Aug. 22, 1967 S. G. VARGO 3,337,828

TAPPED MULTI-LAYER CYLINDRICAL WINDING

Filed Oct. 11, 1965 2 Sheets-Sheet 1

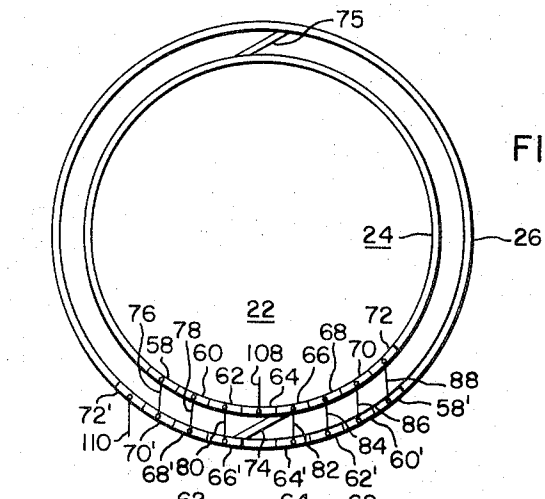


FIG. 3.

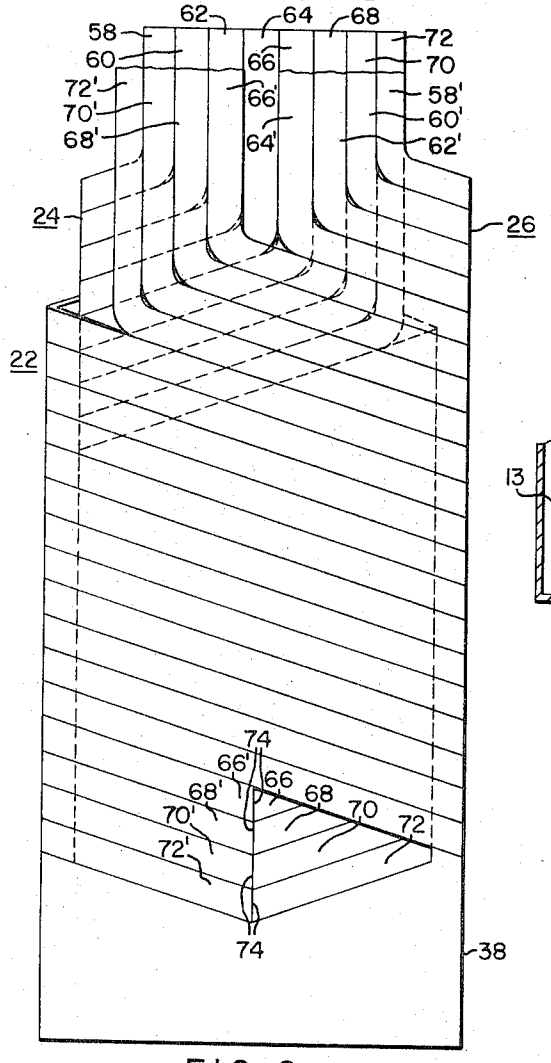


FIG. 2.

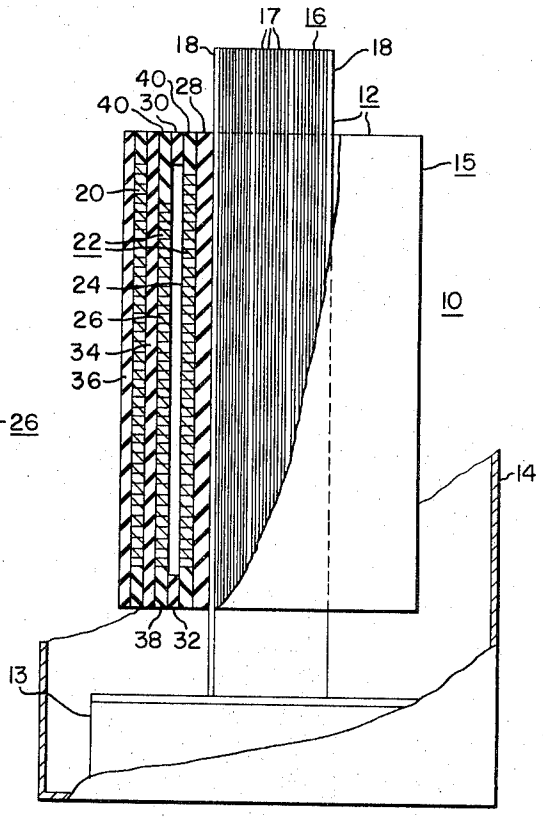


FIG. 1.

INVENTOR
Stephen G. Vargo
BY
Donald R. Lackey
ATTORNEY

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TAPPED MULTI-LAYER CYLINDRICAL WINDING

Filed Oct. 11, 1965 2 Sheets-Sheet 2

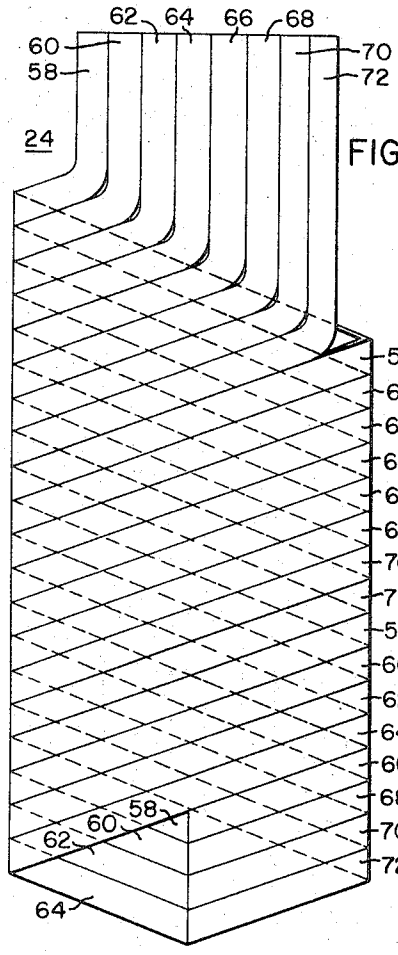


FIG. 4.

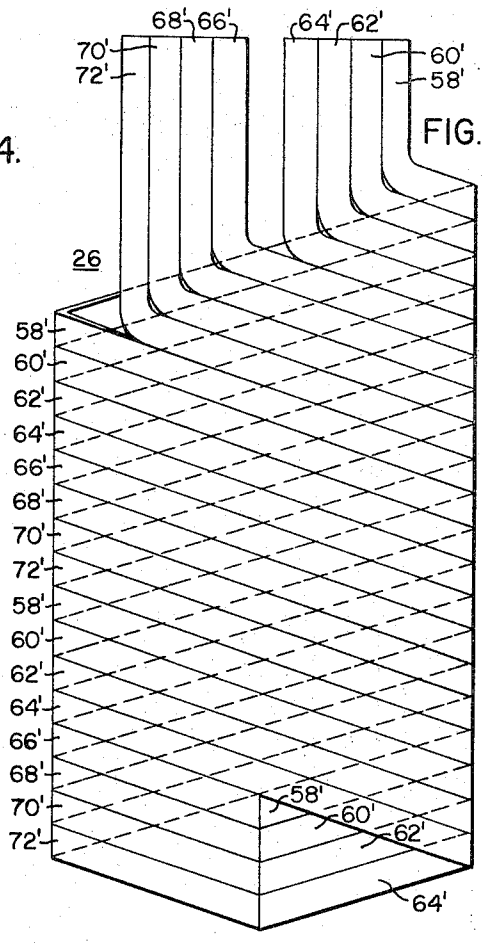


FIG. 5.

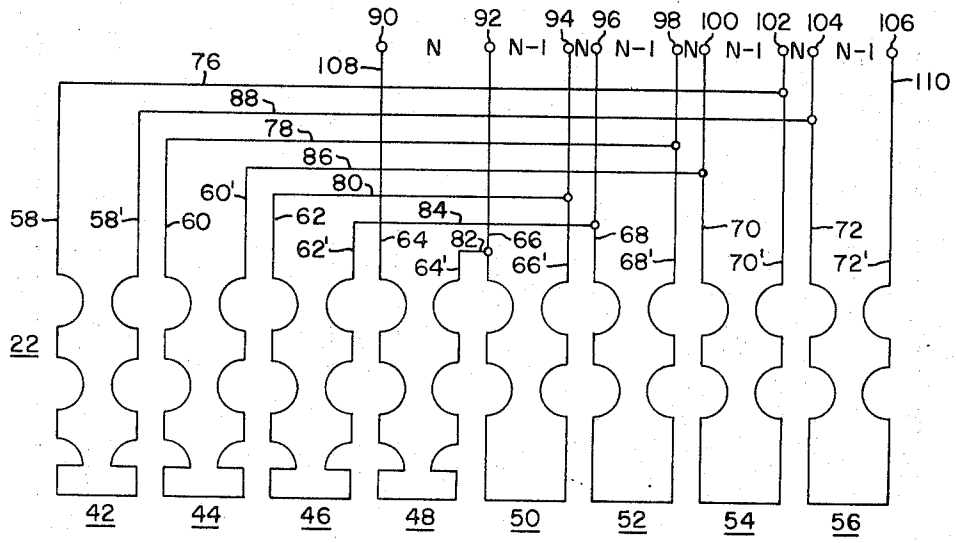


FIG. 6.

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Patented Aug. 22, 1967

3,337,828

TAPPED MULTI-LAYER CYLINDRICAL WINDING

Stephen G. Vargo, Campbell, Ohio, assignor to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

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4 Claims. (Cl. 336—150)

ABSTRACT OF THE DISCLOSURE

A tapped multi-layer cylindrical winding structure for electrical inductive apparatus, in which the coil ends in each of the layers, and tap connections thereto, are all disposed at one axial end of the winding structure. Certain of the coils in each layer have more turns than the other coils of the layer, to provide a winding structure in which there are N turns between certain tap connections, and $N-1$ turns between the remaining tap connections.

It is important in tapped transformer windings to obtain a uniform axial distribution of ampere turns, in order to reduce losses in the transformer tank wall and core lock plates, reduce eddy current losses in the electrical conductors, and reduce mechanical stresses in the electrical windings. For example, if the tap leads are connected intermediate the ends of the column forming the tapped winding, in most of the tap positions current will not flow through the length of the column forming the winding, resulting in a non-uniform axial distribution of ampere turns. This non-uniform distribution of ampere turns produces a cross component of the normal leakage flux between the tapped or regulating winding, and other windings inductively associated therewith, which effects the additional losses and mechanical stresses hereinbefore referred to. Also, tapping the winding intermediate its ends requires long tap leads, which take up valuable winding space and add still further to the losses of the transformer.

United States Patent 2,757,347, issued July 31, 1956 to J. Pazaryski, and assigned to the same assignee as the present application, teaches a tapped winding arrangement in which all of the taps are disposed at one end of the winding column, and thus provides a uniform axial distribution of ampere turns, which overcomes the disadvantages associated with bringing the tap leads out intermediate the winding column. United States Patent 2,757,347, however, while a significant advance in the art, has the disadvantage of inherently fixing the volts per turn, as the turns between taps are always equal. Thus, given a certain number of taps such as eight, and given a regulating range such as + or −10%, the volts per turn of the regulating winding is inflexibly determined. Thus, the arrangement taught by Patent 2,757,347 is only useful in certain applications, with less desirable and/or more costly winding arrangements being necessary in other regulating transformer applications.

It would be desirable to provide a new and improved regulating or tapped winding arrangement for an electrical transformer, which has a uniform axial distribution of ampere turns, and which does not inherently require the number of turns between taps to be equal.

Accordingly, it is an object of this invention to provide a new and improved transformer having one or more tapped windings.

A further object of the invention is to provide a new and improved tapped winding arrangement for a transformer which has a substantially uniform axial distribution of ampere turns.

Another object of the invention is to provide a new and improved tapped winding arrangement for a transformer which has a uniform axial distribution of ampere turns, and which does not require the number of turns between adjacent taps to be equal.

Still another object of the invention is to provide a new and improved winding arrangement for a transformer which has a uniform axial distribution of ampere turns, all of the taps disposed at one end of the winding, and which does not require the number of turns between adjacent taps all be equal.

Briefly, the present invention accomplishes the above cited objects by winding a conductor having a predetermined number of conductive strands in a first axial direction to form a first cylindrical layer having a predetermined number of turns. A predetermined number of the strands of the conductor are terminated at the end of the predetermined number of turns, with the remaining strands continuing in the same axial direction for an additional one half turn. The strands which continue for an additional one half turn are bent to form a new cylindrical layer in predetermined spaced relation with the first layer, and also bent to start winding the new layer in an axial direction opposite to the first axial direction.

When the strands in the new layer have progressed one half turn, strands are connected to the terminated strands in the first layer and bent to join the strands already in the new layer to form a conductor having the original number of strands. This conductor is wound to form a predetermined number of turns in the second layer, with the ends of the strands of the second layer being terminated adjacent the ends of the strands at the start of the first layer. Predetermined ends of the two layers are joined together and taps connected thereto, which give the desired number of turns between adjacent taps. Since some strands have one less turn than other strands, the disclosed arrangement allows the disposition of N turns between certain taps and $N-1$ turns between certain taps. Thus, the winding has all of the tap connections at one end thereof, the strands twice traverse substantially the full length of the winding, providing a uniform distribution of ampere turns, and the arrangement is not limited to providing an equal number of turns between all adjacent taps.

Further objects and advantages of the invention will become apparent as the following description proceeds and features of novelty which characterize the invention will be pointed out in particularity and the claims annexed to and forming a part of this specification.

For a better understanding of the invention, reference may be had to the following detailed description taken in connection with the accompanying drawings in which:

FIGURE 1 is an elevational view of a transformer, partially cut away and partially in section, which may be constructed according to the teachings of the invention.

FIG. 2 is an elevational view of a tapped winding arrangement constructed according to the teachings of the invention.

FIG. 3 is a plan view of the tapped winding structure of FIG. 2.

FIGS. 4 and 5 are elevational views of the inner and outer winding layers, respectively, of the tapped winding arrangement shown in FIGS. 2 and 3, and

FIG. 6 schematically illustrates the tapped winding arrangement shown in FIG. 2, illustrating the manner in which the various coils are connected to form a continuous winding.

Referring now to the drawings, and FIGURE 1 in particular, there is illustrated a transformer **10** which may utilize the teachings of the invention. Transformer **10** in-

cludes a coil and core assembly **12** disposed within a tank or casing **14**, shown partially cut away, on mounting means **13**. Tank **14** may contain a suitable dielectric medium (not shown), as required by specific applications. More specifically, coil and core assembly **12** includes a winding assembly **15** disposed in inductive relation with a magnetic core member **16**. Magnetic core member **16** has a plurality of laminations **17** formed of magnetic material, and lock plate members **18** disposed to hold the laminations **17** in assembled relation. Winding assembly **15**, partially shown in section, includes a primary winding **20** and a tapped secondary winding **22**, with the tapped secondary winding **22** including at least two concentric, spaced layers of turns, such as inner layer **24** and outer layer **26**. Inner layer **24** is insulated from the magnetic core member **16** by insulating means **28**. Insulating space members, such as those shown at **30** and **32**, are utilized to space and electrically insulate the inner and outer layers **24** and **26** of secondary winding **22** from one another.

In order to insulate the primary winding **20** from the secondary winding **22**, insulating means **34** is disposed between primary winding **20** and the outer layer **26** of the secondary winding **22**. Insulating means **36** may be disposed to surround the outer periphery of winding assembly **15**, for mechanical and electrical protection.

In order to start and terminate the tapped secondary winding **22** properly, as well as position the inner and outer layers **24** and **26** of tapped secondary winding **22** at predetermined positions relative to one another, and relative to the primary winding **20**, lower and upper collar members **38** and **40**, respectively, are disposed at the ends of the inner and outer layers **24** and **26**. As will be shown in greater detail hereinafter, secondary winding **22** starts at one end of one of the layers, **24** or **26**, progresses spirally to the other end of the layer, crosses to the adjacent layer, and progresses spirally to the other end of the new layer to finish near the start of the first layer. The tapped connections are then made to the ends of the inner and outer layers **24** and **26**, assuring a uniform axial distribution of ampere turns.

FIGURES 2 and 3 illustrate elevational and plan views, respectively, of tapped secondary winding **22**. In this instance, tapped secondary winding **22** includes eight coils, **42**, **44**, **46**, **48**, **50**, **52**, **54**, and **56** (see FIGURE 6), formed by eight conductors or strands **58**, **60**, **62**, **64**, **66**, **68**, **70** and **72**, disposed in insulated side-by-side relation and wound together as a turn to form the inner and outer layers **24** and **26**, respectively. Inner and outer layers **24** and **26** are illustrated individually in FIGURES 4 and 5, respectively, with the conductors or strands **58**, **60**, **62**, **64**, **66**, **68**, **70** and **72** including a prime mark in the outer layer **26** to distinguish them from corresponding conductors in the inner layer **24**.

Referring now to inner layer **24** of tapped secondary winding **22**, shown in FIGURE 4, the conductors **58**, **60**, **62**, **64**, **66**, **68**, **70** and **72** are spirally wound together to form a predetermined number of cylindrical turns. The conductors start in a substantially vertical position, and are then bent to cause the spiral winding of the conductor to proceed in a predetermined direction along the axis of the cylindrical layer **24**. After forming a predetermined number of turns, such as the two turns shown in FIGURE 4, a predetermined number of the lower strands of the turn are terminated, and the remaining strands continue for an additional one half turn. As shown in FIGURE 4, conductors **66**, **68**, **70** and **72** are terminated after having formed substantially two complete turns, while conductors **58**, **60**, **62** and **64** are continued in the same axial direction for an additional one half turn. Conductors **58**, **60**, **62** and **64** are then bent outwardly, as shown at bend **75**, to form the start of the outer layer **26**, which is shown in FIGURE 5, and they are also bent to start the spiral winding of layer **26** in a direction opposite the axial winding direction of layer **24**. In other words, outer layer **26**

is wound back towards the start of the inner layer **24**. As illustrated in FIGURE 5, conductors **58'**, **60'**, **62'**, and **64'** spiral upwardly for one half turn, at which point conductors **66'**, **68'**, **70'** and **72'** are added. Conductors **66'**, **68'**, **70'** and **72'** are electrically connected to the terminated ends of conductors **66**, **68**, **70** and **72** of inner layer **24**, with a bend **74** being made in the connecting means, as shown in FIGURE 3, which makes the transition of these conductors from the inner layer **24** to the outer layer **26**. Conductors **58'**, **60'**, **62'**, **64'**, **66'**, **68'**, **70'**, and **72'**, then spiral together in the same axial direction, back to the start of inner layer **24**. It should be noted that coils **42**, **44**, **46** and **48**, which include conductors **58** and **58'**, **60** and **60'**, **62** and **62'**, and **64** and **64'**, respectively, include one more complete turn than coils **50**, **52**, **54**, and **56**, which include conductors **66** and **66'**, **68** and **68'**, **70** and **70'**, and **72** and **72'**, respectively. Thus, if the number of turns in coils **42**, **44**, **46** and **48** is equal to N, the number of turns in coils **50**, **52**, **54** and **56** is equal to $N-1$. It should also be noted that the conductor which forms each of the coils traverses substantially the complete axial length of both the inner layer **24** and outer layer **26**. Therefore, during the operation of transformer **10**, there is always a substantially uniform axial distribution of ampere turns along the winding assembly **15**, resulting in a minimum cross flux. Thus, transformer losses and mechanical stresses on the electrical conductors are reduced. It will be understood that instead of winding first the inner layer and then the outer layer, continuously, the inner and outer layers may be individually formed and electrically connected as shown at the bends **74** and **75** in FIGURE 3.

In order to complete the tapped secondary winding **22**, certain ends of the inner layer conductors are connected to certain ends of the outer layer conductors, and the common connections are connected to appropriate taps on a load tap changer (not shown). The inner and outer winding layers, **24** and **26**, respectively, may be wound such that the ends to be connected are adjacent one another. For example, as shown in FIGURES 2, 3, 4 and 5, the conductors **58**, **60**, **62**, **64**, **66**, **68**, **70** and **72** all start in a substantially vertical manner in side-by-side relation, and in the order named from left to right. The conductors **72'**, **70'**, **68'**, **66'**, **64'**, **62'**, **60'** and **58'** of outer layer **26** all finish in substantially vertical manner, in the order named from left to right, with a space equal to the width of one conductive strand occurring between conductive strands **66'** and **64'**. Then, by aligning the edges of the conductive strands on the right, as shown in FIGURE 2, all of the strands that should be interconnected will be adjacent one another, and the strands which have no interconnections will not be adjacent a strand in the other layer. More specifically, as shown in FIGURES 3 and 6, conductor **58** is connected to conductor **70'** by a conductor **76**, and this common connection is connected to a tap or terminal **102**. In like manner, conductor **60** is connected to conductor **68'** by a conductor **78**, and the common connection is connected to a tap or terminal **98**. Conductor **62** is connected to conductor **66'** by a conductor **80**, and the common connection is connected to a tap or terminal **94**. Conductor **66** is connected to conductor **64'** by a conductor **82**, and the common connection is connected to a tap or terminal **92**. Conductor **68** is connected to conductor **62'** by a conductor **84**, and the common connection is connected to a tap or terminal **96**. Conductor **70** is connected to conductor **60'** by a conductor **86**, and the common connection is connected to a tap or terminal **100**. Conductor **72** is connected to conductor **58'** by a conductor **88**, and the common connection is connected to a tap or terminal **104**. Conductor **64** and conductor **72'** form the ends of the completed tapped secondary winding **22**, and they are connected through conductors **108** and **110** to taps or terminals **90** and **106**, respectively.

By winding tapped secondary winding **22** in the manner illustrated in FIGURES 2 and 3, and connecting the inner and outer layers **24** and **26**, respectively, as shown in FIGURES 3 and 6, a tapped winding arrangement is achieved which has the low losses, and low mechanical stress advantages of the hereinbefore mentioned patent, and additionally a structure is obtained which is not inflexibly tied to an equal number of turns between adjacent taps. This may be more clearly understood by referring to FIGURE 6, which illustrates the various coils **42**, **44**, **46**, **48**, **50**, **52**, **54** and **56**, in a substantially unwound manner. The conductors which form the left side of each coil in FIGURE 6 represent the turns of the inner layer **24**, and the conductors which form the right side of each coil represent the turns of the outer layer **26**. One complete turn is represented by a half circle in FIGURE 6, and a half turn is represented by a quarter circle. Thus, coil **42** has a total of five turns, with two and one-half turns occurring in each layer. Coils **44**, **46** and **48** also have five turns. Coils **50**, **52**, **54** and **56**, on the other hand, have only four turns, with two turns occurring in each layer, as the conductors which form these particular turns were the ones which were terminated one-half turn before the other conductors were terminated in the inner layer **24**, and started one-half turn after the other conductors were started in the outer layer **26**.

By interconnecting the ends of the inner and outer layers as shown in FIGURE 6 and hereinbefore described, a tapped winding arrangement is obtained which has N turns between certain adjacent taps, and $N-1$ turns between certain adjacent taps. More specifically, assuming that N is equal to five, there are N turns between taps or terminals **90** and **92**. Between taps **92** and **94**, there are $N-1$ or four turns. This pattern is repeated, with N turns occurring between taps **94** and **96**, $N-1$ turns occurring between taps **96** and **98**, N turns occurring between taps **98** and **100**, $N-1$ turns occurring between taps **100** and **102**, N turns occurring between taps **102** and **104**, and $N-1$ turns occurring between taps **104** and **106**. It will be understood that this pattern may be varied, by increasing or decreasing the number of coils which have one fewer turn. For example, instead of terminating four conductors and continuing four conductors for the additional partial turn as shown in FIGURES 4 and 5, three conductors could be terminated and five conductors could be continued, or five conductors could be terminated and three conductors continued. It is also to be understood that the eight coils shown in the drawings are for purposes of illustration only, as any desired number of coils may be utilized, depending upon the particular transformer design and load tap changer, to be utilized. Also, more than two layers or columns may be utilized in tapped secondary winding **22**, as long as the number of layers is a multiple of two.

In summary, there has been disclosed a new and improved tapped winding arrangement for a transformer which has many advantages. The tapped winding arrangement provides a substantially uniform axial distribution of ampere turns, as in all tap positions the current flows throughout the axial length of both the inner and outer layers of the secondary winding. Thus, there is minimum cross component of the normal leakage flux established, which minimizes losses in the tank wall, core lock plates, and minimizes eddy current losses in the electrical conductor. Further, the uniform axial distribution of ampere turns minimizes the mechanical stresses in the windings which tend to move the conductors axially apart. These advantages have been realized without restricting the use of the windings to those applications where the turns between adjacent taps can all be equal. The teachings of this invention allow a great flexibility in the total number of turns in the winding for a given number of taps, thus overcoming limitations in prior art apparatus, which inflexibly set the number of turns in the tapped winding.

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

I claim as my invention:

1. A winding for electrical inductive apparatus comprising first and second winding layers having first and second ends, said first and second winding layers being disposed with their first and second ends adjacent one another, respectively, each of said winding layers having a plurality of turns formed of an electrical conductor having a first predetermined number of conductive strands, each winding layer having a predetermined part turn at their adjacent seconds ends, said part turns each having a second predetermined number of conductive strands which is less than the first predetermined number of conductive strands, the ends of the conductive strands of the part turn at the second end of each layer being electrically connected, the ends of the conductive strands at the second ends of said layers which do not form part of the part turn being electrically connected, and means interconnecting certain adjacent ends of the conductive strands of said first and second winding layers at the first ends of said winding layers, to form a continuous winding having N turns between the adjacent electrically connected ends which include part turns and $N-1$ turns between the remaining adjacent electrically connected ends.

2. A winding for electrical inductive apparatus comprising first and second cylindrical winding layers having first and second ends, said first and second winding layers being disposed in spaced, concentric relation with their first and second ends adjacent one aother, respectively, each of said winding layers having a plurality of spiral turns formed of an electrical conductor having a first predetermined number of conductive strands, each winding layer having a half turn at their adjacent second ends which has a second predetermined number of conductive strands which is less than the first predetermined number of conductive strands, the ends of the conductive strands of the half turn at the second end of each layer being disposed adjacent one another and electrically connected, the ends of the conductive strands in each layer which do not form part of the half turn at the second end of the layer being disposed adjacent one another and electrically connected, and means interconnecting certain adjacent ends of the conductive strands of said first and second winding layers at the first end of said winding layers, to form a continuous winding having N turns between the adjacent electrically connected ends which include the half turns and $N-1$ turns between the remaining adjacent electrically connected ends.

3. A winding for electrical inductive apparatus comprising first and second winding layers having first and second ends, said first and second winding layers being disposed in spaced, concentric relation with their first and second ends adjacent one another, respectively, each of said winding layers having a plurality of turns formed of an electrical conductor having a predetermined even number of conductive strands, each winding layer having a half turn at their adjacent second ends which includes one half of said predetermined number of conductive strands, the ends of the conductive strands of the half turn at the second end of each layer being disposed adjacent one another and electrically connected, the ends of the conductive strands in each layer which do not form part of the half turn being disposed adjacent one another and electrically connected, and means interconnecting certain adjacent ends of the conductive strands of said first and second winding layers at the first ends of said winding layers, to form a continuous winding having N turns between the adjacent electrically connected ends which in-

clude the half turns, and $N-1$ turn between the remaining adjacent electrically connected ends.

4. An electrical transformer comprising a magnetic core, first and second windings disposed in inductive relation with said magnetic core, said second winding including first and second winding layers having first and second ends, said first and second winding layers being disposed in spaced concentric relation, with their first and second ends adjacent one another, respectively, each of said winding layers having a plurality of turns formed of an electrical conductor having a predetermined number of conductive strands, each winding layer having a half turn at their adjacent second ends, each including a predetermined number of conductive strands less than the predetermined number of conductive strands in said electrical conductor, the ends of the conductive strands of the half turn at the second end of each layer being disposed adjacent one another and electrically connected,

the ends of the conductive strands in each layer which do not form part of the half turn at the second end of the layers being disposed adjacent one another and electrically connected, and means interconnecting certain adjacent ends of the conductive strands of said first and second winding layers at the first end of said layers to form a continuous winding having N turns between the adjacent electrically connected ends which include the half turns, and $N-1$ turn between the remaining adjacent electrically connected ends.

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LEWIS H. MYERS, *Primary Examiner.*

T. J. KOZMA, *Assistant Examiner.*