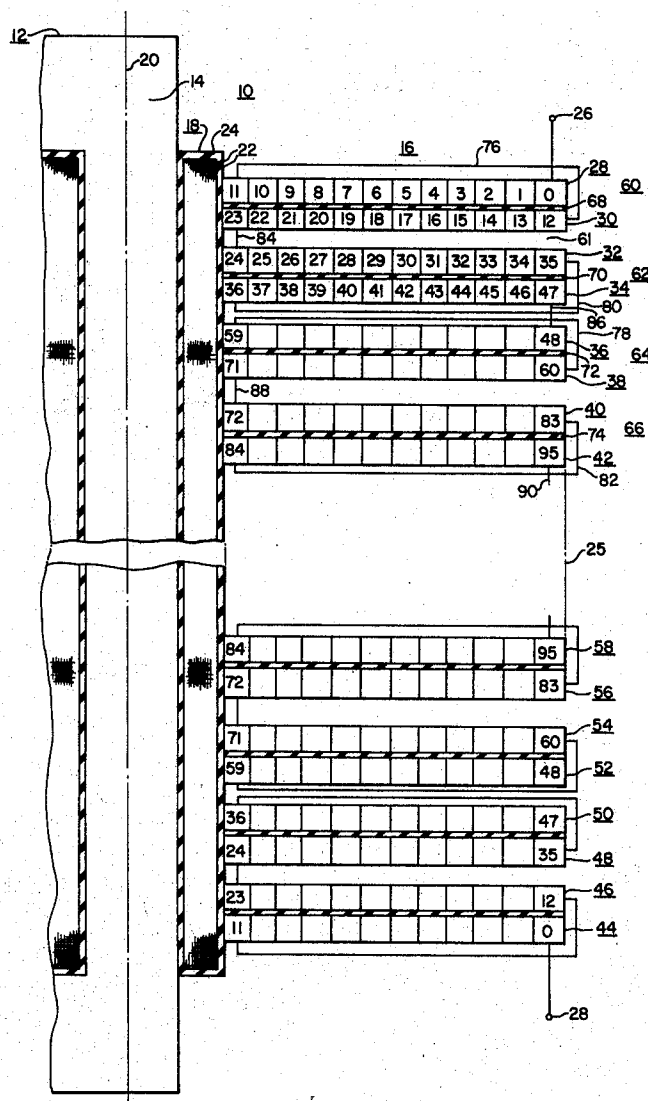
Primary Examiner—Thomas J. Kozma

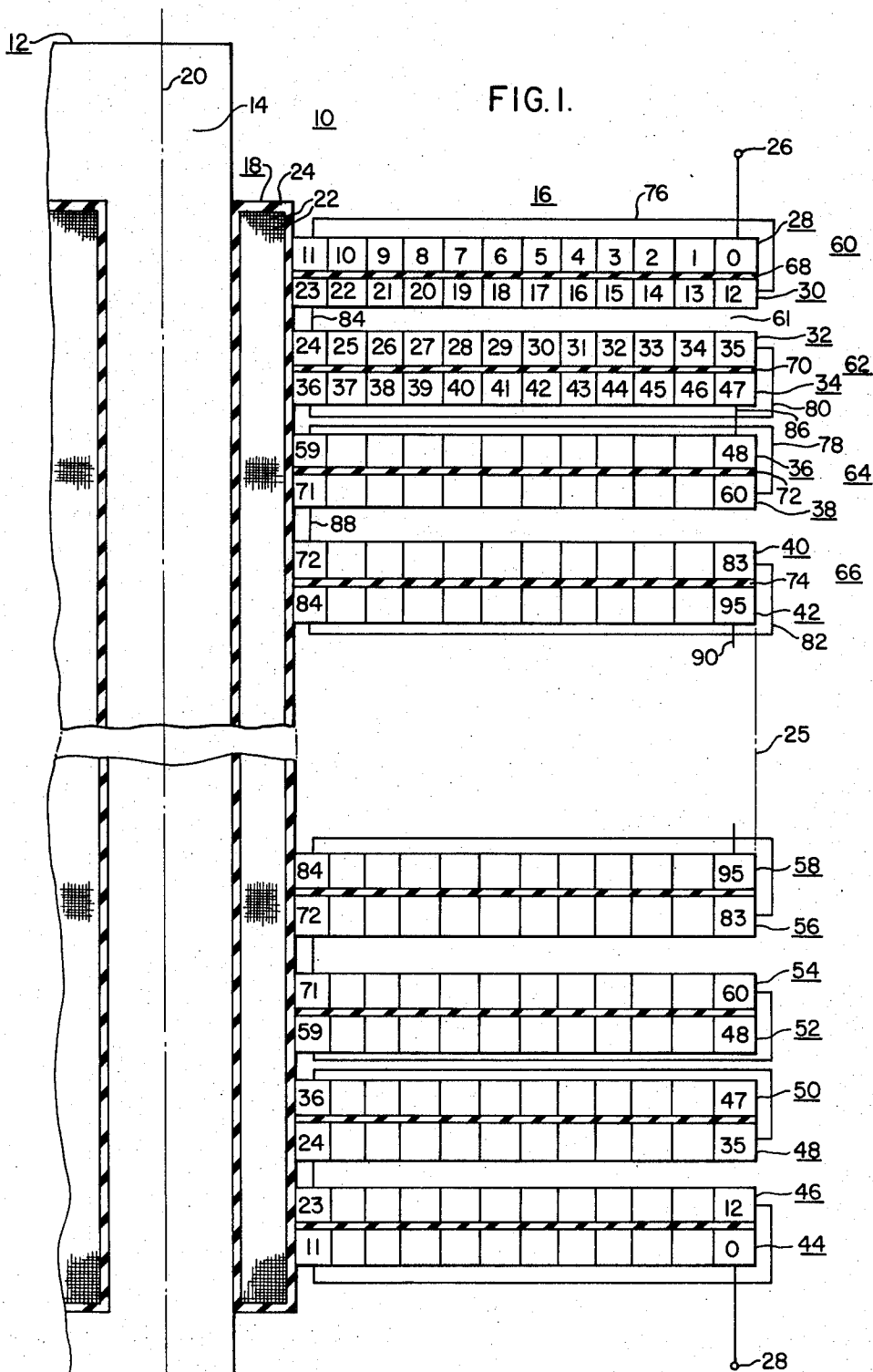
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[57] ABSTRACT

An electrical winding including a stack of axially aligned, continuous, pancake coils. The pancake coils are divided into pairs, and the coils of each pair are disposed closely adjacent one another to increase the capacitance between them. Adjacent pairs are spaced by a dimension selected to enable cooling fluid to flow between the pairs. The coils in each pair are directly interconnected, and the pairs of coils are interconnected, providing at least one electrical path through the winding.

29 Claims, 9 Drawing Figures





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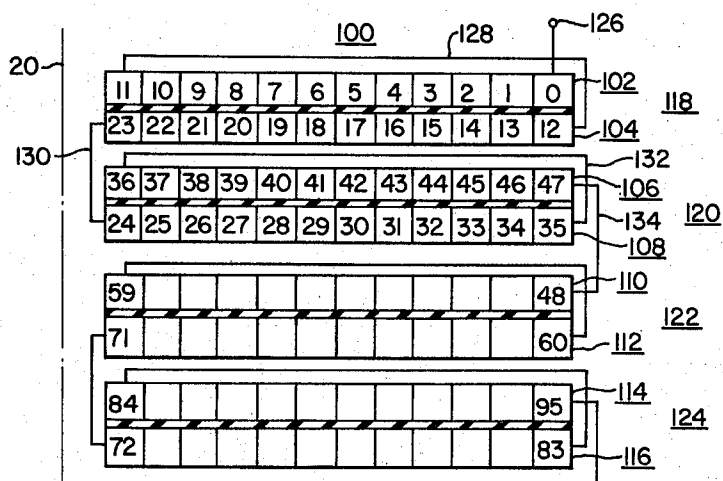


FIG. 2.

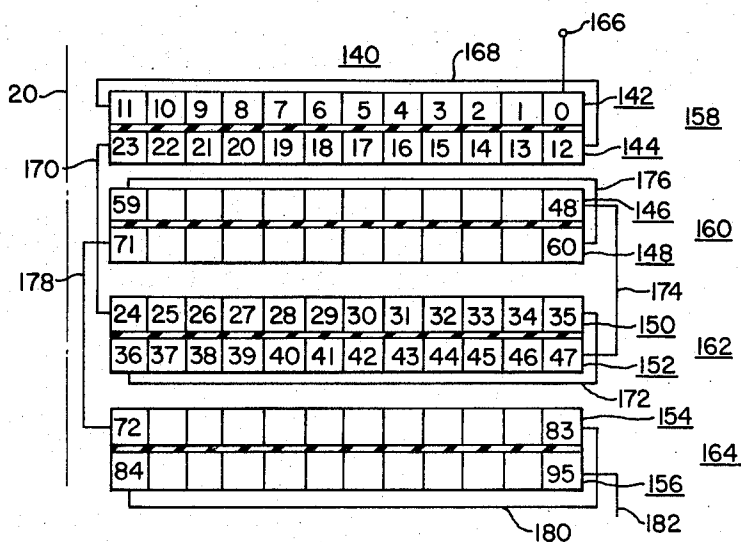


FIG. 3.

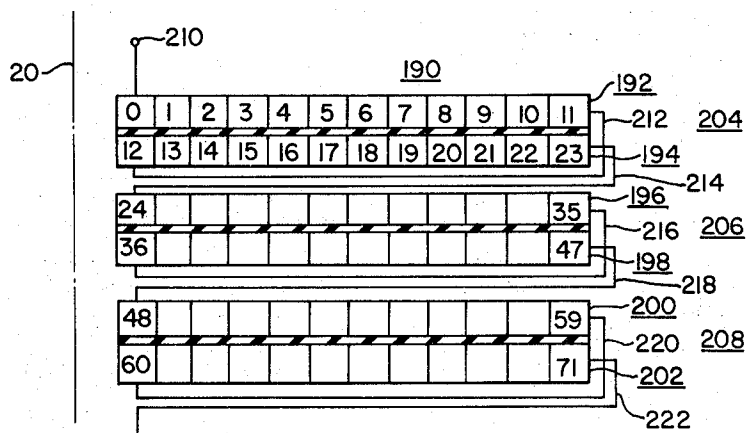


FIG. 4.

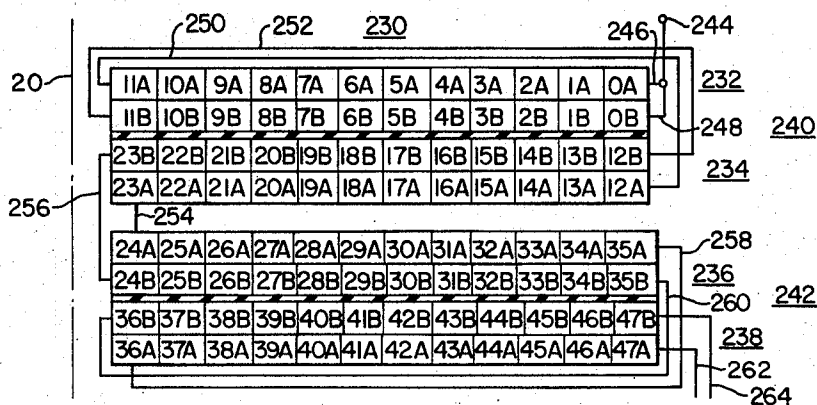


FIG. 5.

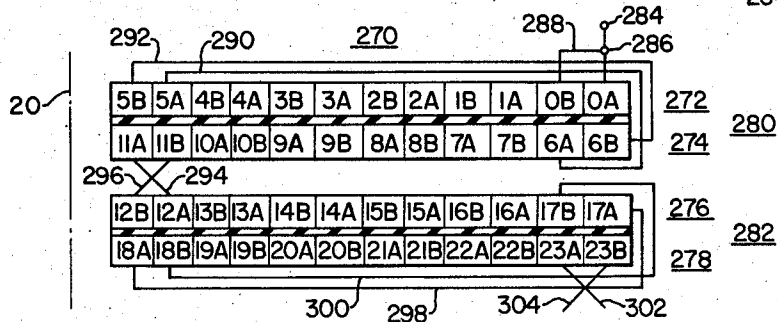


FIG. 6.

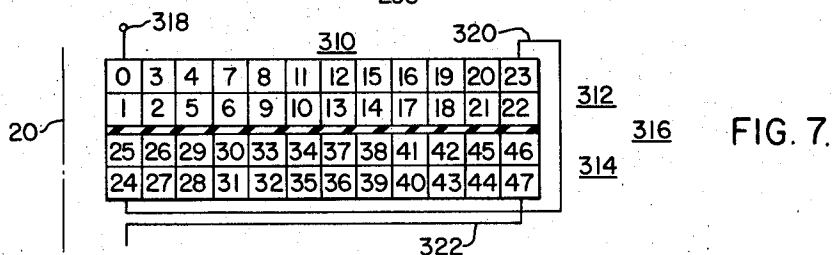


FIG. 7.

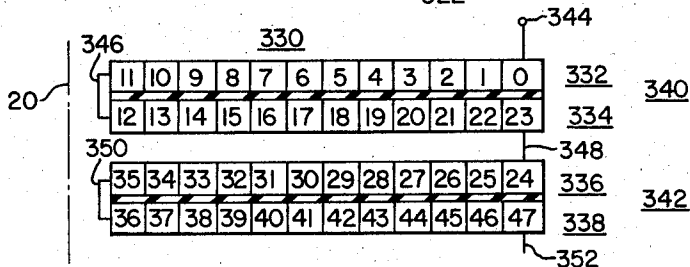


FIG. 8.

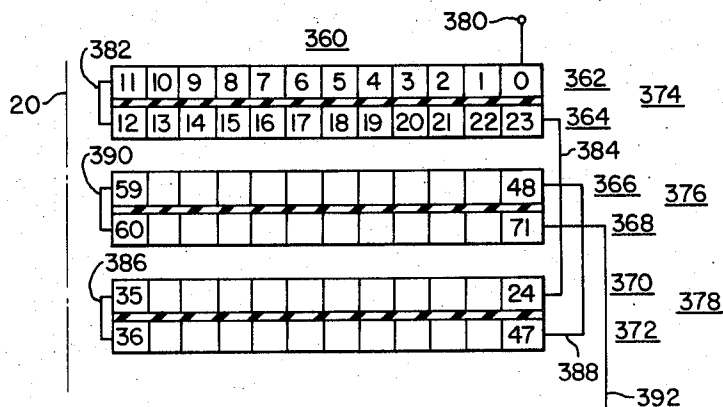


FIG. 9.

ELECTRICAL WINDINGS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to electrical inductive apparatus, and more specifically to windings for electrical power transformers.

2. Description of the Prior Art

Electrical power transformers of the core-form type usually utilize high voltage windings constructed of axially aligned pancake or disc coils, as opposed to layer wound construction, as the pancake type coil has a much higher mechanical strength. Pancake coils of the continuous type, i.e., physically adjacent turns are from electrically adjacent portions of the winding, are relatively easy to wind and interconnect to provide a winding, and are thus attractive from the cost viewpoint. Windings for coreform transformers constructed of continuous pancake coils, however, distribute surge voltages non-uniformly, concentrating surge stresses across the conductor turns of the line end coils, between adjacent line end coils, and from the line end coils to ground. To accommodate these high surge stress concentrations, the turn, interpancake, and pancake to ground insulation is increased. However, in addition to deleteriously affecting the space factor of the winding, the increased insulation at the line end of the winding results in even higher surge stresses, requiring even more insulation, as the series capacitance of the line end of the winding is reduced when the insulating clearances are increased. This is due to the fact that the uniformity of a surge voltage distribution across a winding is responsive to the distribution constant α (α) of the winding, and the distribution constant is determined by the square root of the ratio of the capacitance of the winding to ground to the through or series capacitance of the winding. The smaller the distribution constant α , the more uniformly a surge voltage will be distributed across a winding. Thus, increasing the insulation and thus the spacing between pancake coils at the line end, reduces the series capacitance at this location of the winding, resulting in a higher percentage of the surge voltage being dropped across the line end coils.

Prior art constructions which provide a more uniform voltage distribution across the high voltage winding of core-form power transformers usually suffer from one or more disadvantages, when compared with a winding constructed in the conventional manner of continuous pancake coils, such as increased complexity and a concomitant higher manufacturing cost, and poorer space factor. For example, shielding the windings to reduce the ground capacitance of the winding deleteriously affects cost and space factor, while radially interleaving turns from electrically distant portions of the winding to increase the effective series capacitance of the winding, increases the complexity and cost of the winding, especially when multiple electrical paths are required through the winding.

Thus, it would be desirable to provide a new and improved high voltage electrical winding for power transformers of the core-form type, which winding combines the attractive cost and size of the continuous winding, with the surge voltage distribution characteristics of the shielded or interleaved turn type winding.

SUMMARY OF THE INVENTION

Briefly, the present invention is a new and improved winding for electrical power transformers of the core-form type, which winding includes a plurality of axially aligned, continuous, pancake coils. The pancake coils are divided into pairs, and coil of each pair are disposed with their major surfaces closely adjacent one another to increase the capacitance between them. Adjacent pairs are spaced by a dimension selected to provide cooling ducts between them. The coils of each pair are interconnected, and the pairs are interconnected, to provide at least one electrical path through the winding. The decreased spacing between the coils of each pair increases the series capacitance of the winding, resulting in a more uniform distribution of surge voltages across the winding.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be better understood, and further advantages and uses thereof more readily apparent, when considered in view of the following detailed description of exemplary embodiments, taken with the accompanying drawings, in which:

FIG. 1 is a fragmentary, elevational view, in section, of a core-form power transformer having a high voltage winding constructed according to the teachings of the invention;

FIG. 2 is a fragmentary, elevational view, in section, of a modified form of a high voltage winding which may be used with the transformer shown in FIG. 1;

FIG. 3 is a fragmentary, elevational view, in section, of a high voltage winding constructed according to another embodiment of the invention;

FIG. 4 is a fragmentary, elevational view, in section, of the high voltage winding for a power transformer constructed according to still another embodiment of the invention;

FIG. 5 is a fragmentary, elevational view, in section, of a high voltage winding having two electrical paths therethrough, constructed according to the teachings of the invention;

FIG. 6 is a fragmentary, elevational view, in section, of a high voltage winding for a power transformer illustrating another multi-path embodiment of the invention;

FIG. 7 is a fragmentary, elevational view, in section, of a high voltage winding for a power transformer illustrating an embodiment of the invention in which a single circuit utilizes both axially disposed and radially disposed conductor turns;

FIG. 8 is a fragmentary, elevational view, in section, of a high voltage winding for a power transformer constructed according to another embodiment of the invention; and

FIG. 9 is a fragmentary, elevational view, in section, of a high voltage winding constructed according to still another embodiment of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, and FIG. 1 in particular, there is shown a partial sectional elevation of a transformer 10, which embodies the teachings of the invention. Transformer 10 is a power transformer of the core-form type, it is filled to a predetermined level

with an insulating and cooling dielectric fluid, such as oil, or askarel, and it may be either single or polyphase. Since each phase of the transformer would be similar in the event it is a polyphase transformer, only one phase is shown in FIG. 1 in order to simplify the drawing.

Transformer 10 includes a magnetic core 12, which may be of conventional construction, including a winding leg 14 having an axis 20 about which high and low voltage windings 16 and 18, respectively, are concentrically disposed. Low voltage winding 18, which may be of conventional construction, has a plurality of conductor turns 22 insulated from the magnetic core 12 and the high voltage winding 16 by electrical insulating means 24. High voltage winding 16 includes a plurality of pancake or disc coils, axially aligned in a stacked arrangement with their openings in alignment, about the axis 20 of the magnetic core leg 14. High voltage winding 16 has first and second ends 26 and 28, respectively, with the first end 26 being a line terminal adapted for connection to an elevated electrical potential, and with end 28 being either a line terminal adapted for connection to an elevated potential, or a terminal adapted for connection to ground or the neutral of a wye connected three-phase winding configuration.

High voltage winding 16 includes a plurality of continuous pancake coils, with eight pancake coils being illustrated adjacent each end of the winding 16, and with additional pancake coils being indicated generally by broken line 25.

More specifically, pancake coils 28, 30, 32, 34, 36, 38, 40 and 42 are illustrated disposed about winding leg 14, adjacent to line terminal 26, and pancake coils 44, 46, 48, 50, 52, 54, 56 and 58 are illustrated disposed about winding leg 14, adjacent to terminal 28. Each of the pancake coils are of the continuous type, i.e., they are wound and connected such that electrically adjacent turns are also physically adjacent one another in the coils and winding, as opposed to interleaved turn type pancake coils which are wound and connected such that physically adjacent turns are from electrically distant portions of the winding. Each of the pancake coils includes at least one insulated metallic strand, formed of a good electrical conductor such as copper or aluminum, with FIG. 1 illustrating a single strand embodiment of the invention. The insulated conductor turns, which are formed by the wound conductive strand, define first and second major opposed surfaces. The conductive strand and its surrounding insulation for each conductor turn are not detailed in the drawings, as the construction of the insulated strand and the resulting conductor turns are well known in the art. For purposes of explaining the interpancake connections, the "start" are "finish" ends of a pancake coil are the ends of the innermost and outermost turns thereof, respectively, regardless of where the electrical circuit first enters the pancake coil.

The pancake coils of winding 16 are axially divided or grouped to provide a plurality of pairs of coils, and the coils of each pair are disposed with their major surfaces closely adjacent one another. Adjacent pairs are axially spaced by a greater dimension than are the coils in a pair, in order to provide cooling ducts for removal of heat from the coils. Thus, pancake coils 28 and 30, which are adjacent to line terminal 26, are grouped to provide a first pair 60, coils 32 and 34 are grouped to

provide a second pair 62, coils 36 and 38 are grouped to provide a third pair 64, and coils 40 and 42 are grouped to provide a fourth pair 66. In like manner, the remaining coils are grouped into pairs, such as the coils adjacent to terminal 28, as well as the coils indicated generally by broken line 25. As hereinbefore stated, the axial spacing between adjacent pairs of coils is selected to provide cooling ducts, such as duct 61 between pairs 60 and 62, with a duct having a width dimension of about .188 inch being suitable in most applications.

The first and second pancake coils of each pair are disposed with their major surfaces closely adjacent to one another, in order to increase the capacitance between them. In addition to the insulation surrounding each conductor turn, a thin insulating washer member is preferably disposed between the two coils of each pair, such as insulating washer members 68, 70, 72 and 74, indicated in pairs 60, 62, 64, and 66, respectively. The insulating washer member, which preferably has a thickness dimension in the order of about 0.030 inch, mechanically protects the conductor turns, as the coils of a pair are preferably pressed tightly together to reduce the clearance or space between them to a predetermined small dimension. The solid insulating washer member disposed between the pancake coils of a pair also adds electrical strength to the insulation between the turns, without adding greatly to the spacing between the coils. While the insulating washer members may be formed of pressboard, which is the usual solid insulation utilized in liquid filled power transformers, they may also be formed of a material which has a higher dielectric constant than pressboard, i.e., at least five, and preferably even higher, in order to further increase the capacitance between the coils, such as a material formed of or containing aluminum oxide, barium titanate, titanium dioxide, or mixtures thereof. Resinous insulation systems having a high electrical breakdown strength may be used to provide the washer members, with the systems being filled with means for increasing the overall dielectric constant of the insulating member, if desired.

The first and second pancake coils of each pair of coils are electrically interconnected such that an electrical circuit, or circuits, after once entering a pair, completely traverse the conductors turns of the two coils before leaving the pair. In a preferred embodiment of the invention, the two coils of each pair are interconnected such that a steady state voltage difference is created between axially adjacent turns of the coils of a pair, which difference is substantially uniform from turn-to-turn across the coil builds. This uniform voltage difference across the builds of the coil pairs is equal to one voltage unit, with a voltage unit being the steady state voltage across either coil of a pair. This arrangement uniformly stresses the insulation between the coils of a pair, utilizing it in the most efficient manner, it increases the electrical charge stored between the coils of a pair, and it effectively connects the capacitors formed between adjacent turns in parallel, resulting in these capacitors adding to increase the series capacitance of the winding.

In the embodiment of the invention illustrated in FIG. 1, the coils of a pair are interconnected with a start-finish connection in alternate pairs, and with a finish-start connection in the remaining pairs, which ar-

range facilitates the interconnection of adjacent pairs, as adjacent coils of adjacent pairs are interconnected with the shortest possible interpancake connections. For example, the start of coil 28 is connected to the finish of coil 30 via start-finish connection 76 in the first pair 60, and the start of coil 36 is connected to the finish of coil 38 via start-finish connection 78 in the third pair 64. In the intervening pairs, i.e., pairs 62 and 66, the finish of pancake coil 32 is connected to the start of pancake coil 34 via finish-start connection 80 in pair 62, and the finish of coil 40 is connected to the start of coil 42 via finish-start connection 82 in pair 66.

Adjacent pairs of coils are interconnected with start-start, finish-finish connections across winding 16, with the start ends of the second and first coils 30 and 32 of the first and second pairs 60 and 62, respectively, being interconnected with start-start connection 84, the finish ends of the second and first pancake coils 34 and 36 of the second and third pairs 62 and 64, respectively, being interconnected with finish-finish connection 86, the start ends of the second and first pancake coils 38 and 40 of the third and fourth pairs 64 and 66, respectively, being interconnected with start-start connection 88, and the finish end of pancake coil 42 being connected to the finish end of the next pancake coil via finish-finish connection 90.

Thus, the electrical circuit enters the finish end of pancake coil 28 from the line terminal 26, and it spirals inwardly in a predetermined circumferential direction, with the turns being consecutively numbered in FIG. 1, starting from the line terminal 26. Upon reaching the end of the innermost turn, the circuit proceeds to the finish end of the second pancake coil of pair 60, via start-finish connection 76, and the circuit again spirals inwardly, in the same circumferential direction as the first coil 28 of pair 60. It will be noted that the same number of turns separate axially adjacent turns across the coil build dimensions, illustrating that the interpancake insulation is uniformly stressed. It will further be noted that the turn difference between axially adjacent turns of the pancake coils of a pair is equal to the number of turns in either coil of the pair, illustrating that the voltage difference between axially adjacent turns of the two coils is equal to the voltage across one of the coils, or one voltage unit. In addition to stressing the insulation uniformly between the coils, this arrangement effectively connects the capacitances in parallel, causing the individual capacitors between axially adjacent turns to add and increase the effective series or through capacitance of the pairs of coils, and thus of the winding 16. The circuit then proceeds from the start end of coil 30 to the start end of coil 32 in the next or second pair 62, via start-start connection 84. This circuit then spirals outwardly through coil 32 in the same circumferential direction as the inward spiral through coils 28 and 30, in order to provide an additive magnetomotive force in magnetic core 12, and upon reaching the finish end of coil 32 it proceeds to the start end of coil 34 via finish-start connection 80, and the circuit spirals outwardly through coil 34 in the same circumferential direction as in coil 32. The circuit then proceeds through each succeeding groups of two pairs, as just described for the first group of two pairs, i.e., for pairs 60 and 62.

In the embodiment of the invention shown in FIG. 1, the successive start-start, finish-finish connections between adjacent pairs of coils were made between adjacent coils of adjacent pairs, which construction has the advantage of keeping interpair connections as short as possible. It has the disadvantage of requiring the interpancake connections between the coils of a pair to change from pair to pair, being a start-finish connection in one pair, and a finish-start connection in the next pair. The invention is not limited to this specific arrangement, however, as the coils in each pair may be interconnected in a similar manner. FIG. 2 is a fragmentary elevational view, in section, which illustrates a winding 100 in which the coils in each pair are all interconnected with a start-finish connection.

More specifically, FIG. 2 illustrates a winding 100 having a plurality of pancake coils 102, 104, 106, 108, 110, 112, 114 and 116, and these coils are grouped or axially divided into a plurality of pairs. Pancake coils 102 and 104 are grouped to provide a first pair 118, coils 106 and 108 are grouped to provide a second pair 120, coils 110 and 112 are grouped to provide a third pair 122, and coils 114 and 116 are grouped to provide a fourth pair 124. The coils of each pair are disposed in closely adjacent relation, as hereinbefore described relative to the winding 16 of FIG. 1, and the inner end of the first coil in each pair is connected to the outer end of the second coil of the same pair. Thus, the outer end of the first pancake coil 102 is connected to a line terminal 126, the inner end of pancake coil 102 is connected to the outer end of pancake coil 104 via start-finish connection 128, the inner end of pancake coil 104 is connected to the inner end of pancake coil 108 via start-start connection 130, the finish end of pancake coil 108 is connected to the start end of pancake coil 106 via start-finish connection 133, and the finish end of pancake coil 106 is connected to the finish end of pancake coil 110 via finish-finish connection 134. The remaining coils in each pair, and pairs of coils are interconnected as described relative to the first two pairs 118 and 120.

In the embodiments of the invention shown in FIGS. 1 and 2, the means interconnecting the pairs has been illustrated as interconnecting adjacent pairs of coils. FIG. 3 is a fragmentary, elevational view, in section, of a winding 140 in which the pairs are interconnected in basic groups of four, such that the electrical circuit successively traverses the first, third, second and fourth pairs of coils, instead of successively traversing the first, second, third and fourth pairs as hereinbefore described.

More specifically, FIG. 3 illustrates a winding 140 having a plurality of pancake coils 142, 144, 146, 148, 150, 152, 154 and 156, with these coils being axially divided to provide a plurality of pairs 158, 160, 162 and 164. The finish end of pancake coil 142 is connected to a line terminal 166, and the circuit spirals inwardly through pancake coil 142 until reaching its start end, at which point the circuit continues via start-finish connection 168 which interconnects the start of pancake coil 142 with the finish of pancake coil 144. The circuit spirals inwardly through pancake coil 144 and upon reaching the end of its innermost turn, it continues to the third pair 162, instead of being connected to the immediately adjacent pair 160. The start of pancake

coil 144 is connected to the start of pancake 150 via start-start connection 170, and the circuit traverses both pancakes of pair 162 by an interpancake connection 172 connected between the finish end of pancake coil 150 and the start end of pancake coil 152. After traversing pair 162, the circuit proceeds to the second pair 160 via finish-finish connection 174 connected between the finish of pancake coil 152 and the finish of pancake coil 146. The circuit then traverses pancake coils 146 and 148 of the second pair 160, proceeding from the start end of pancake coil 146 to the finish end of pancake coil 148 via start-finish connection 176. After traversing the second pair 160, the circuit proceeds to the fourth pair 164 via start-start connection 178 connected between the start of pancake coil 148 and the start of pancake 154. The circuit then completely traverses the pancake coils 154 and 156 of the fourth pair 164, proceeding from the finish end of the first pancake coil 154 to the start end of the second pancake coil 156 via finish-start connection 180. The remaining portion of winding 140 is interconnected in basic groups of four pairs, as hereinbefore described relative to the first four pairs of the winding.

While the embodiments of the invention described to this point have described the line terminal as being connected to the finish end of one of the pancake coils of the first pair, the line terminal may also be connected to the start of one of the coils of the first pair, with this construction having the advantage of being able to utilize all machine wound pancake coils, as the circuit spirals outwardly in each pancake coil FIG. 4 is a fragmentary elevational view, in section, of a winding 190 constructed according to this embodiment of the invention.

More specifically, FIG. 4 illustrates a winding 190 having a plurality of pancake coils 192, 194, 196, 198, 200 and 202, with these pancake coils being axially grouped into pairs 204, 206 and 208. The end of the innermost turn of the first pancake 192 of pair 204 is connected to a line terminal 210, the finish end of pancake coil 192 is connected to the start end of pancake coil 194 via finish-start connection 212, the finish end of pancake coil 194 is connected to the start end of pancake coil 196 via finish-start connection 214, the finish end of pancake coil 196 is connected to the start end of pancake coil 198 via finish-start connection 216, the finish end of pancake coil 198 is connected to the start end of pancake coil 200 via finish-start connection 218, the finish end of pancake coil 200 is connected to the start of pancake coil 202 via finish-start connection 220, and the finish end of pancake coil 202 is connected to the start of the next pancake coil via finish-start connection 222.

The embodiments of the invention hereinbefore described have used examples in which there was a single electrical path or circuit through the high voltage winding, but all of the embodiments of the invention may utilize more than one electrical path, and indeed the invention is particularly applicable to multipath applications as it adds little to the manufacturing cost of the winding, unlike prior art arrangements, such as interleaved turn type arrangements which may become quite complex when multiple paths are necessary to handle the power requirements of a winding. FIGS. 5 and 6 are fragmentary, elevational views, in section, of

two different approaches to the use of multiple circuits, with the turns of the multiple paths being axially disposed in the embodiment of FIG. 5, and radially disposed in the embodiment of FIG. 6.

More specifically, FIG. 5 illustrates a winding 230 having a plurality of pancake coils 232, 234, 236 and 238, which are axially divided into pairs, with pancake coils 232 and 234 being grouped to provide a first pair 240, and pancake coils 236 and 238 being grouped to provide a second pair 242. Each of the pancake coils is formed of two insulated conductors, disposed side-by-side, such that when the two conductors are wound to provide a pancake coil the two circuits are axially spaced from one another. In this embodiment, a line terminal 244 is connected to the finish ends of pancake coil 232, via conductors 246 and 248. The two circuits spiral inwardly through pancake coil 232, with the first circuit being referenced the A circuit and the second circuit being referenced the B circuit. The turn numbers and the circuit in which the turns are located are indicated on the turns. After reaching the innermost ends of the A and B circuits, the two circuits proceed to the finish ends of the two circuits of pancake coil 234 via start-finish connections 250 and 252. The ends of the innermost turns of the A and B circuits of pancake coil 234 then proceed to the start ends of the two circuits of pancake coil 236 via start-start connections 254 and 256, and the circuits spiral outwardly through pancake coil 236. Upon reaching the ends of the outermost turns of pancake coil 236, the A and B circuits continue to the starts of the A and B circuits of pancake coil 238, via finish-start connections 258 and 260. Upon reaching the ends of the outermost turns of pancake coil 238, the circuit proceeds to the next adjacent pair of pancake coils via finish-finish connections 262 and 264.

In the multiple conductor embodiment shown in FIG. 5, the axial placement of the multiple conductors in each pancake coil may impede the transfer of heat from the conductive strands to the cooling fluid, especially from the strands located immediately adjacent to the insulating washer member disposed between adjacent pancake coils. FIG. 6 illustrates a multiple conductor embodiment of the invention which does not have this disadvantage, as the multiple conductors are disposed radially relative to one another, instead of axially. FIG. 6 illustrates a winding 270 having a plurality of pancake coils 272, 274, 276 and 278, which are grouped to provide a first pair 280 which includes pancake coils 272 and 274, and a second group 282 which includes pancake coils 276 and 278. Each of the pancake coils of winding 270 are wound with two conductors disposed radially relative to one another, which radially interleaves the turns of the two circuits, referenced the A and B circuits, but unlike the interleaved turn type construction, the two circuits are not interconnected to impart a voltage difference between the adjacent turns of the two circuits. The A and B circuits of the first pancake coil 272 are connected to a line terminal 284 via conductors 286 and 288, respectively, and the two circuits spiral inwardly together until reaching the ends of their innermost turns, at which point they proceed to the finish ends of the A and B circuits of pancake coil 274 via start-finish connections 290 and 292. The circuits then spiral inwardly

through the second pancake coil 274 of the first pair 280, and upon reaching the ends of the innermost turns of the A and B circuits they proceed to the starts of the A and B circuits of the third pancake coil 276, via start-start connections 294 and 296. The finish ends of the A and B circuits of the third pancake coil 276 are connected to the start ends of the A and B circuits of the fourth pancake coil 278 via finish-start connections 298 and 300, and the circuits spiral outwardly until reaching the ends of the outermost turns of pancake coil 278, at which point they proceed to the next adjacent pancake coil via finish-finish connections 302 and 304.

FIG. 7 is a fragmentary, elevational view, in section, of a winding 310 constructed according to another embodiment of the invention, in which each pancake coil has a single electrical circuit or path, but with the turns of each pancake coil being both axially and radially disposed relative to one another. In other words, as the circuit enters each radial turn location, it is wound to provide two or more axially disposed turns before proceeding to the next radial layer.

More specifically, FIG. 7 illustrates a winding 310 having a plurality of pancake coils 312 and 314 which are grouped to provide a pair 316. Only one pair is illustrated, as the other pairs would be similarly constructed and interconnected. The pancake coil 312 is connected to a line terminal 318 and the circuit enters pancake coil 312 at the start end of the coil. As the circuit enters pancake coil 312, it proceeds through two turns at the first radial turn location, and then proceeds to the next radial location and proceeds through two turns. This procedure is followed completely through the first pancake coil 312, and upon reaching the end of its outermost turn, it proceeds to the start end of the pancake coil 314 via finish-start connection 320. Pancake coil 314 is constructed in a manner similar to pancake coil 312, having two axially adjacent turns in each radial turn position. Upon reaching the end of the outermost turn of pancake coil 314, the circuit proceeds to the next pancake coil via finish-start connection 322.

In the preferred embodiment of the invention, the voltage difference between axially adjacent turns of the two pancake coils of a pair is uniformly one voltage unit across the build of the two coils of each pair, in order to provide the most uniform distribution of surge potentials and most efficient usage of the insulation between the coils of the pair. However, it would also be beneficial to arrange the continuous coils of a winding in pairs and dispose the coils of a pair closely together, when the coils of a pair are interconnected such that the voltage varies between axially adjacent turns across the coil build. FIGS. 8 and 9 are fragmentary, elevational views, in section of windings 330 and 360, respectively, which illustrate embodiments of this latter mentioned arrangement.

More specifically, FIG. 8 illustrates a winding 330 having a plurality of pancake coils 332, 334, 336 and 338, which are axially divided to provide a first pair 340 which includes pancake coils 332 and 334, and a second pair 342 which includes pancake coils 336 and 338. The circuit enters the outermost turn or finish end of pancake coil 332 from a line terminal 344 and spirals inwardly until reaching the innermost end of pancake coil 332 at which point the circuit proceeds to the start

of pancake coil 334 via start-start connection 346. While the circuit spirals inwardly in the first pancake coil 332 of pair 340, it spirals outwardly in the second pancake coil 334, but the circumferential direction of the circuit is the same in each of the pancake coils in order to provide an additive magnetomotive force in the magnetic core. The circuit then proceeds to the second pair 342 via finish-finish connection 348 between the finish ends of pancake coils 334 and 336, it proceeds from the start end of pancake coil 336 to the start end of pancake coil 338 via start-start connection 350, and then continues to the next pancake coil from the finish end of pancake coil 338 via finish-finish connection 352. Winding 330 is easy to manufacture since the interpancake and interpair connections are all very short connections.

While winding 330 illustrated in FIG. 8 interconnects adjacent pairs of coils, the invention is not to be limited to this embodiment, as in some instances it is advantageous to interconnect remote pairs. An example of this embodiment is illustrated in FIG. 9 in which a winding 360 is illustrated having a plurality of pancake coils 362, 364, 366, 368, 370 and 372. The pancake coils are axially divided into pairs, with pancake coils 362 and 364 being grouped to provide a first pair 374, pancake coils 366 and 368 are grouped to provide a second pair 376, and pancake coils 370 and 372 are grouped to provide a third pair 378. The circuit enters the outermost end of pancake coil 360 from a line terminal 380 and spirals inwardly to the innermost turn, proceeding to the second pancake coil 364 of the first pair 374 via start-start connection 382. The finish end of pancake coil 364, instead of being connected to a coil in the second pair 376 proceeds to the third pair 378 via finish-finish connection 384, and enters the finish end of pancake coil 370. The start ends of pancake coils 370 and 372 are interconnected via start-start connection 386 and the finish end of pancake coil 388 proceeds to the finish end of pancake coil 366 in the second pair 376. The start ends of pancake coils 366 and 368 are interconnected via start-start connection 390, and the finish end of pancake coil 368 is connected to the finish end of a coil in the fourth pair of pancake coils via finish-finish connection 392. The next group of three pairs of coils will be interconnected as described relative to the three pairs of coils shown in FIG. 9.

In summary, there has been disclosed new and improved high voltage electrical windings for power transformers of the core-form type, which combine the attractive cost and size of continuous pancake coils with an improved surge voltage distribution characteristic approaching that of the more complicated and costly interleaved turn and shielded windings. In all of the embodiments of the invention, the pancake coils utilized are continuous, with the improved impulse stress distribution being obtained by dividing the continuous pancake coils into pairs and disposing the coils of each pair in closely adjacent relation to substantially increase the series capacitance between them. Cooling ducts are provided by spacing adjacent pairs of coils by a dimension necessary to provide the required heat transfer.

I claim as my invention:

1. A winding for electrical inductive apparatus, comprising:

an axially aligned stack of continuous pancake coils wherein radially adjacent turns are from electrically adjacent portions of the winding, each of said pancake coils having start and finish ends and a plurality of insulated conductor turns which define first and second major opposed surfaces,

said pancake coils being axially divided into pairs, with each pair having first and second pancake coils, the adjacent major surfaces of the first and second pancake coils in each pair are closely adjacent to increase the capacitance between them, and the second and first coils of adjacent pairs are spaced by a greater dimension than the spacing between the coils of a pair, to define cooling ducts, first means interconnecting the first and second coils of each pair to provide a difference in potential between axially adjacent turns, and second means interconnecting said pairs of coils to provide at least one electrical path through said stack of pancake coils.

2. The winding of claim 1 wherein the first means interconnects the start end of one pancake coil in each pair to the finish end of the other pancake coil of the pair.

3. The winding of claim 2 wherein the first means interconnects the start and finish ends of the first and second coils, respectively, of each pair.

4. The winding of claim 2 wherein the first means interconnects the start and finish ends of the first and second coils, respectively, of alternate pairs, and the finish and start ends of the first and second coils, respectively, of the intervening pairs.

5. The winding of claim 2 wherein the finish end of the first pancake coil of the pair at one end of the stack is adapted for connection to an elevated electrical potential.

6. The winding of claim 5 wherein the second means interconnects adjacent pairs of pancake coils, with alternate interpancake connections being start-start connections, and the intervening interpancake connections being finish-finish connections.

7. The winding of claim 6 wherein the first means interconnects the start and finish ends of the first and second coils, respectively, of alternate pairs, and the finish and start ends of the first and second coils, respectively, of the intervening pairs.

8. The winding of claim 6 wherein the first means interconnects the start and finish ends of the first and second coils, respectively, of each pair.

9. The winding of claim 2 wherein the second means interconnects the pairs in groups of four, successively interconnecting the first and third pairs, the third and second pairs, and the second and fourth pairs.

10. The winding of claim 9 wherein the finish end of the first pancake coil of the pair at one of the stack is adapted for connection to an elevated electrical potential, the connection between the first and third pairs is a start-start connection, the connection between the third and second pairs is a finish-finish connection, and the connection between the second and fourth pairs is a start-start connection.

11. The winding of claim 2 wherein the start end of the first coil of the pair at one end of the stack is adapted for connection to an elevated electrical potential.

12. The winding of claim 11 wherein the second means interconnects adjacent pairs of coils with finish-start connections.

13. The winding of claim 2 wherein the first means interconnect the first and second coils of each pair with finish-start connections, respectively, and the second means interconnects the second and first coils of adjacent pairs with finish-start connections, respectively.

14. The winding of claim 2 wherein an insulating washer member is disposed between the coils in each pair pancake coils, with the coils of each pair being butted against the insulating washer member.

15. The winding of claim 1 wherein an insulating washer member is disposed between the coils in each pair of pancake coils, with the coils of each pair being butted against the insulating washer member.

16. The winding of claim 14 wherein the insulating washer member has a dielectric constant of at least five.

17. The winding of claim 15 wherein the insulating washer member has a dielectric constant of at least five.

18. The winding of claim 2 wherein each coil includes at least first and second discrete conductors, with the first and second means interconnecting the coils of each pair, and the pairs, respectively, to provide at least two electrical paths through the stack of pancake coils.

19. The winding of claim 1 wherein each coil includes at least first and second discrete conductors, with the first and second means interconnecting the coils of each pair, and the pairs, respectively, to provide at least two electrical paths through the stack of pancake coils.

20. The winding of claim 18 wherein the conductor turns of the first and second discrete conductors are radially interleaved with one another in each pancake coil.

21. The winding of claim 19 wherein the conductor turns of the first and second discrete conductors are radially interleaved with one another in each pancake coil.

22. The winding of claim 18 wherein the conductor turns of the first and second conductors are disposed axially adjacent one another in each pancake coil.

23. The winding of claim 19 wherein the conductor turns of the first and second discrete conductors are disposed axially adjacent one another in each pancake coil.

24. The winding of claim 2 wherein each pancake coil includes a single electrical path, and at least two axially adjacent conductor turns, with the single electrical path traversing the axially disposed turns of each radial turn position, before proceeding to the turns of the next radial turn position.

25. The winding of claim 1 wherein each pancake coil includes a single electrical path, and at least two axially adjacent conductor turns at each radial turn position, with the single electrical path traversing the axially disposed turns of each radial turn position, before proceeding to the turns of the next radial turn position.

26. The winding of claim 1 wherein the first means interconnects the start ends of the first and second pancake coils in each pair.

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27. The winding of claim 26 wherein the second means interconnects the finish ends of the second and first pancake coils of predetermined pairs of pancake coils.

28. The winding of claim 27 wherein the second means interconnects adjacent pairs of coils.

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29. The winding of claim 27 wherein the second means interconnects the pairs in basic groups of three, such that the electrical circuit successively traverses the first, third and second pairs of coils.

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