United States Patent

Van Nice

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[54] **ELECTRICAL WINDINGS**

[72] Inventor: **Robert I. Van Nice**, Sharon, Pa.

[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.

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[21] Appl. No.: **96,010**

[52] **U.S. Cl.** **336/70**
[51] **Int. Cl.** **H01f 15/14**
[58] **Field of Search** 336/69, 70, 186, 187

[56] **References Cited**

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3,221,282	11/1965	Brierley et al.	336/69
3,371,300	2/1968	Stein	336/70
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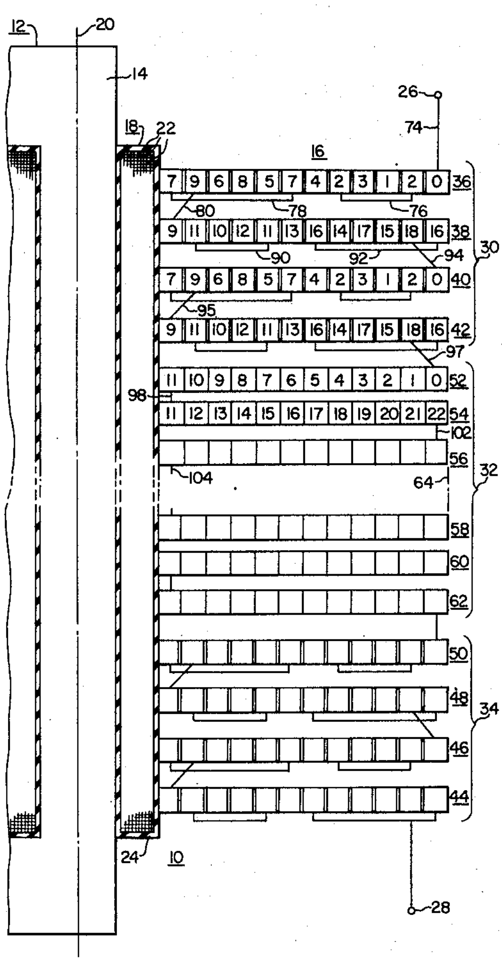
Primary Examiner—Thomas J. Kozma
Attorney—A. T. Stratton, F. E. Browder and D. R. Lackey

[57] **ABSTRACT**

A winding for electrical inductive apparatus, having a plurality of axially spaced, serially connected pancake coils. A first group of pancake coils at one end of the winding are of the interleaved turn type, and a second group of pancake coils, connected to the first group, are of the continuous type. The degree of interleaving of the first group, and the radial spacing between the conductor turns of each pancake coil of the first group, are selected to provide a series capacitance for the first group which is a maximum of four times the series capacitance of the second group.

10 Claims, 12 Drawing Figures



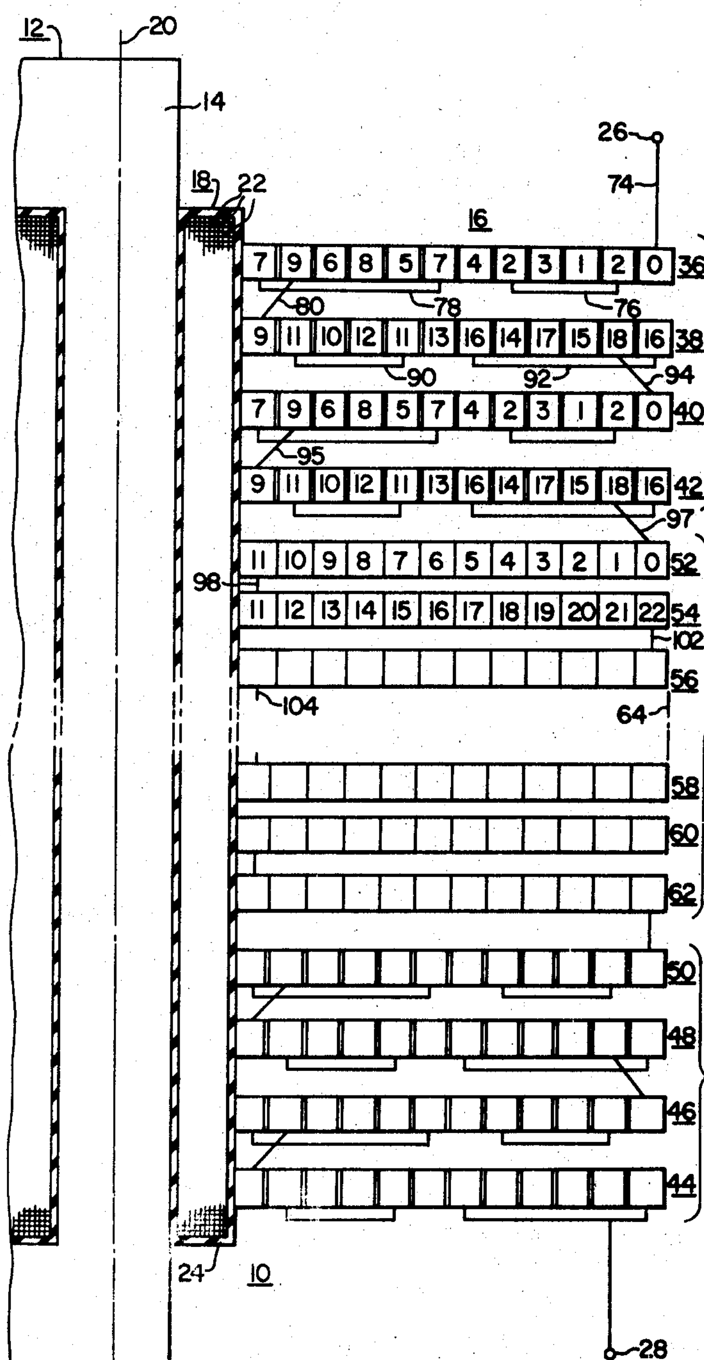


FIG. 1.

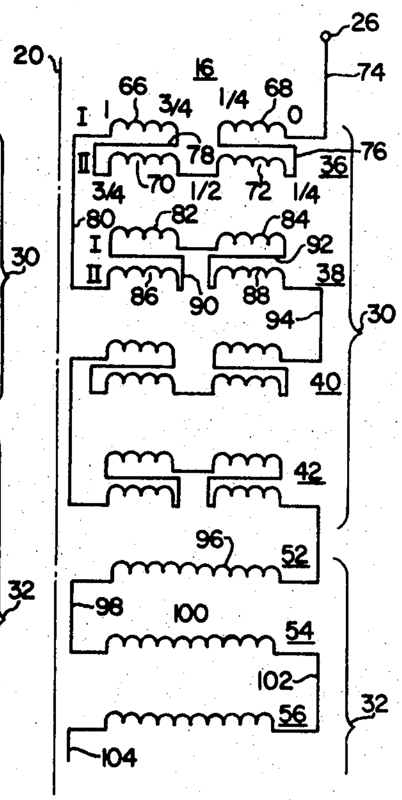


FIG. 1A.

WITNESSES

Theodore F. Wrobel

James F. Young

INVENTOR

Robert I. Van Nice

BY Donald R. Lackey

ATTORNEY

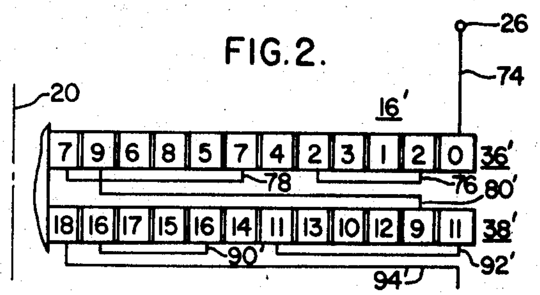


FIG. 2.

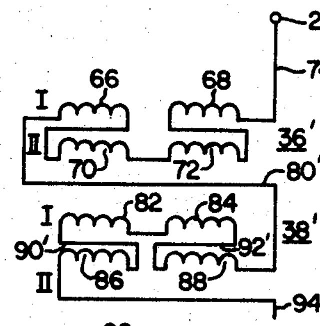


FIG. 2A.

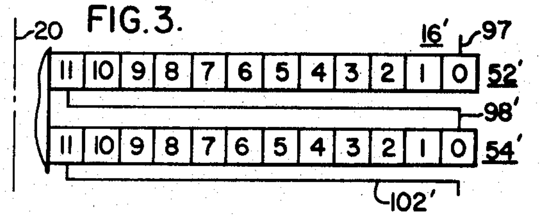


FIG. 3.

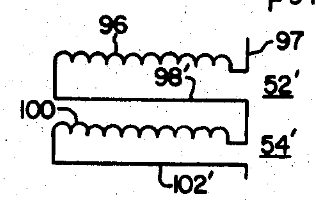


FIG. 3A.

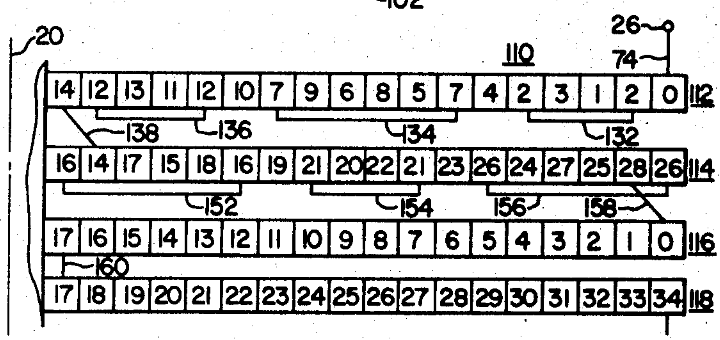


FIG. 4.

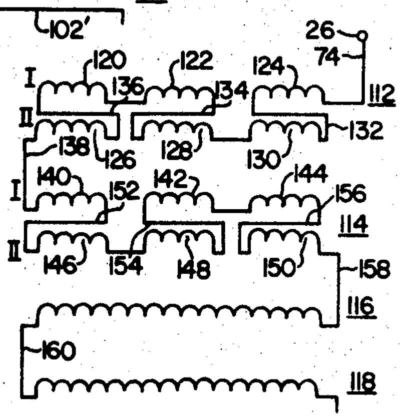


FIG. 4A.

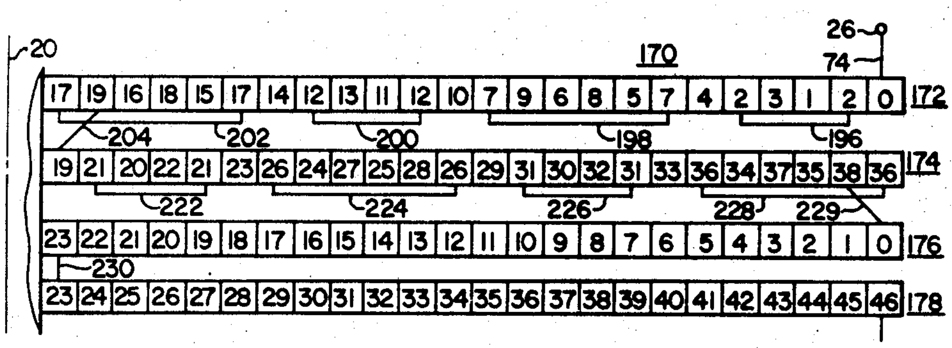


FIG. 5.

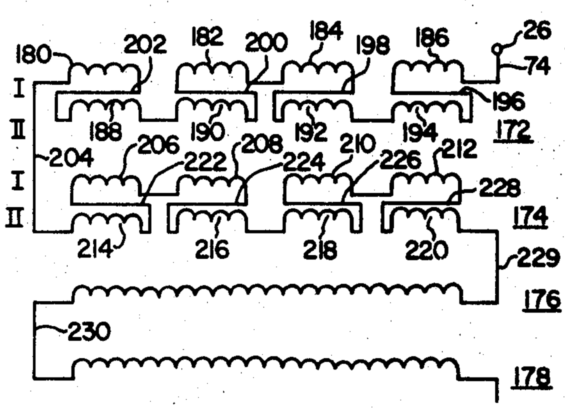


FIG. 5A.

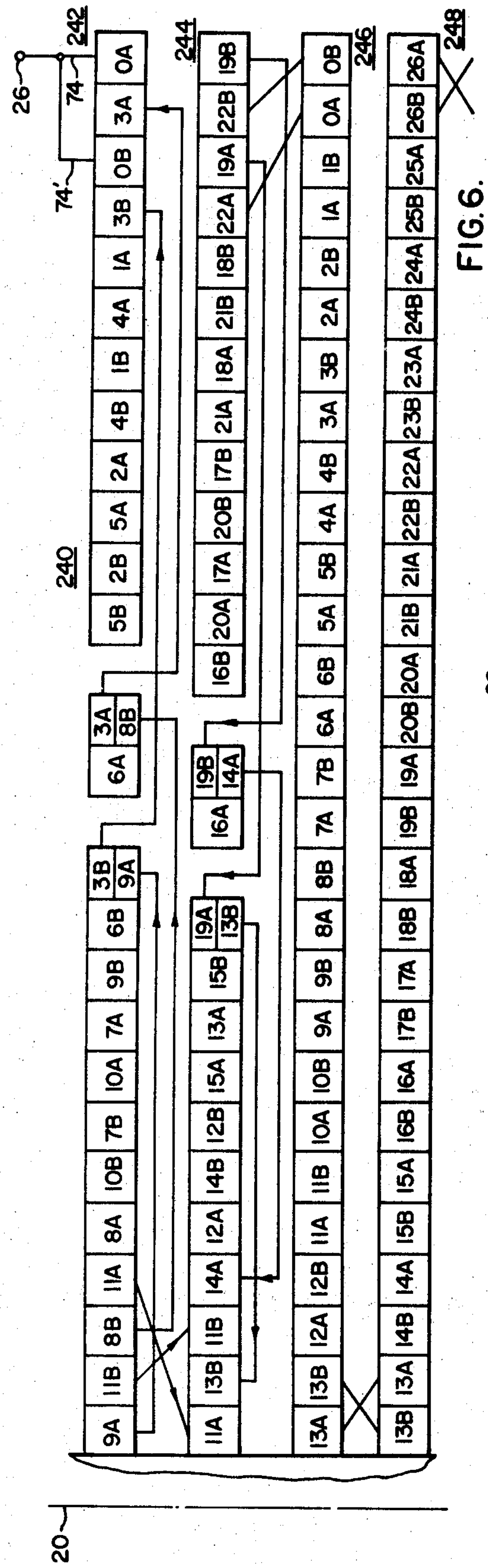

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FIG. 6.

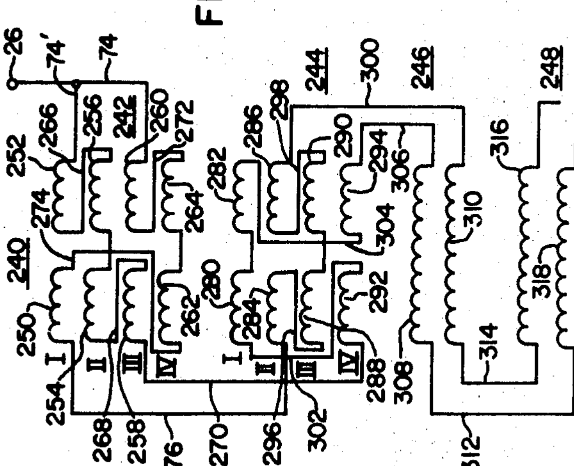
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FIG. 6A.

ELECTRICAL WINDINGS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to electrical inductive apparatus, such as transformers, and more particularly to windings for electrical power transformers of the core-form type.

2. Description of the Prior Art

Electrical inductive apparatus, such as power transformers of the core-form type, commonly utilize windings constructed of a plurality of axially spaced, interconnected disc or pancake type coils. Pancake coils of the continuous type are relatively easy to wind, and thus provide a winding which is attractive from the manufacturing cost standpoint. However, the distribution of surge potentials across this type of winding is very non-uniform, concentrating at the line end, or ends of the winding, due to the relatively small through or effective series capacitance C_S of this type of winding, compared with the capacitance C_G of the winding to ground. The uniformity of a surge voltage distribution across the winding can be predicted by the distribution constant alpha of the winding, which is proportional to the square root of the ratio of the capacitance to ground C_G to the through or series capacitance C_S ($\alpha = \sqrt{C_G/C_S}$). The lower the distribution constant alpha, the more uniformly a surge voltage is distributed across a winding. Thus, it is common to construct the pancake coils such that their effective series capacitance is increased, such as by interleaving. Interleaving is performed by winding a pancake coil with two or more radially interleaved conductors, each of which forms a radial coil section, with the various radial coil sections of the pancake coils of the winding being electrically interconnected to substantially increase the voltage between adjacent turns in the pancake coil, compared with the voltage between adjacent turns in a continuous type pancake coil. In other words, electrically adjacent turns are physically separated by a turn from an electrically distant portion of the winding.

The degree of interleaving, i.e., the magnitude of the potential difference between adjacent turns of radially interleaved coil sections, compared with the voltage across a single coil section, is selected to provide as great a voltage difference between adjacent coil turns as practical, as the greater the voltage difference, the higher the effective series capacitance of the winding, and thus the lower the distribution constant alpha and the more uniformly a surge potential will be distributed across the winding. The most common interleaving arrangements employed are the twin and single interleaving arrangements. In the twin interleaving arrangement, two adjacent pancake coils, each having two radially interleaved coil sections, are required to complete one basic interleaving pattern, with the circuit proceeding through a coil section of each coil, and then returning to the first coil and proceeding through the remaining coil sections of the two coils. The series capacitance of the twin interleaved winding is about 100 times the series capacitance of a like rated and dimensioned continuous winding.

The single interleaving arrangement completes the basic interleaving pattern in one coil, without repeating itself, requiring that the coils have two radially interleaved coil sections. The outer end of one coil section is connected to the inner end of the other, with this arrangement providing a series capacitance which is about 25 times greater than the series capacitance of a like rated and dimensioned continuous winding.

Since manufacturing the interleaved turn type pancake coil inherently requires more manufacturing time than the continuous type pancake coil, due to the time required to make the interleaving connections, many attempts have been made in the prior art to utilize a plurality of interleaved turn coils at the line end, or ends, of the winding, with the balance of the coils being of the lower cost continuous type. While this approach is theoretically sound, many practical difficulties are

encountered which have largely offset the prospective cost advantage. The large difference between the series capacitance of the interleaved group of pancake coils and the group of continuous coils, produces large oscillatory voltages when the winding is subjected to a surge potential, which oscillations are directly due to the discontinuity or abrupt change in the series capacitance. Further, the number of interleaved coils required in the interleaved group to significantly reduce the voltage applied to the continuous group, is quite large, as relatively little voltage would be dropped across only a few twin or singly interleaved pancake coils. Attempts to gradually reduce the series capacitance of the interleaved group, before connecting the interleaved group to the continuous group, and thus prevent a large discontinuity in the series capacitance at their juncture, have been made, such as disclosed in U.S. Pat. No. 3,221,282, but this arrangement further complicates the manufacturing of the interleaved group, and extends the number of pancake coils required in the interleaved group. United States Pat. No. 3,387,243 takes another approach, disposing a static plate between the interleaved and continuous groups, but this adds to the axial length of the winding stack, and adds inactive conductive material to the winding.

Thus, it would be desirable to provide a winding for power transformers of the core-form type which has interleaved pancake coils disposed adjacent the line end, or ends, with the balance of the winding being continuous type pancake coils, but it would be desirable to do so while utilizing relatively few pancake coils in the interleaved group, or groups, without resorting to static plates, and without gradually changing the percentage of the radial build of the pancake coils which is interleaved, across the interleaved group.

SUMMARY OF THE INVENTION

Briefly, the present invention is a new and improved winding for electrical power transformers of the core-form type, which has an interleaved turn group of pancake coils connected to each line end of the wind, with the remaining coils being of the continuous type. The interleaved group is connected directly to the continuous group without the necessity of interposing a static plate. Further, the coils of the interleaved group each have a like degree of interleaving, with the interleaving proceeding across the complete radial build dimension of the pancake coils, simplifying the manufacture thereof. This construction is made possible, without encountering large oscillations when the winding is surged, by an arrangement which resulted from the finding that an interleaved turn winding is substantially non-oscillatory when surged, regardless of its series capacitance. In the prior art, a large series capacitance is strived for, in order to reduce the distribution constant alpha of the winding, and thus provide a more uniform distribution of a surge voltage across the winding. However, when connecting interleaved groups and continuous groups, it has been found that instead of striving for a high series capacitance for the interleaved group, that a series capacitance should be obtained for the interleaved group which is in the range of only about 2.5 to 4 times the series capacitance of the continuous group. The interleaved group provides a non-oscillatory voltage dropping impedance when a surge potential is applied to the winding, reducing the surge potential to a value which may be accommodated by the continuous group. With a series capacitance in the range of 2.5 to 4 times that of the continuous group, a substantial portion of the surge voltage will be dropped over a relatively few interleaved pancake coils. The increased turn insulation which may be required in the interleaved group to withstand the resulting high surge stresses aids in reducing the series capacitance of the interleaved group to the desired value. The duct spacing between the pancake coils of the interleaved group may be selected to be that which is necessary for the high surges to be dropped across the interleaved group, as the series capacitance in interleaved windings is substantially developed between the turns in each pancake coil, with very little being due to the spacing of the interleaved pancake coils. Continuous coils, on the other hand, develop most of their series capacitance by the spacing between coils, and the dropping of a large portion of the surge potential across the interleaved group enables the pancake coils of the continuous group to be closely spaced, desirably adding to the series capacitance of the continuous group.

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 transformer having a high voltage winding including interleaved and continuous groups of pancake coils, constructed and connected according to an embodiment of the invention;

FIG. 1A is a schematic diagram of the high voltage winding shown in FIG. 1;

FIG. 2 is a fragmentary elevational view, in section, of a portion of the high voltage winding shown in FIG. 1, illustrating the interleaved group of pancake coils modified according to another embodiment of the invention;

FIG. 2A is a schematic diagram of the interleaved group of pancake coils shown in FIG. 2;

FIG. 3 is a fragmentary elevational view, in section, of a portion of the high voltage winding shown in FIG. 1, illustrating the continuous group of pancake coils modified according to another embodiment of the invention;

FIG. 3A is a schematic diagram of the pancake coil of FIG. 3.

FIG. 4 is a fragmentary, elevational view, in section, illustrating another interleaved group of pancake coils which may be used in a high voltage winding for a transformer such as shown in FIG. 1;

FIG. 4A is a schematic diagram of the pancake coil shown in FIG. 4;

FIG. 5 is a fragmentary, elevational view, in section, illustrating still another interleaved group of pancake coils which may be used with the transformer shown in FIG. 1;

FIG. 5A is a schematic diagram of the pancake coils shown in FIG. 5;

FIG. 6 is a fragmentary, elevational view, in section, of another high voltage winding constructed according to the teachings of the invention, illustrating two conductors connected in parallel through the winding, to increase the current carrying capacity of the winding; and

FIG. 6A is a schematic diagram of the winding shown in FIG. 6.

DESCRIPTION OF THE 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, and it may be either single or polyphase. Since each phase of the transformer would be similar, in the event it is polyphase, 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 type coils, spaced axially apart in a stacked arrangement with their openings in alignment, about the axis of the magnetic core leg **14**. High voltage winding **16** has first and second ends **26** and **28**, respectively, and for purposes of example, it will be assumed that each end is adapted for connection to an elevated electrical potential, i.e., to a line voltage. The pancake coils of high voltage winding **16** are axially divided into first, second and third groups **30**, **32** and **34**, respectively. The first group **30** is connected to the first end **26** of the winding **16**, and includes a predetermined number of pancake coils of the interleaved turn type, such as pancake coils **36**, **38**, **40** and **42**. The third group **34** is connected to the second end **28** of the winding **16**, and similar to the first group, it includes a predetermined number of pancake coils of the interleaved turn type, such as pancake coils **44**, **46**, **48** and **50**. The second group **32**, which is connected between the first and third groups **30** and **34**, includes a plurality of pancake coils of the continuous type, with six pancake coils **52**, **54**, **56**, **58**, **60** and **62** being shown, and the balance being indicated generally by dotted line **64**. High voltage windings which have only one end connected to a line or elevated potential, and the other end adapted for connection to ground or to the neutral of a Y-configuration, would have only two groups of pancake coils, an interleaved group connected to the line end, and a continuous group connected to the grounded or neutral end.

The plurality of pancake coils in each of the groups, and adjacent groups, are interconnected to provide at least one series circuit or path between the first and second ends **26** and **28** of the high voltage winding assembly **16**, with one series path being shown in the embodiment of FIG. 1. Predetermined ends of adjacent coils across the winding assembly are interconnected to provide the series path, as will be hereinafter explained.

The first and third groups **30** and **34** of pancake coils are interleaved turn groups, acting as surge voltage dropping impedances for the continuous group **32**. If the complete high voltage winding were to be constructed of continuous type pancake coils, a surge voltage would be distributed across the winding in a very non-uniform manner, as the distribution constant alpha of continuous windings is relatively high, i.e., about 10, which causes a large portion of the surge potential to be dropped across the first two or three pancake coils, creating very high turn-to-turn stresses, and coil-to-coil stresses. The additional turn insulation, and axial spacing, required to provide adequate insulation for these line end continuous coils further increases the distribution constant alpha at the line end of the winding assembly, as it reduces the series capacitance C_S of these line end coils, causing even high electrical stresses at the line end of the winding assembly. The series capacitance of continuous type pancake coils is largely determined by the spacing between coils, and the large ducts or spacing between the line end continuous coils required to accommodate the high stresses would seriously reduce the series capacitance of the line end coils and increase the magnitude of the distribution constant alpha.

Disposing a group of interleaved turn type pancake coils adjacent to the line end, or ends, and then using continuous pancake coils for the remainder of the winding, is an attractive solution to the problem, but the large change in the series capacitance from the interleaved group to the continuous group presents its own problems in the form of high voltage oscillations when the winding is subjected to a surge potential. Attempts have been made in the prior art to make use of interleaved turn pancake coils and continuous pancake coils in the same winding practical, by placing a static plate between the two different groups of coils, or by gradually changing the percentage of interleaved turns in each pancake coil to gradually reduce the series capacitance C_S of the interleaved group, and thus make the transition between groups without a large change in series capacitance.

The present invention discloses a new and improved construction for the high voltage winding of a core-form power transformer, in which all pancake coils of the interleaved group, or groups, are of like construction, each interleaved across their complete radial builds, and which eliminates the need for auxiliary static plates. The new construction is the result of the finding that interleaved turn type pancake coils may be interconnected to be substantially non-oscillatory, regardless of their series capacitance. Then, instead of striving for a high series capacitance in the interleaved group, the interleaved group is constructed to have a relatively low series capacitance, and thus a relatively high distribution constant alpha, to more closely match the distribution constants of the interleaved and continuous groups and thus reduce the magnitude of voltage oscillations due to the mismatch when the winding is surged. The relatively high distribution constant alpha of the interleaved group is also beneficial from another viewpoint. It substantially reduces the number of interleaved turn pancake coils required at the line end, or ends, as a greater proportion of the surge stresses are dropped across each pancake coil as the distribution constant is increased. The degree of interleaving is deliberately chosen to produce a higher distribution constant alpha, and if thicker turn insulation is required to withstand the turn-to-turn surge stresses, the thicker turn insulation reduces the series capacitance still further, to more nearly match the series capacitance of the interleaved group with that of the continuous group. The pancake coils of the interleaved turn group may be spaced, as required, to withstand the higher duct stresses, without regard to the series capacitance C_S of the interleaved group, as the series capacitance of the interleaved group is largely controlled by the radial spacing of the turns in the pancake coils and not by the axial spacing of the coils.

More specifically, the degree of interleaving chosen for the interleaved turn group is at least double interleaving. The degree of interleaving is determined by the voltage between adjacent interleaved turns, compared with the voltage across a complete coil section of the coil. In twin interleaving, where each coil has two interleaved coil sections, and the circuit goes through one coil section of one coil, through a coil section of the next coil, back to the remaining section of the first coil, and then through the remaining section of the second coil, the voltage between adjacent interleaved turns is two units, or twice the voltage across one complete coil section of a pancake coil. This provides a series capacitance which is about 100 times the series capacitance of a continuous winding having the same dimensions.

In single interleaving, each pancake coil has two interleaved coil sections, with the outermost end of one coil section being connected to the innermost end of the other coil section. This provides a voltage between adjacent interleaved turns of 1 unit, or equal to the voltage across the coil section of one pancake coil, and a series capacitance of about 25 times that of a continuous winding having the same dimensions.

In double interleaving, each pancake coil has two interleaved coil sections, with one of the coil sections being severed at substantially its midpoint, to provide first and second radial portions. The circuit starts at one end of the pancake coil and proceeds through one of the radial portions of the divided coil section, it returns to the same end of the pancake coil and proceeds completely through the other coil section, and returns to the midpoint of the pancake coil and then proceeds through the remaining radial portion of the divided coil section. This provides a voltage between adjacent interleaved turns equal to one-quarter unit, and a series capacitance of about 6 times that of a continuous winding having the same dimensions. Six times the series capacitance of the interleaved group is still too high, however, with the maximum desirable ratio being about four to one, in order to reduce oscillatory voltages produced by the mismatch to a reasonable value. The double interleaved pancake coil may have its series capacitance reduced by increasing the thickness dimension of its turn insulation, but since the turn insulation may have to be increased anyway in the interleaved pancake coils to accommodate the high surge stresses, that they will be subjected to because of their relatively high distribution constant, this is not a disadvantage; or, instead of using double interleaving with thicker turn insulation than that used between the conductors of the continuous group, still lower degrees of interleaving may be used, such as triple or quadruple interleaving, which reduces the series capacitance of the interleaved group to the point where no or very little additional insulation is required on the turns of the interleaved group, compared with the thickness of the turn insulation used in the continuous group. In other words, if the alpha is increased by going to lower degrees of interleaving than double, the voltage between adjacent turns is reduced, making it unnecessary to use thicker turn insulation than that used in the continuous group.

FIG. 1 illustrates double interleaving in the interleaved turn groups **30** and **34**, with FIG. 1A being a schematic diagram of the high voltage winding **16**. Pancake coil **36** is constructed by winding two insulated conductors together such that they are radially disposed, forming first and second coil sections I and II, the turns of which are radially interleaved across the complete radial build dimension of the pancake coil. One of the coil sections, such as coil section I, is dividied into first and second radial portions **66** and **68**, while the other coil section has first and second radial portions **70** and **72**, which may remain connected. End **26** of winding **16**, which is adapted for connection to a high voltage bushing, is connected to the outermost end of the second or outer radial portion **68** of coil section I, via conductor **74**, and it spirals inwardly, appearing at every other turn until reaching the inner end of portion **68**. The turns are numbered in FIG. **1** to denote the coil turn number relative to the end **26** of the winding, and the thicker than normal turn insulation is indicated by the double lines between turns. After traversing radial portion **68**, the circuit returns to the outermost end of coil section II, via interleaving connection **76**, and the circuit spirals inwardly through both radial portions **72** and **70** of coil section II. Upon reaching the innermost end of portion **70** of coil section II, the circuit returns to substantially the midpoint of the coil build, via interleaving connection **78**, and enters the outermost end of the first or inner radial portion **66** of coil section I, and again spirals inwardly to the innermost end of this coil section. This completes pancake coil **36**, and in this embodiment, the adjacent pancake coils are interconnected with start-start, finish-finish connections. The "start" of a pancake coil is an end of one of the innermost turns of a coil section and the "finish" is the end of one of the outermost turns of one of the coil sections. Thus, the end of the innermost turn of portion **66** of coil section I is connected to pancake coil **38** via start-start connection **80**.

Pancake coil **38** includes first and second coil sections I and II, with coil section I including first and second or inner and outer radial portions **82** and **84**, and coil section II includes first and second radial portions **86** and **88**. The turns of pancake coil **38** spiral outwardly in the same circumferential direction as the turns of pancake coil **36**, in order to provide an additive magnetomotive force in the magnetic core **12**. The start-start connection **80** enters the innermost turn of radial portion **86** of coil section II and spirals outwardly, appearing at every other turn until reaching the outermost end of this section. The circuit then proceeds via interleaving connection **90** to the end of the innermost turn of radial portion **82** of coil section I, and spirals outwardly through both radial portions **82** and **84** of coil section I. At the end of the outermost turn of radial portion **84**, the circuit returns, via interleaving connection **92**, to substantially the midpoint of the coil build, entering the end of the innermost turn of radial portion **88** of coil section II, and spiraling outwardly until reaching the end of this coil section. The circuit then proceeds via finish-finish connection **94**, entering the end of the outermost turn of one of the radial portions of pancake coil **40**. Pancake coils **40** and **42** are constructed and interconnected similar to the pancake coils **36** and **38**, respectively, hereinbefore described, with pancake coils **40** and **42** being interconnected with start-start connection **95**.

The first pancake coil **52** of the continuous group **32** is constructed of an insulated conductor **96**, with all of the mechanically adjacent turns being electrically adjacent, which construction is well known in the art. Pancake coil **42** is connected to the first continuous pancake coil **52** via finish-finish connection **97**, and the circuit spirals inwardly through pancake coil **52** until reaching the end of its innermost turn. The next adjacent continuous pancake coil **54** spirals outwardly in the same circumferential direction as the inward spiral of the turns of pancake coil **52**, in order to provide an additive magnetomotive force in the magnetic core **12**, with pancake coils **52** and **54** being interconnected by start-start connection **98**. Pancake coil **54** includes an insulated conductor **100**, with the end of the outermost turn of pancake coil **54** being connected to the outermost turn of pancake coil **56** via finish-finish connection **102**. The end of the last coil **62** of the continuous group **32** is connected to one end of the interleaved group **34**, with the interleaved group **34** being constructed and arranged as hereinbefore described relative to the first interleaved group **30**.

The double interleaved pancake coils of the first and third interleaved groups **30** and **34** have their series capacitance reduced by increasing the turn insulation of the pancake coils of these groups such that it is 2 to 3 times the thickness of the turn insulation used in the continuous group. As hereinbefore stated, the thicker insulation between the turns of the interleaved groups, compared with thickness of the insulation between the turns of the coils in the continuous group, is indicated by the double lines between adjacent turns of the interleaved pancake coils.

The duct width or spacing between adjacent pancake coils in the interleaved groups **30** and **34** may be made large enough to accommodate the required insulation between adjacent coils of these highly stressed groups, and the continuous group **32** of the winding, since it sees a relatively small surge voltage, may have small or narrow ducts, such as three-sixteenths or one-quarter inch wide, which will provide a higher series capacitance for the continuous group than it would if the continuous groups were to use wider ducts. Therefore, the surge distribution of the whole winding is improved, and so is its space factor. The turn insulation on the pancake coils of the continuous group may be quite small, such as 14 to 18 mils, which also improves the space factor of the winding. The degree of interleaving, the thickness of the turn insulation on the turns of the pancake coils of the interleaved group, and the number of pancake coils of the interleaved group, are all selected to enable the continuous portion of the winding to be designed for a predetermined BIL, with the specific BIL voltage selected being that which will give the lowest overall winding cost. For purposes of example, consider a high voltage winding having 58 pancake coils designed for a BIL of 450 KV. If the complete winding were to be constructed of continuous coils having one-quarter inch ducts, the distribution constant alpha would be in the order of 8–10 and a stress across the first duct of 24 percent, or more than 100 KV. This would provide no margin of safety, necessitating wider ducts, and/or more turn insulation, and/or a greater spacing between the high and low voltage windings to reduce the capacitance to ground Cg. Singly interleaved pancake coils using the same wire and the same turn insulation dimension would provide a distribution constant alpha of about 2. To increase the distribution constant of the singly interleaved winding to about eight would require 16 times the amount of turn insulation as the continuous section, which is not practical. Double interleaved pancake coils would have a distribution constant alpha of about 4 when using 14 mil tape, the same turn insulation dimension as the continuous section, and a distribution constant alpha of 8 using 56 mils of tape, which is practical. Thus the winding may use two double interleaved pancake coils having 56 mils of turn insulation and a quarter inch duct at each line end, with 54 or 56 continuous pancake coils, depending on whether the winding has two or one line end, with 14 mil turn insulation and one-quarter inch ducts. By using four double interleaved pancake coils at each line end, 42 percent of the surge voltage would be dropped across them, leaving 260 KV for the continuous group of pancake coils, which may be more preferable than utilizing two double interleaved pancake coils at each line end.

While the pancake coils of the interleaved group are illustrated as being start-start, finish-finish connected in FIG. **1**, it is to be understood they may be interconnected with any other arrangement, such as finish-start, or start-finish. For example, FIGS. **2** and **2A** are diagrammatic and schematic representations, respectively of the pancake coils **36** and **38** shown in FIG. **1**, except connected with start-finish connections. Like reference numerals in FIGS. **1** and **2** indicate like components, while like reference numerals with a prime mark indicate components having like functions but modified as required to provide the different interconnection. In other words, instead of connecting the innermost turn of radial section **66** of coil section I to the end of the innermost turn of radial section **86** of coil section II of pancake coil **38**, the innermost turn of radial portion **66** may be connected to the outermost turn of the radial portion **88** of coil section II of pancake coil **38'**, via start-finish connection **80'**.

In like manner, the continuous pancake coils of the continuous section **32** may be interconnected with finish-start, or with start-finish connections, with FIGS. **3** and **3A** being diagrammatic and schematic representations of pancake coils **52** and **54** shown in FIG. **1**, except interconnected with start-finish connections. Instead of interconnecting the two innermost turns of pancake coils **52** and **54**, the innermost turn of pancake coil **52'** is connected to the outermost turn of the adjacent pancake coil **54'**.

Instead of utilizing double interleaving and increased turn insulation in the interleaved group, compared with the turn insulation in the continuous group, it would also be practical to increase the degree of interleaving to triple or quadruple, which would increase the distribution constant alpha of the interleaved group, or groups, to the point where no, or very little additional turn insulation would be required in the interleaved group, compared with the turn insulation used in the continuous group, since the voltage between adjacent turns drops as the degree of interleaving is reduced. FIGS. **4** and **4A** are diagrammatic and schematic representations of a high voltage winding **110** which utilizes triple interleaving in the interleaved group. The interleaved group includes pancake coils **112** and **114**, which are connected to a continuous group, represented by pancake coils **116** and **118**. Pancake coil **112** has first and second coil sections I and II, respectively, each of which have first, second and third radial portions. Coil section I has first, second and third radial portions **120**, **122** and **124**, respectively, and coil section II has first, second and third radial portions **126**, **128** and **130**, respectively. End **26** of the winding is connected to the end of the outermost turn of the third radial portion **124** of the first coil section I, and the circuit spirals inwardly, appearing at every other turn until reaching the innermost turn of this section. The circuit then returns to the outermost end of the third radial portion **130** of coil section II, via interleaving connection **132**, and the circuit spirals inwardly through the third and second radial portions **130** and **128** of coil section II. The circuit then returns to the outermost turn of the second radial portion **122** of the first coil section, via interleaving connection **134**, and spirals radially inward through the second and first radial portions **122** and **120** of the first coil section. The circuit then proceeds, via interleaving connection **136**, to the outermost end of the first radial portion **126** of the second coil section, and then proceeds radially inward to the innermost end of this section.

Pancake coil **114** includes first and second coil sections, I and II, respectively, the turns of which are radially interleaved across the complete radial build of the pancake coil, with each coil section having first, second and third radial portions. The first coil section includes first, second and third radial portions **140**, **142** and **144**, and the second coil section includes first, second and third radial portions **146**, **148** and **150**, respectively. The circuit from the pancake coil **112**, enters the innermost turn of the first radial portion **140** of the first coil section, via start-start connection **138**, and spirals outwardly until reaching the end of this section, proceeding back to the end of the innermost turn of the first radial portion **146** of the second coil section, via interleaving connection **152**, and spirals outwardly through the first and second radial portions **146** and **148** of the second coil section. The circuit then returns, via interleaving connection **154**, to the end of the innermost turn of the second radial portion **142** of the first coil section, and spirals outwardly through the second and third radial portions **142** and **144**, respectively, of the first coil section. The circuit returns via interleaving connection **156** to the end of the innermost turn of the third radial portion **150** of the second coil section, and spirals radially outward to the end of this portion. The circuit then proceeds, via finish-finish connection **158**, to the end of the outermost turn of the continuous pancake coil **116**, and spirals inwardly until reaching the innermost turn of this pancake coil. The circuit then proceeds via start-start connection **160** to the end of the innermost turn of continuous pancake coil **118**. While start-start, finish-finish connections have been illustrated in FIG. **4**, it is to be understood that the pancake coils of winding **110** may be interconnected with start-finish, or finish-start connections, if desired.

FIGS. **5** and **5A** are diagrammatic and schematic representations of a high voltage winding **170**, constructed according to the teachings of the invention, in which the pancake coils of the interleaved group are quadruple interleaved. High voltage winding **170** includes quadruple interleaved pancake coils **172** and **174** in the interleaved group, and continuous pancake coils **176** and **178** at the start of the continuous group. Pancake coil **172** has first and second coil sections, I and II, respectively, each of which are divided into first, second, third and fourth radial portions. The first coil section of pancake coil **172** includes first, second, third and fourth radial portions **180**, **182**, **184** and **186**, while coil section II includes first, second, third and fourth radial portions **188**, **190**, **192** and **194**, respectively. The circuit proceeds from the first end **26** of the winding **170**, and enters the outermost end of the fourth radial portion **186** of the first coil section, and spirals inwardly, appearing at every other turn until reaching its innermost end. The circuit then returns, via interleaving connection **196**, to the outermost end of the fourth radial portion **194** of the first coil section, and spirals inwardly through the fourth and third radial portions **194** and **192** of the second coil section. The circuit then returns via interleaving connection **198** to the end of the outermost turn of the third radial portion **184** of the first coil section, and spirals inwardly, through the third and second radial portions **184** and **182**, respectively, of the first coil section. The circuit then returns, via interleaving connection **200**, to the end of the outermost turn of the second radial portion **190** of the second coil section, and spirals inwardly through the second and first radial portions **190** and **188**, respectively, of the second coil section. The circuit then returns, via interleaving connection **202**, to the end of the outermost turn of the first radial portion **180** of the first coil section, and spirals inwardly to the end of this section, completing pancake coil **172**.

Pancake coil **174** includes first and second coil sections I and II, respectively, each of which have first, second, third and fourth radial portions. The first coil section I includes first, second, third and fourth radial portions **206**, **208**, **210** and **212**, respectively while the second coil section II includes first, second, third, and fourth radial portions **214**, **216**, **218** and **220**, respectively. The circuit from pancake coil **172** enters the innermost end of the first radial portion **214** of the second coil section, via start-start connection **204**, and spirals radially outward to the end of this section. The circuit then returns, via interleaving connection **222**, to the end of the innermost turn of the first radial portion **206** of the first coil section, and spirals outwardly through the first and second radial portions **206** and **208** of the first coil section. The circuit then returns, via interleaving connection **224** to the end of the innermost turn of the second radial portion of the second coil section, spiraling outwardly through the second and third radial portions **216** and **218**, respectively, of the second coil section. The circuit then returns via interleaving connection **226**, to the end of the innermost turn of the third radial portion **210** of the first coil section, and spirals outwardly through the third and fourth radial portions **210** and **212** of the first coil section. The circuit then returns, via interleaving connection **228**, to the end of the innermost turn of the fourth radial portion **220** of the second coil section, and spirals outwardly to the end of this section, completing pancake coil **174**. The circuit then proceeds, via finish-finish connection **229**, to the end of the outermost turn of the continuous pancake coil **176**, and the innermost turns of pancake coils **176** and **178** are interconnected via start-start connection **230**.

When the current requirements of the high voltage winding of core-form electrical apparatus is such that more than one series path is required through the winding, which paths are connected in parallel, it would be even more desirable to reduce the number of interleaved turn type coils required in the winding. This is true because multiple conductors increase the number of interleaving connections which must be made in an interleaved coil, which increases the cost of the winding, while multiple conductor continuous type pancake coils may be constructed with very little additional labor. The teachings of the invention may be applied to multiple conductor windings, with FIGS. **6** and **6A** being diagrammatic and schematic representations, respectively, of a high voltage winding **240** having two series paths between its ends, which paths are connected together at least at the start and finish ends of the winding. High voltage winding **240** includes pancake coils **242** and **244** in the interleaved group, with the pancake coils of this group being double interleaved, and pancake coils **246** and **248** at the start of the continuous group.

Pancake coil **242** includes first, second, third and fourth coil sections I, II, III and IV, respectively, with each coil section being divided into first and second radial portions. The first coil section includes first and second radial portions **250** and **252**, the second coil section includes first and second radial portions **254** and **256**, the third coil section includes radial portions **258** and **260**, and the fourth coil section includes first and second radial portions **262** and **264**. The first end **26** of the winding **240** is connected to the outermost end of the second radial portion **252** of the first coil section, it proceeds inwardly through this coil section, and then returns, via interleaving connection **266** to the outermost end of the second radial portion **256** of the second coil section, and it spirals inwardly through the second and first radial portions **256** and **254** of the second coil section. The circuit then returns, via interleaving connection **268**, to the outermost end of the first radial portion **258** of the third coil section, and proceeds inwardly through this coil section to its innermost end. The circuit from end **26** also enters the outermost end of the second radial portion **260** of the third coil section, spiraling inwardly to the innermost end of this coil section, returning, via interleaving connection **272**, to the outermost end of the second radial portion **264** of the fourth coil section. The circuit then spirals inwardly through the second and first radial portions **264** and **262**, respectively, of the fourth coil section, and returns, via interleaving connection **274**, to the end of the outermost turn of the first radial portion **250** of the first coil section, completing pancake coil **242**.

Pancake coil **244** includes first, second, third and fourth coil sections I, II, III and IV, respectively, with the first coil section including first and second radial portions **280** and **282**, the second coil section including first and second radial portions **284** and **286**, the third coil section including first and second radial portions **288** and **290**, and the fourth coil section including first and second radial portions **292** and **294**. The end of the innermost turn of coil section **250** of pancake coil **242** proceeds via start-start connection **276** to the end of the innermost turn of the first radial portion **284** of the second coil section, spiraling outwardly to the end of the section, and returning via interleaving connection **296** to the end of the innermost turn of the first radial portion **288** of the third coil section. The circuit spirals outwardly through the first and second radial portions **288** and **290** of the third coil section, and returns, via interleaving connection **298**, to the end of the innermost turn of the second radial portion **286** of the second coil section. The circuit then spirals outwardly through radial portion **286** to its outermost end. The end of the innermost turn of the first radial portion **258** of the third coil section enters the end of the innermost turn of the first radial portion **292** of the fourth coil section of pancake coil **244**, via start-start connection **270**, and the circuit spirals outwardly to the end of this section. The circuit returns, via interleaving connection **302**, to the start of the first radial portion **280** of the first coil section, and spirals outwardly through the first and second radial portions **280** and **282** of the first coil section. The circuit then returns, via interleaving connection **304** to the end of the innermost turn of the second radial portion **294** of the fourth coil section, spiraling radially outward therethrough, which completes the second pancake coil **244**.

The first continuous pancake coil **246** of the continuous group includes first and second radially interleaved conductors **308** and **310**, with the end of the outermost turn of radial portion **294** of pancake coil **244** entering the end of the outermost turn of coil section **308** of pancake coil **246**, via finish-finish connection **306**, and the end of the outermost turn of the second radial portion **286** of pancake coil **244** entering the end of the outermost turn of coil section **310** of pancake coil **246**, via finish-finish connection **300**. Pancake coil **248** includes first and second radially interleaved portions **316** and **318**, with the end of the innermost turn of portion **310** of pancake coil **246** being connected to the end of the innermost turn of portion **316** of pancake coil **248**, via start-start connection **314**, and the end of the innermost turn of portion **308** of pancake coil **246** entering the end of the innermost turn of portion **318** of pancake coil **248**, via start-start connection **312**. Although not shown in FIG. **6**, the turn insulation in the double interleaved pancake coils **242** and **244** may be greater than the turn insulation in the continuous pancake coils **246** and **248**, such as 2 to 3 times the thickness, in order to increase the distribution constant alpha of the interleaved group.

In summary, there has been disclosed new and improved high voltage windings for power transformers of the core-form type, which successfully combine pancake coils of the interleaved turn type with pancake coils of the continuous type. The successful combination of interleaved and continuous pancake coils is made possible by deliberately reducing the series capacitance of the interleaved group of pancake coils to increase the distribution constant alpha of the interleaved group. This construction does not provide the same low surge voltage drop that the normally constructed interleaved turn type winding would possess, but in the disclosed invention this is an advantage, as the number of pancake coils in the interleaved group may consist of only one, two or three pairs of coils, in order to provide the required voltage drop. Thus, this aids the object of providing a winding having as many pancake coils of the continuous type as possible. Further, the coil to coil insulation required in the interleaved group may be achieved without regard to the width of the coil ducts, greatly simplifying the insulation of the line end coils. This is due to the fact that the series capacitance of the interleaved turn type pancake coils is largely determined by the conductor taping. Therefore, increasing the duct width between interleaved coils does not cause a noticeable discontinuity in winding capacitance. This is opposite to the situation for continuous type pancake coils, where the grading of duct sizes is very critical, with larger ducts leading to large increases in electrical stress.

The interleaved group of pancake coils, disposed at the line end, or ends of the winding, although having a distribution constant which is relatively high, still provide limited or damped oscillations upon being surged, with any oscillations being largely confined within the interleaved group. Thus, the interleaved part of the disclosed winding will handle voltage surges without oscillations of damaging magnitude, even though it has a large distribution constant which is close to the distribution constant of the continuous portion of the winding. While the continuous portion of the winding will have oscillations taking place when surged, they will be of limited magnitude because the interleaved group of pancake coils has dropped the surge to a value which enables the continuous pancake coils to be properly insulated without substantially increasing the width of the ducts between the pancake coils. Since the continuous portion of the winding will see a relatively small surge voltage, it may use ducts in the order of three-sixteenths or one-quarter of an inch, which provide a higher series capacitance for the continuous portion of the winding than it would ordinarily have, when constructed for higher voltages with wider ducts, and, therefore, the surge distribution pattern for the whole winding is improved.

The series capacitance of the interleaved group, or groups, is selected to be in the range of about 2½ to 4 times the series capacitance of the continuous group. The limitation of 4 times the series capacitance of the continuous group is about the greatest mismatch that can be tolerated without encountering excessive oscillatory voltages upon being surged. The 2½ limitation is about the closest match that can be tolerated from an economic viewpoint, as a closer match would require that the turn insulation be increased to an impractical thickness, or the degree of interleaving required would make the interleaved coils costly to manufacture, or both.

I claim as my invention:

1. A winding for electrical inductive apparatus, comprising:

a plurality of axially spaced pancake coils, each having a plurality of insulated conductor turns,

means interconnecting predetermined ends of adjacent pancake coils to connect said pancake coils in series and provide a winding assembly having first and second ends,

at least the first end of said winding assembly being adapted for connection to an elevated electrical potential,

a first group of said pancake coils starting at the first end of said winding assembly being of the interleaved turn type, wherein electrically connected turns are physically separated by turns from an electrically distant portion of the winding assembly across the complete radial build of each pancake coil,

a second group of said pancake coils, starting at the end of said first group, being of the continuous type,

said first group of pancake coils having a degree of interleaving and spacing between turns selected to provide a relatively low series capacitance, which is a maximum of about four times the series capacitance of the second group.

2. The winding of claim **1** wherein the series capacitance of the first group of pancake coils is in the range of 2.5 to 4 times the series capacitance of the second group of pancake coils.

3. The winding of claim **1** wherein the axial spacing dimension between the pancake coils of the first group exceeds the axial spacing dimension between the pancake coils of the second group.

4. The winding of claim **1** wherein the pancake coils of the first group are double interleaved, and the radial spacing dimension between conductor turns of the pancake coils of the first group is at least twice the spacing between the conductor turns of the pancake coils of the second group.

5. The winding of claim **1** wherein the pancake coils of the first group are triple interleaved and the radial spacing between the conductor turns of the pancake coils is substantially the same in both the first and second groups.

6. The winding of claim **1** wherein the pancake coils of the first group are quadruple interleaved, and the radial spacing between the conductor turns of the pancake coils is substantially the same in both the first and second groups.

7. The winding of claim **1** wherein the winding assembly has at least two series circuits connected between its ends, with said at least two series circuits being connected together, at least at the first and second ends of the winding assembly.

8. The winding of claim **1** including a third group of pancake coils starting at and connected to the end of the second group, said third group of pancake coils being of the interleaved turn type having substantially the same series capacitance as the first group of pancake coils.

9. The winding of claim 1 wherein the means which connects the pancake coils in series, connects adjacent ends of adjacent pancake coils to provide a succession of start-start, finish-finish type connections across the winding assembly.

10. The winding of claim 1 wherein the means which connects the pancake coils in series, connects an inner end of one pancake coil to an outer end of the next adjacent pancake coil to provide start-finish type connections across the winding assembly.

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