United States Patent

[11] 3,621,428

[72] Inventors Robert L. Johnston
Sharon;
Wallace G. Chambers, West Middlesex,
both of Pa.

[21] Appl. No. 75,126
[22] Filed Sept. 24, 1970
[45] Patented Nov. 16, 1971

[73] Assignee Westinghouse Electric Corporation
Pittsburgh, Pa.

[54] **ELECTRICAL WINDINGS AND METHOD OF CONSTRUCTING SAME**
20 Claims, 7 Drawing Figs.

[52] U.S. Cl. 336/146, 29/605, 323/43.5, 336/150
[51] Int. Cl. H01f 21/00
[50] Field of Search 336/145, 146, 147, 150; 323/43.5; 29/592, 602, 605

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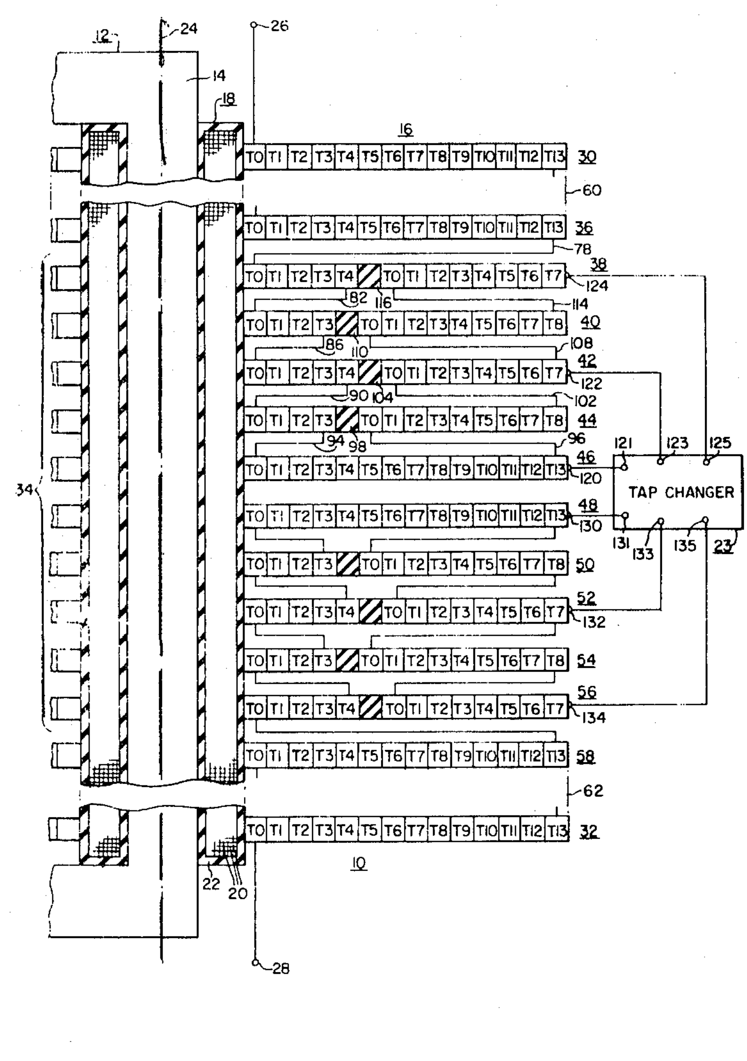
Primary Examiner—Thomas J. Kozma
Attorneys—A. T. Stratton, F. E. Browder and Donald R. Lackey

ABSTRACT: A tapped winding for electrical inductive apparatus, and method of constructing same, including a plurality of axially spaced pancake or disk-type continuous coils. Each turn to be tapped is directed to the outermost turn of a pancake coil by successively winding and interconnecting a first portion of a plurality of pancake coils, proceeding from coil to coil in a first axial direction, and returning in the opposite axial direction to complete each pancake coil, with the number of turns added to complete each pancake coil being predetermined to locate the taps at the outer turns of certain pancake coils.



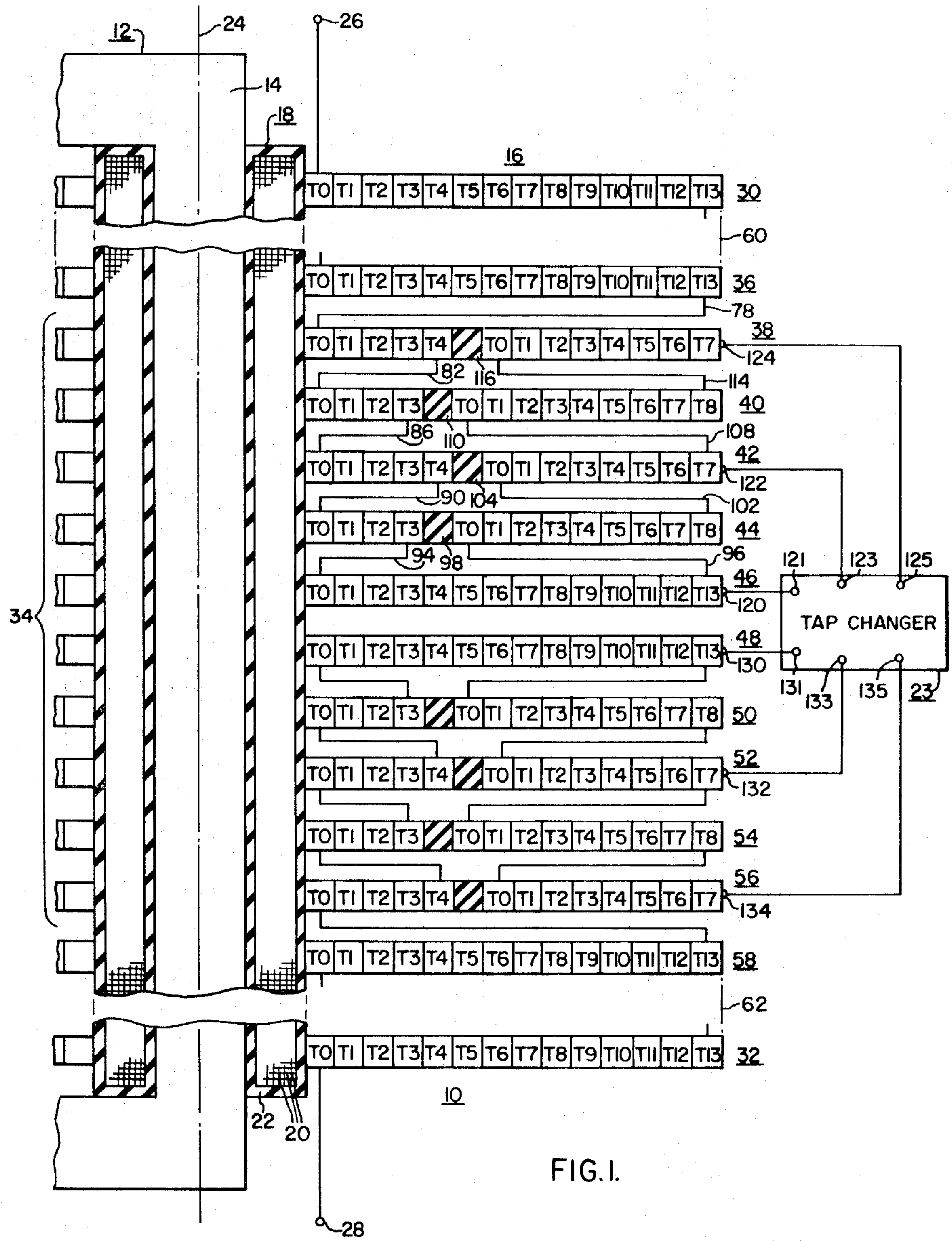


FIG. I.

WITNESSES

Theodore F. Wobel

James F. Young

INVENTORS
Wallace G. Chambers and
Robert L. Johnston

BY Donald R. Lackey
ATTORNEY

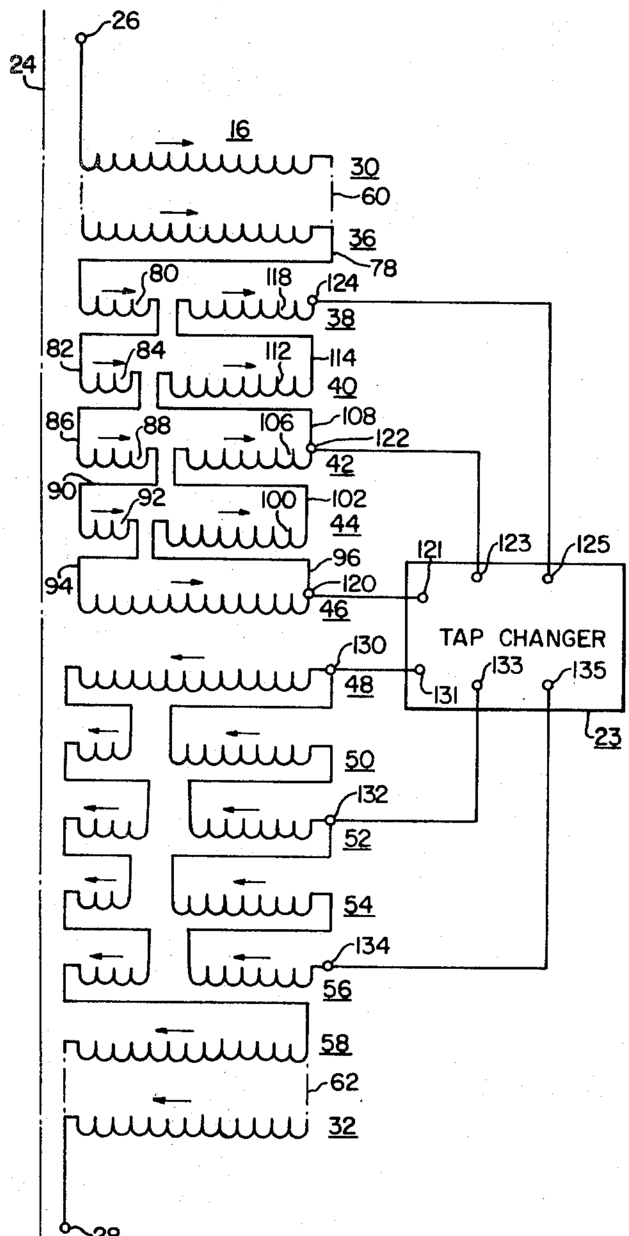
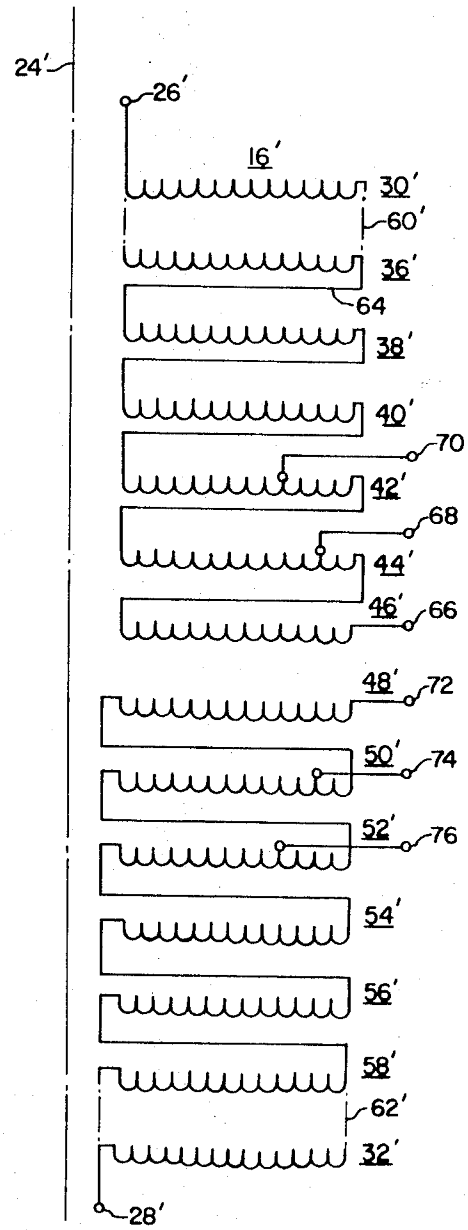


FIG. 2.



PRIOR ART

FIG. 3.

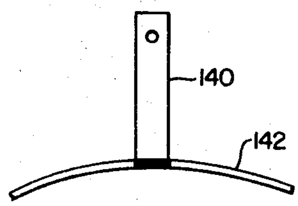


FIG. 4.

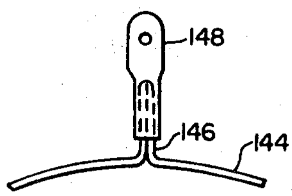


FIG. 5.

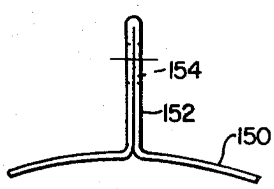


FIG. 6.

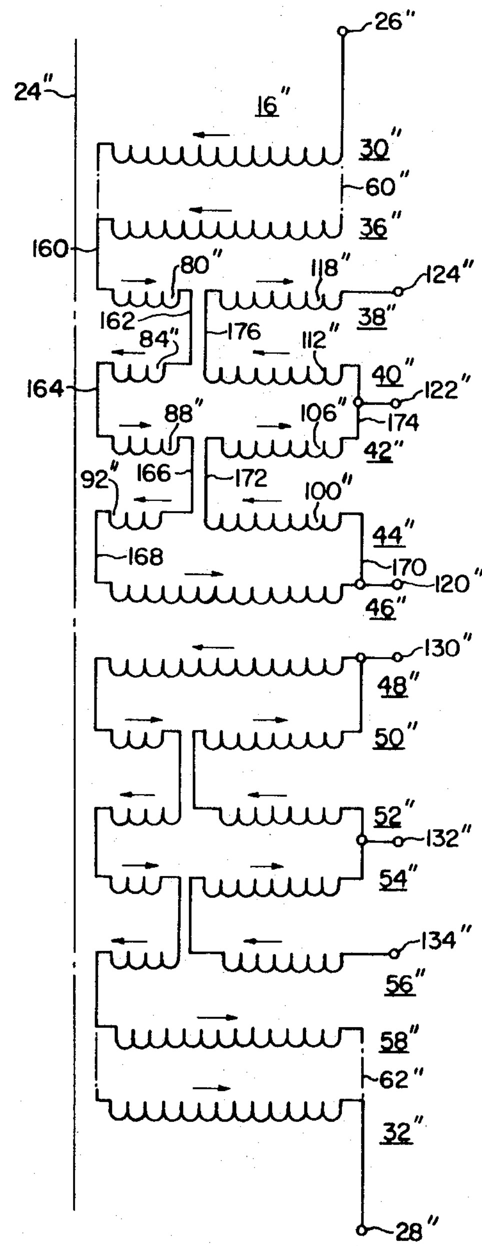


FIG. 7.

ELECTRICAL WINDINGS AND METHOD OF CONSTRUCTING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to electrical inductive apparatus, such as power transformers, and more specifically to tapped winding structures for such apparatus.

Description of the Prior Art

In the design of electrical power transformers of the core-form type, having a winding which includes a plurality of continuous pancake or disk coils, the number of coils, and the number of turns per coil, are determined by the required electrical characteristics of the apparatus. It is often necessary to provide a tapped section in such a winding, either for use with a no-load tap changer, or with an underload tap changer, depending upon the specific application. When the output voltage of a transformer is to be adjusted only at the time of installation, or only a few times during the operating life of the transformer, a relatively low-cost no-load tap changer is used to interconnect taps across a tap break in the winding, with tap changes being made when the winding is deenergized. When the output voltage of a transformer is subject to frequent adjustment, such as in response to a regulator to maintain a predetermined output voltage despite load changes, or where it is desirable to provide an adjustable output voltage which may be changed periodically, an underload tap changer is utilized. In either type of tap changer arrangement, the number of turns between adjacent taps is determined by the magnitude of the voltage steps desired, and is usually specified by the user. Thus, the turns to be tapped will usually not be the outermost turns of the continuous pancake coils, making it necessary to braze or weld tap leads to intermediate turns of the pancake coils. The tap leads are brought out through the ducts between adjacent coils, with special insulation being required to adequately electrically insulate the tap leads from the adjacent coils. This arrangement increases the cost of constructing the tap section, and it increases the axial length of the tap section due to the increased duct width required to insulate and bring out the tap leads. It is especially troublesome when aluminum conductor is used in the winding, because the welding procedure required to metallurgically bond the tap lead to an aluminum conductor buried at an intermediate turn location of the coil is difficult and time consuming. Thus, it would be desirable to construct the tap section of an electrical power transformer winding, whether it is for a no-load or an underload tap changer application, such that all of the tap connections are made to the outermost turns of the pancake coils to be tapped.

In the applications of no-load taps to electrical transformers, the tap section of each phase winding conventionally has an electrical discontinuity therein, termed the coil or tap break, thus dividing the tap section into first and second sections, with taps disposed on each section. Suitable no-load switching or tap changer means is disposed to bridge the coil break, selectively interconnecting the taps on the two sections, to select the desired turn ratio between the high and low-voltage windings of the transformer.

Extreme care must be taken in the design of this tap section, because of the "gap" created in the ampere turns as the winding is tapped out. The tap section should be located at the electrical center of phase, i.e., the center line which divides the ampere turns into two equal portions, in order to produce minimal axial unbalance and reduce the variation in impedance over the tap range, and also reduce the magnitude of short circuit forces caused by the unbalance. In the prior art, if the tap range exceeds about 10 percent of the total turns of the phase, it may be necessary to utilize two tap sections, spaced apart in the phase, to reduce the size of "gap" in the ampere turns produced in the winding when all of the turns of the tap section are tapped out, which gap allows magnetic flux to fringe outwardly and cause stray losses and tank wall heating. The greater the percentage of the winding tapped out on a tap section, the greater the steady state voltage stress and surge stress between the two portions of the tap sections at the coil break. The coil break is, therefore, heavily insulated to withstand surge stresses, which requires additional space between the two portions of the tap sections, requiring a larger magnetic core than would be otherwise necessary, deleteriously affecting the weight and cost of the apparatus.

Thus, in addition to providing a new and improved tap section in which all of the taps are connected to the outermost turns of predetermined pancake coils, it would be desirable to be able to reduce the effective size of the "gap" in the ampere turns associated with no-load type tap changing arrangements as the winding is tapped out, in order to reduce axial unbalance, reduce the variation in impedance over the tap range, and reduce the magnitude of short circuit forces caused by the unbalance, compared with prior art arrangements, and it would be desirable to be able to increase the spacing between the ends of the two tap sections joined by the no-load tap changer, without increasing the axial length of the tap section.

SUMMARY OF THE INVENTION

Briefly, the present invention is new and improved tapped winding section for electrical inductive apparatus, such as power transformers of the core-form type, having a plurality of pancake- or disk-type coils in which all of the taps are directed to the outermost turns of the coils of the tap section, providing the desired number of coils of the tap section, regardless of the total number of turns in the coils. This is accomplished by winding the coils of the tap section such that they are first wound as electrically interconnected part coils having a predetermined number of turns, which number is less than the required number of turns in the pancake coils. The last part coil to be wound is then completed, and the remaining coils completed in reverse sequence, with the number of turns added per coil being predetermined to direct the turns to be tapped to the outer turns of predetermined pancake coils.

When a no-load tap section is constructed, another similarly constructed tap section is wound adjacent to the first section, and the two sections are interconnected via a no-load tap changer. The disclosed construction wherein the first or inner portions of the pancake coils are not tapped out, prevents complete gaps from being created in the ampere turns, which reduces axial unbalance and reduces impedance variation over the tap range, and since the ends of the adjacent tap sections have a plurality of pancake coils between them, insulating these ends from one another is not a problem.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may better be understood, and further advantages and usages 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 an elevational view, partially in section, of one phase of a transformer having a high-voltage winding constructed according to the teachings of the invention;

FIG. **2** is a schematic diagram of the high-voltage winding shown in FIG. **1**;

FIG. **3** is a schematic diagram of a high-voltage winding constructed according to the teachings of the prior art;

FIGS. **4**, **5**, and **6** illustrate different arrangements for making a tap connection to the outermost turn of a pancake coil; and

FIG. **7** is a schematic diagram of the high-voltage winding shown in FIG. **1**, connected start-start, finish-finish, instead of finish-start.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, and FIG. **1** in particular, there is shown an elevational view of a transformer **10** of the core-form type, constructed according to the teachings of the invention, which may be single-phase or polyphase, as desired.

Since the invention may be adequately illustrated by a portion of a single-phase winding assembly, only one phase is shown in the elevational view of transformer **10** in FIG. **1**.

Transformer **10** includes a magnetic core **12** which may be of conventional construction, having a winding leg **14** about which high- and low-voltage phase winding assemblies **16** and **18** are concentrically disposed. Low-voltage winding **18** may also be of conventional construction, having a plurality of electrically insulated conductor turns **20**, which are insulated from magnetic core **12** and high-voltage winding assembly **16** by insulating means **22**.

The invention applies to tapped windings of the continuous disk or pancake coil type for electrical inductive apparatus, such as transformers of the isolated winding type, or of the autotransformer type. It applies to any type winding of such apparatus, used either with a no-load tap changer, or an underload tap changer. For purposes of the example, transformer **10** is illustrated as being of the isolated winding type, with its outer or high-voltage winding being tapped and connected to a no-load tap changer **23**.

High-voltage phase assembly **16** includes a plurality of continuous pancake- or disk-type coils which are spaced axially apart in a stacked arrangement about the longitudinal center line **24** of magnetic core leg **14**. Winding **16** has terminals **26** and **28** connected to opposite ends thereof, i.e., to pancake coils **30** and **32**, respectively, and a tap section **34** which includes a plurality of pancake coils, such as pancake coils **38**, **40**, **42**, **44**, **46**, **48**, **50**, **52**, **54**, and **56**. The tap section **34** is usually disposed intermediate the ends of winding **16**, in order to protect the tap section from transient or surge voltages, which may enter the terminals **26** and **28**. A plurality of pancake coils, indicated generally by pancake coils **30** and **36** and line **60**, are disposed between one end of the tap section **34** and terminal **26**, and a plurality of pancake coils, indicated generally by pancake coils **58** and **32** and line **62**, are disposed between the other end of the tap section **34** and terminal **28**.

Before describing the construction and connection of winding **16** shown in FIG. **1**, it will be helpful to understand how winding **16** would be constructed and connected according to the teachings of the prior art. Accordingly, FIG. **3** is a schematic diagram of winding **16** shown in FIG. **1**, constructed and connected according to the teachings of the prior art, with like reference numerals in FIGS. **1** and **3** indicating like components. A prime mark has been added to the reference numerals in FIG. **3** to distinguish the different constructions.

More specifically, FIG. **3** illustrates a high-voltage winding **16'** having a plurality of continuous-type pancake coils **30'**, **36'**, **38'**, **42'**, **44'**, **48'**, **50'**, **52'**, **54'**, **56'**, **58'**, and **32'**, with the pancake coils starting with pancake coil **30'** and ending with pancake coil **46'** being disposed on one side of the tap break, and the pancake coils starting with pancake **48'** and ending with pancake coil **32'** being disposed on the other side of the tap break. The number of pancake coils, and the number of turns per pancake coil, are determined by the electrical requirements of the apparatus. A plurality of no-load taps are provided on winding **16'** which are interconnected through a no-load tap changer or movable connector (not shown), which selectively interconnects a tap on one side of the tap break with a tap on the other side of the tap break, with any tap change being made when the winding **16'** is deenergized. As illustrated, the pancake coils may be serially interconnected with finish-start interpancake connections, starting at each terminal **26'** and **28'**, such as finish-start connection **64** between the outermost turn of pancake coil **36'** and the innermost turn of pancake coil **38'**. The "start" of a coil, or section of a coil, as used in this specification, is the end of its innermost turn, and the "finish" of a coil, or section of a coil, is the end of its outermost turn, regardless of where the electrical circuit first enters the coil. The pancake may also be serially interconnected with start-finish connectors, or with successive start-start finish-finish connections, as desired.

The no-load taps are conventionally uniformly disposed, from an electrical viewpoint, having a desired number of turns N between adjacent taps. Thus, a tap **66** is disposed at one end of the tap break, connected to the outermost turn of pancake coil **46'**, and the next tap **68** is located N turns from the outermost turn of pancake coil **46'**, which location may be an intermediate turn of an adjacent pancake coil, such as an intermediate turn of pancake coil **44'**. This is due to the fact that the number of turns between adjacent taps will seldom be the same as the number of turns that are wound into each pancake coil. The next tap **70** will be N turns from tap **68**, and may be an intermediate turn of another pancake coil, such as pancake coil **42'**.

In like manner, a tap **72** is disposed at the other end of the tap break, i.e., at the end of the outermost turn of pancake coil **48'**. The next tap **74** will be located N turns from tap **72**, such as an intermediate turn of pancake coil **50'**. The last tap **76** will be located N turns from tap **74**, such as an intermediate turn of pancake coil **52'**. Six taps are conventionally used, providing five different output voltages, but any number of taps may be used, as dictated by the user's specific application.

It will be noted that taps **68**, **70**, **74**, and **76** are connected to an intermediate turn of their associated pancake coils. The connection of these taps is, therefore, more difficult to make than taps **66** and **72**, which are connected to the outermost turns of their associated pancake coils, with the tap leads connected to intermediate turns requiring additional insulation to properly insulate the tap lead from the adjacent coils. The more heavily insulated tap lead increases the width of the ducts between adjacent pancake coils, which deleteriously affects the space factor of the winding, it increases the length of the winding leg and the size of the magnetic core, and it reduces the series capacitance of the winding at this point, as the major portion of the series capacitance of a continuous type winding is provided between adjacent pancake coils. Increasing the spacing between continuous type pancake coils thus reduces the series capacitance of the winding. This discontinuity in the series capacitance of the winding may produce voltage oscillations of an undesirable magnitude when the winding is surged, such as by a lightening or switching surge, even though the tap section is buried in the phase winding, as oscillatory voltages are set up which travel through the winding when a continuous winding is subjected to a surge potential.

Further, it will be noted that as the winding **16** is tapped out, the "gap" in the ampere turns increases in width. When a winding has a gap in the ampere turns, the magnetic flux, instead of remaining parallel with the axis of the coils or winding, fringes outwardly from the winding at the gap. The amount of flux which fringes is proportional to the size of the gap. Since the fringing flux may cause heating of the tank walls and other surrounding metallic parts, it would be desirable to reduce the size of the gap produced in the ampere turns as the tap section is tapped out.

The present invention discloses a new and an improved tapped winding, and method of constructing same, which directs all of the taps to the outermost turns of predetermined pancake coils in the tap section, and at the same time reduces the size of the effective gap in the ampere turns produced as the tap section is tapped out. Thus, the new winding aids in reducing flux fringing, it reduces axial unbalance and concomitant mechanical stresses, and it reduces the variation in impedance across the tap range.

More specifically, FIG. **1** illustrates winding **16** constructed according to a first embodiment of the invention, with FIG. **2** being a schematic diagram of winding **16**.

Winding **16** has two main parts, one on each side of a tap break, and each part if constructed in like manner, starting from line terminals **26** and **28**, respectively. The first part includes a plurality of conventional pancake coils of the continuous type, indicated by pancake coils **30** and **36**, with a line **60** between them, which in this embodiment are serially interconnected with finish-start interpancake connections. For purposes of example, it will be assumed that each pancake coil has 13 turns, which are given the letter T plus a turn number in each coil, and that the number of turns required between adjacent taps is 15. In carrying out the teachings of the invention, a predetermined number of part coils are wound and interconnected, proceeding axially inward from each terminal, and then the coils are completed by proceeding axially outward toward each terminal. Once the number of turns per conventional pancake coil are determined, and the turns between taps, as well as the number of taps are known, it is then decided how many pancake coils will be required in the tap section. In other words, in order to direct the turns to be tapped to the outermost turns of the pancake coils, it is necessary to determine whether every pancake coil will have a tap, or whether there will be one or more pancake coils between the tapped coils. Since the pancake coils in the untapped portion of the winding have 13 turns, in this example, and since it is usually desirable to build the coils in the tap section to have the same build or outside dimension as those outside the tap section, in order to facilitate the mechanical bracing of the complete winding assembly, it will be apparent that every pancake coil in the tap section, in this example, cannot be tapped, but that every other pancake coil may be tapped. Thus, with the conventional six taps, three on each side of the tap break, a total of 10 pancake coils will be required in the tap section, five on each side of the tap break. Since the turns between any two adjacent taps will then include turns added to two pancake coils to complete the associated part coils, the 15 turns of the example may be achieved by adding eight turns to one part coil and seven turns to the next. Since it is desirable to provide the same build or outside dimension for all of the coils within the tap section 34, the part coils to be completed with eight turns should be constructed with one less turn than the part coils which are to be completed with seven turns. With these relationships in mind, the tap section 34 may then be started.

As illustrated in FIGS. 1 and 2, the "finish" or outermost turn of pancake coil 36 is connected to the "start" of pancake coil 38 via finish-start connection 78. Pancake coil 38 is then started by winding an insulated conductor in the same circumferential direction as pancake coils 30 and 36, in order to provide an additive magnetomotive force in the coil 14, providing a first part coil 80, best shown in FIG. 2, which has a predetermined number of radially disposed conductor turns therein, such as 4. The insulated conductor of which part coil 80 was wound may be bent to provide a finish-start connection 82, and pancake coil 40 may be started, providing a part coil 84, which in this example has one less turn than part coil 80, such as three. The insulated conductor may then be used to form a finish-start connection 86, and pancake coil 42 may be started, providing a part coil 88 having four turns. The insulated conductor then forms the finish-start connection 90, and pancake coil 44 may be started, providing a part coil 92. The insulated conductor may then be bent to form a finish-start connection 94, and pancake coil 46 may be started and completed. The construction of pancake coil 46 may be thought of as winding a part coil, similar to the other part coils of the tap section, and then completing the part coil. Since there is no electrical discontinuity between this part coil and its completing turns, additional insulation is not required between the inner and outer portions of pancake coil 46. Thus, up to this point, an electrical path is created through tap section 34 having first and second ends located in pancake coils 38 and 46, respectively.

The next step of the new and improved method is to complete the partially wound pancake coils 44, 42, 40, and 38 returning the electrical path through tap section 34 back to pancake coil 38. The pancake coils are completed in reverse or opposite sequence to that used when the part coils were constructed, taking care to wind the added turns to each part coil such that the magnetomotive force or ampere turns provided by the additional turns, add to the ampere turns provided by turns of its associated part coil. Thus, the insulated conductor from the "finish" of pancake coil 46 may be used to provide the finish-start connection 96. Suitable electrical insulating means 98 is disposed about the outermost turn of part coil 92, and pancake coil 44 is completed by winding an outer portion 100 having the required number of turns therein, which in this example is eight. The insulated conductor may then be used to form the finish-start connection 102, insulating means 104 is disposed about the outer turn of part coil 88, and an outer portion 106 is wound about part coil 88, to complete pancake coil 42, with seven turns being provided in the second or outer portion 106. The insulated conductor may then be bent to form the finish-start connection 108, insulating means 110 is disposed about the outer turn of part coil 84, and outer portion 112 is wound to complete pancake coil 40, with the outer portion 112 having eight turns. The insulated conductor may then be bent to form the finish-start interpancake connection 114, and insulating means 116 is disposed about the outer turn of part coil 80. Pancake coil 38 is then completed by winding section 118 about part coil 80, with the outer portion 118 having seven turns therein. This completes the first part of the tap section 34, except for the connection of the taps to the pancake coils.

The outermost turn of pancake coil 46 is tapped at 120 and the tap lead is electrically connected to terminal 121 on the tap changer 23. The circuit then traverses eight turns through pancake coil 44 and seven turns through pancake coil 42, thus directing the 15th turn to the outermost turn of pancake coil 42, which is tapped at 122 and the tap lead electrically connected to terminal 123 on tap changer 23. The circuit then traverses eight turns through pancake 40, and 7 turns through coil 38, directing the 15th turn to the outermost turn of pancake coil 38, which is tapped at 124 and the tap lead electrically connected to terminal 125 on tap changer 23.

The other half of winding 16 is constructed similar to the first half, starting from terminal 28 and proceeding axially inward, winding each coil and portion thereof to provide a magnetomotive force in the magnetic core which adds to that provided by the first half of the winding. This half of the winding 16 is tapped at the outer turn of the pancake coil 48 at 130 and the tap lead electrically connected to terminal 131 on the tap changer 23, the outer turn of pancake coil 52 is tapped at 132 and the tap lead connected to terminal 133 on tap changer 23, and the outer turn of pancake coil 56 is tapped at 134 and the tap lead electrically connected to terminal 135 of the tap changer 23.

Tap changer 23 may be of any suitable construction, providing five different voltages, in this example. Terminals 125 and 135 of the tap changer 23 may be connected together to connect the complete tap section into the winding circuit. Other tap connections selectively connect terminals 125 to terminal 133, terminal 123 to terminal 133, terminal 123 to terminal 131, and terminal 121 to terminal 131, with the last-named connection shorting the tap section completely out of the active winding circuit. It is important to note, however, that a complete gap is not created in the ampere turns in any position of the tap changer 23. Even when the tap section is completely tapped out, pancake coils 46 and 48 are still completely in the active winding circuit, as are all of the part coils. Pancake coils 46 and 48 also "divide" the reduction in ampere turns as the tap section is tapped out, directing the reduction in the ampere turns to two spaced locations, instead of concentrating the reduction at one location. Thus, it is evident that the disclosed winding construction will reduce axial unbalance, and short circuit stresses resulting therefrom, regardless of the connection of the tap changer 23, and the disclosed construction reduces flux fringing, and the losses resulting therefrom due to the heating of adjacent metallic parts, as there is always an active circuit to direct the flux parallel with the winding axis. Further, variation in impedance is minimized across the tap range.

The disclosed method and winding construction direct all of the taps to outer turns of predetermined pancake coils where the tap connections may be more easily made, without increasing the width of ducts, which thus improves the space factor of the winding, and without requiring special insulation for the tap leads.

FIGS. 4, 5, and 6 are fragmentary views of an outer turn of a pancake coil having a terminal or "stub tap" connected thereto. Leads may be connected to the terminals, or when used as stub taps a movable connector may be used to directly interconnect predetermined stub taps. More specifically, FIG. 4 illustrates that a tap lead **140** may be easily brazed or welded to an outer turn **142**, by stripping the insulation from the turn at the point of the connection, and metallurgically connecting terminal **140** to the bare conductor. FIG. 5 illustrates that an outer turn **144** may be looped at **146**, and the insulation removed from the end of the looped portion. A terminal **148** may then be brazed, crimped, or otherwise suitably fastened to the exposed metal in the loop. FIG. 6 illustrates that an outer turn **150** may be looped at **152**, the insulation stripped from the loop, and an opening **154** drilled or otherwise formed through the bare conductor, with the opening accepting a bolt for fastening a lead thereto. The last two arrangements, shown in FIGS. 5 and 6, are especially useful when the winding is formed with an aluminum conductor instead of copper, as it is more difficult to form a metallurgical bond to aluminum than it is to copper.

While the disclosed method and winding structure has been illustrated utilizing all finish-start connections between pancake coils, it would be equally suitable to use successive start-start, finish-finish interpancake connections, with FIG. 7 being a schematic diagram of a winding 16'' constructed according to this embodiment of the invention. Like reference numerals in FIGS. 1 and 7, except for a double prime mark in FIG. 7, indicate like components, and will not be again described in detail.

More specifically, winding 16'' shown in FIG. 7 interconnects the innermost turn of pancake coil 36'' with the innermost turn of part coil 80'' via start-start connection **160**. The outermost ends of part coils 80'' and 84'' are interconnected via finish-finish connection **162**. The innermost turns of part coils 84'' and 88'' are interconnected with start-start connection **164**, and the outermost turns of part coils 88'' and 92'' are interconnected with finish-finish connection **166**. The innermost turn of part coil 92'' is connected to the outermost turn of pancake coil 46'' via start-start connection **168**. Finish-finish, start-start interpancake connections are also used when completing the part coils, with the outermost turn of pancake coil 46'' being connected to the outermost turn of the outer portion 100'' of pancake coil 44'', via finish-finish connection **170**, the innermost turn of portion 100'' is connected to the innermost turn of the completing portion 106'' via start-start connection **172**, the outermost turns of portions 106'' and 112'' are interconnected with finish-finish connection **174**, and the innermost turns of portions 112'' and 118'' are interconnected via start-start connection **176**.

In this embodiment of the invention, tap 120'' is connected to the finish-finish connection **170**, tap 122'' is connected to the finish-finish connection **174**, and tap 124'' is connected to the outermost turn of pancake coil 38''.

The portion of winding 16'' on the other side of the tap break is constructed in a manner similar to that hereinbefore described relative to the first half of the winding, with the winding starting at terminal 28'' and proceeding axially inward until reaching the tap break, and the proceeding axially outward to complete the part coils of the tap section. Tap 130'' is connected to the finish-finish connection between the pancake coils 48'' and 50'', tap 132'' is connected to the finish-finish connection between pancake coils 52'' and 54'' and tap 134'' is connected to the end of the outermost turn of pancake coil 56''.

The specific example used to describe the new and improved method of constructing a tap section selected an odd number of turns between taps. If an even number of turns between taps is required, each part coil may be constructed to have the same number of turns. Further, the outer sections may be constructed with a like number of turns. Also, when each pancake coil of the tap section is tapped, each part coil may have the same number of turns and each added outer section may have the same number of turns, regardless of whether the number of turns between adjacent taps is odd or even. Further, while it is preferable that all of the pancake coils of winding have substantially the same build or outside dimension, to facilitate the mechanical bracing of the winding, as hereinbefore stated, variations may be used. For example, the tap section may have a different build dimension than the untapped portions of the winding.

In summary, there has been disclosed a new and an improved method of constructing a tap section for the winding of an electrical power transformer for either the dry or liquid-filled types, as well as a new improved tapped winding structure, wherein all of the turns to be tapped appear at the outermost turns of certain pancake coils of the tap section. This arrangement facilitates the connection of tap leads or terminals to the tapped winding section, and it improves the space factor of the winding as the spacing between pancake coils does not have to be increased in order to bring tap leads out from intermediate turns between two adjacent pancake coils. Further, the new and improved tapped winding structure does not create a complete gap in the ampere turns, in any position of the tap changer, as the two pancake coils adjacent to the tap break, as well as all of the part coils, are always actively connected into the circuit. Thus, instead of complete gaps in the ampere turns, the ampere turns are merely reduced in magnitude, and the reduction is spaced on opposite sides of the two centrally located pancake coils of the tap section, in certain positions of the tap changer, to further reduce the effect of the reduction in ampere turns. The disclosed construction thus substantially reduces axial unbalance as the tap section is tapped out, and it reduces the magnitude of mechanical forces resulting from an unbalance, compared with the prior art arrangements where a complete gap is created in the ampere turns, and it also reduces variations in impedance across the tap range. Since the " floating" ends of the two tapped portions of the tap section have a plurality of pancake coils physically disposed between them when the tapped winding section is completely tapped out, voltage differences between their ends is not a problem.

We claim as our invention:

1. A method of constructing a tapped winding, comprising the steps of:

winding and electrically interconnecting a first plurality of part coils, each having a predetermined number of turns, to provide a first electrical path having first and second ends located at the first and last part coils wound, respectively,

and winding and electrically interconnecting a plurality of turns on each part coil in reverse order, starting at the second end of the first electrical path in the last part coil wound, to return the first electrical path to the first pancake coil and complete the first plurality of part coils, with the number of turns added to each part coil being predetermined to locate each turn to be tapped at the outer turn of a completed coil, and connecting top leads to each of the outer turns to be tapped.

2. The method of claim 1 wherein the number of turns in the part coils are predetermined such that the number of turns added to each part coil provides substantially the same build dimension for each completed coil.

3. The method of claim 1 wherein the steps of interconnecting the part coils connects adjacent part coils with finish-start connections.

4. The method of claim 3 wherein the steps of interconnecting the plurality of turns added to each part coil interconnects the added turns of adjacent part coils with finish-start connections.

5. The method of claim 1 wherein the steps of interconnecting part coils connects the coils with successive start-start, finish-finish connections.

6. The method of claim 5 wherein the steps of interconnecting the plurality of turns added to each part coil, interconnect the added turns with successive start-start, finish-finish connections.

7. The method of claim 1 including the steps of winding and electrically interconnecting a first group of complete coils adjacent to the first end of the first plurality of part coils, and electrically connecting one end of the first group of complete coils to the first end of the first electrical path.

8. The method of claim 1 including the steps of winding and electrically interconnecting a second plurality of part coils, each having a predetermined number of turns, to provide a second electrical path having first and second ends located at the first and last part coils wound, respectively, and with the last part coil wound of the second plurality being adjacent to the last part coil wound of the first plurality, winding and electrically interconnecting a plurality of turns on each part coil of the second plurality in reverse order, starting at the second end of the second electrical path in the last part coil wound, to return the second electrical path to the first pancake coil of the second plurality and complete the second plurality of part coils, with the number of turns added to each part coil being predetermined to locate each turn to be tapped at the outer turn of a completed coil, connecting tap leads to each of the outer turns to be tapped in the first and second plurality of coils, and connecting the tap leads to means for selectively interconnecting the tap leads from the first and second plurality of coils.

9. The method of claim 8 including the steps of winding and electrically interconnecting a second group of complete coils adjacent to the first end of the second plurality of part coils, and electrically connecting one end of the second group of complete coils to the first end of the second electrical path.

10. A tapped winding for electrical inductive apparatus, comprising: a first group of axially spaced pancake coils having first and second ends, each of said pancake coils having inner and outer portions each including a plurality of radially disposed, connected conductor turns, which provide electrical paths through each of the inner and outer portions having inner and outer ends, means interconnecting the pancake coils to direct a first electrical circuit through each of the inner portions, starting at the first end of said first group, and through each of their outer portions, starting at the second end of said first group, and a plurality of taps electrically connected to predetermined outer turns of predetermined pancake coils.

11. The tapped winding of claim 10 wherein the outer end of the inner portion, is connected to the inner end of the outer portion, in the pancake coil at the second end of the first group of pancake coils.

12. The tapped winding of claim 10 wherein each of the pancake coils have substantially the same build dimensions.

13. The tapped winding of claim 10 wherein adjacent first portions of the pancake coils are interconnected with finish-start connections.

14. The tapped winding of claim 13 wherein adjacent second portion of the pancake coils are interconnected with finish-start connections.

15. The tapped winding of claim 10 wherein alternate connections between the first portions of the pancake coils are start-start connections, and the remaining connections between the first portions of the pancake coils are finish-finish connections.

16. The tapped winding of claim 15 wherein alternate connections between the second portions of the pancake coils are start-start connections, and the remaining connections between the second portions of the pancake coils are finish-finish connections.

17. The tapped winding of claim 10 including a first untapped winding section connected to the first portion of the pancake coils at the first end of the first group of pancake coils.

18. The tapped winding of claim 10 including a second group of axially spaced pancake coils having first and second ends, constructed and connected similarly to the first group of axially spaced pancake coils, with the second ends of the first and second groups being adjacent to one another.

19. The tapped winding of claim 18 including tap changer means connected to the plurality of taps, for selectively interconnecting taps on the first and second groups of pancake coils.

20. The tapped winding of claim 18 including first and second untapped winding sections connected to the first portions of the pancake coils at the first ends of the first and second groups of pancake coils, respectively.

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