United States Patent

Moore et al.

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[45] Aug. 29, 1972

[54] **ELECTRICAL INDUCTIVE APPARATUS HAVING SERIALLY INTERCONNECTED COILS**

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

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[52] **U.S. Cl.**..................................**336/183,** 336/187

[51] **Int. Cl.**...**H01f 27/28**

[58] **Field of Search**..........336/186, 187, 69, 70, 180, 336/182, 183, 185

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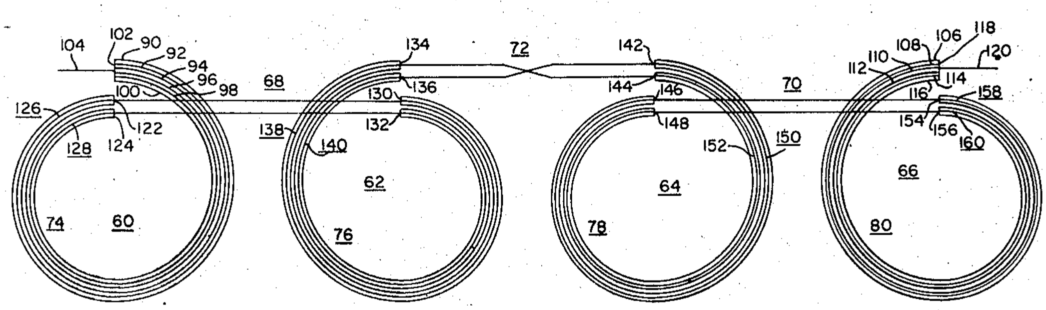
Attorney—A.T. Stratton and F. E. Browder

[57] **ABSTRACT**

Electrical inductive apparatus having pancake-type coils which are serially interconnected to form a winding group. The conductors forming the coils in the winding group are divided into at least two conductor groups by unique lead brazing techniques. Adjacent coils are interconnected by alternate start-start and finish-finish connections. The transposition furnished by the finish-finish connection reduces the circulating currents in the coils due to leakage flux.

3 Claims, 12 Drawing Figures



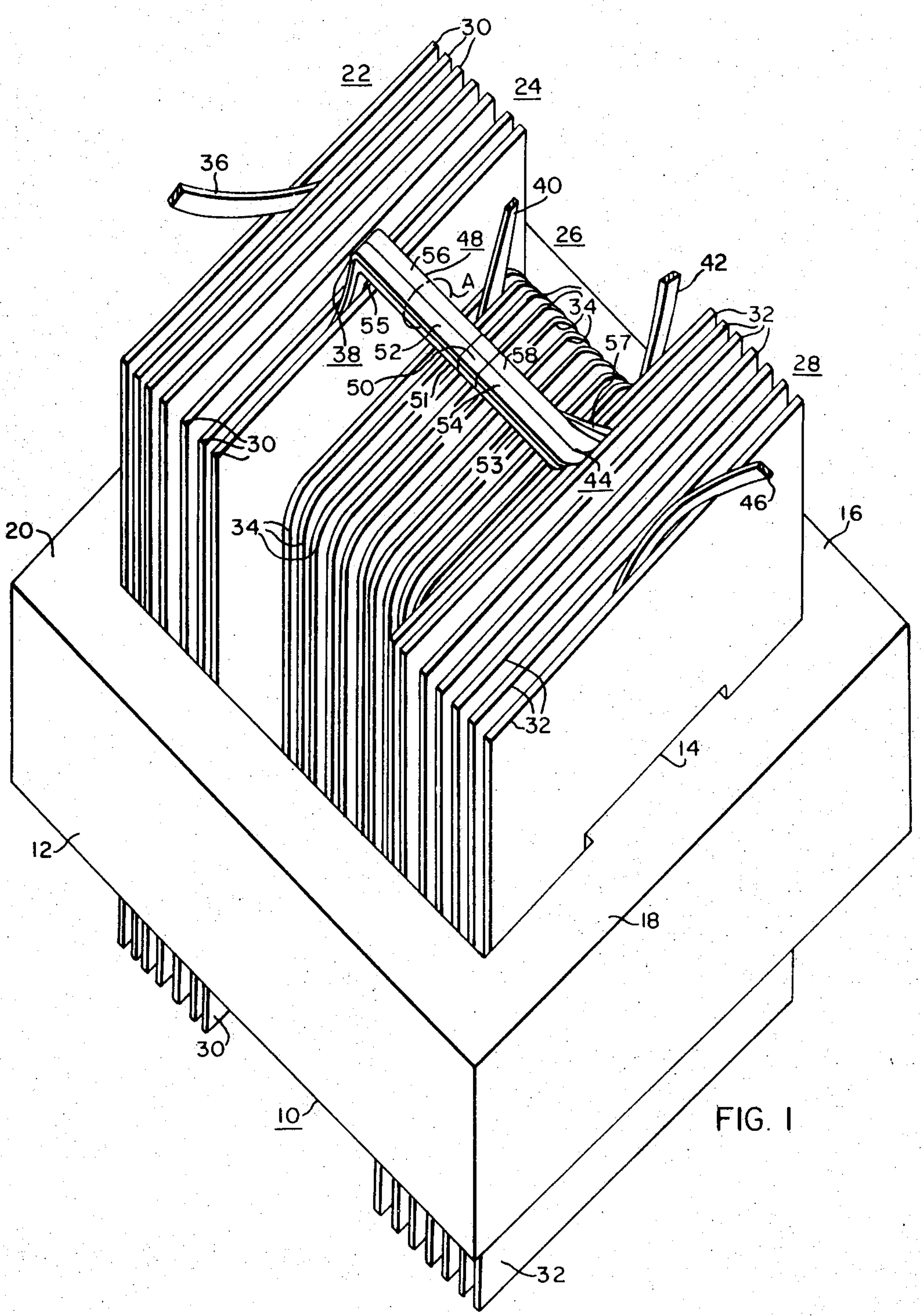


FIG. 1

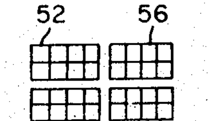


FIG. 1A

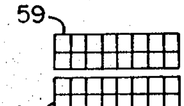


FIG. 1B

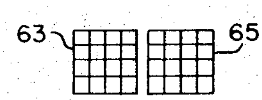


FIG. 1C

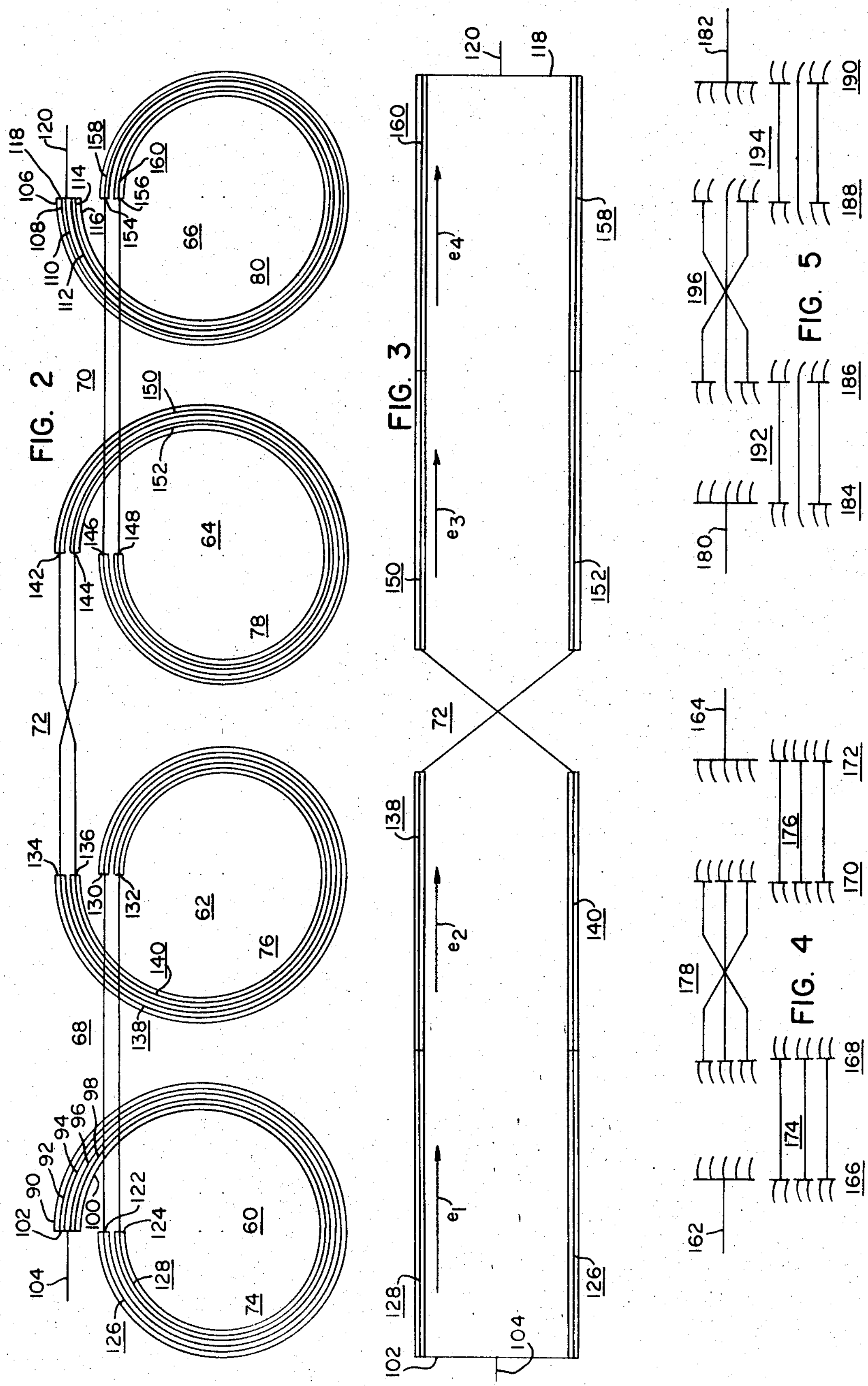


FIG. 2

FIG. 3

FIG. 4

FIG. 5

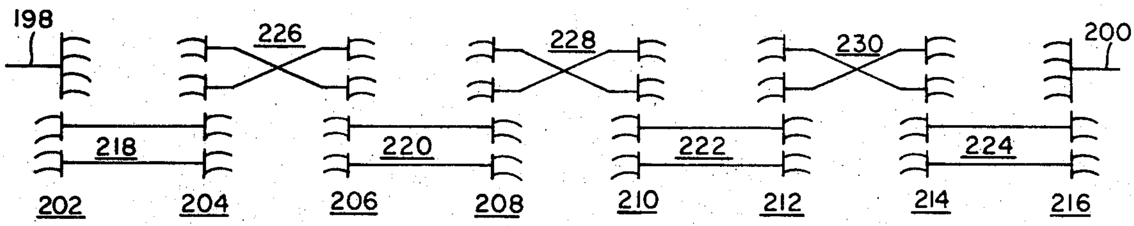


FIG. 6

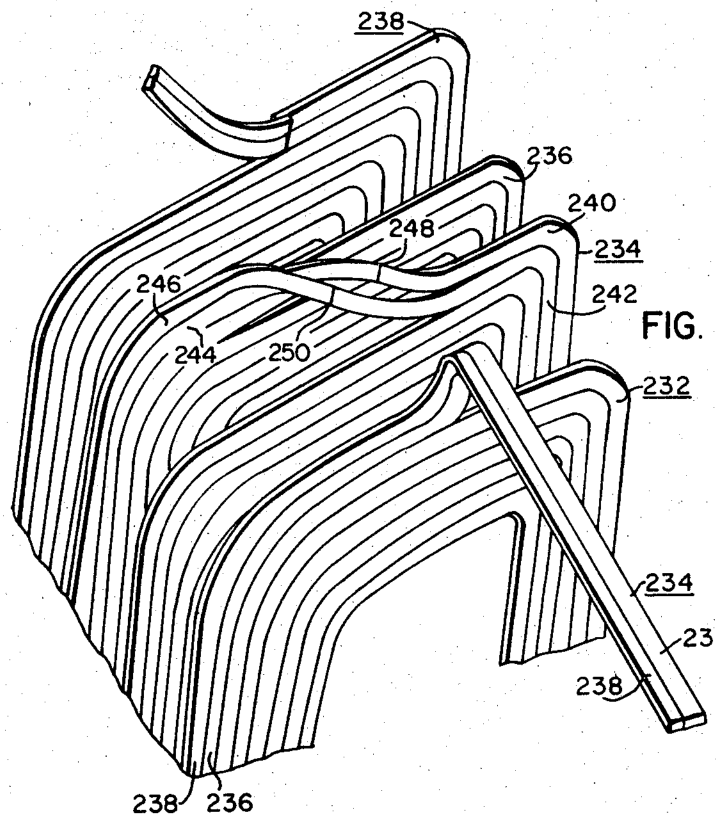


FIG. 7

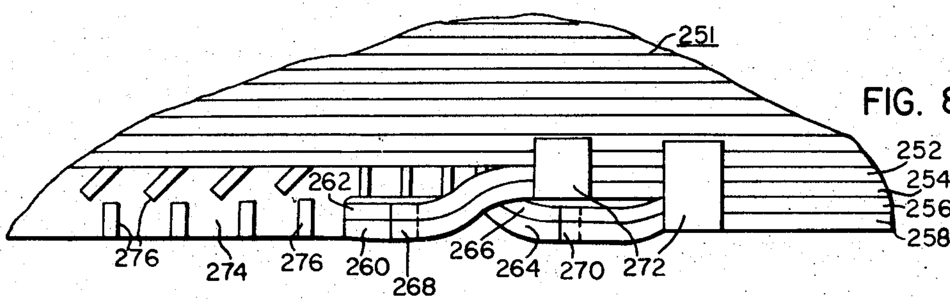


FIG. 8

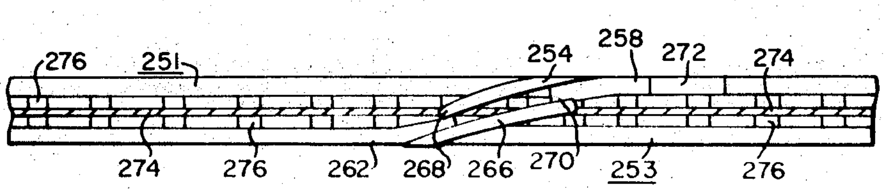


FIG. 9

ELECTRICAL INDUCTIVE APPARATUS HAVING SERIALLY INTERCONNECTED COILS

CROSS REFERENCE TO RELATED APPLICATION

In copending application Westinghouse Case No. 42,664, Ser. No. 123,590, filed Mar. 12, 1971, and assigned to the same assignee as this application, there is disclosed an arrangement for serially interconnecting the windings of electrical inductive apparatus.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates, in general to electrical inductive apparatus and, more specifically, to electrical inductive apparatus having serially interconnected coils.

2. Description of the Prior Art

Electrical inductive apparatus operating at high power levels exhibits various effects which reduce the efficiency and reliability of the apparatus. Prominent among these is the heating of the conductors due to eddy-current losses. Eddy-current losses in a conductor of a transformer winding are proportional to the square of the dimension of the conductor which is at right angles to the leakage flux. Eddy-current losses may thus be reduced by subdividing the required conductor area into two or more parallel connected conductive elements or strands, which are insulated from each other. To prevent an offsetting increase in losses due to circulating currents between the parallel connected strands, the relative position of the strands are transposed with respect to the leakage flux, in an attempt to obtain the same net flux linkages for each strand. If the parallel loops are long, the impedance of the loops aids in reducing circulating currents, but it is still important to obtain a highly efficient transposition of the conductive strands. In practice, however, ideal transpositions are impractical and undesirable circulating currents exist.

Circulating currents are particularly troublesome in shell-form type power transformers having a plurality of individual coils connected in series. According to the prior art, interconnection of the coils requires that the conductors forming each coil have their strands brazed together at each end of each coil. This permits currents to circulate within the individual coils. Therefore, it is desirable to provide a method whereby the circulating currents in serially interconnected coils may be reduced.

SUMMARY OF THE INVENTION

This invention provides a new and useful concept for reducing the total circulating current losses in a transformer winding having serially interconnected coils. The conductors which form the coils of the winding are divided into at least two conductor groups. The coils are connected together by alternate start-start and finish-finish connections. The finish-finish connection is made in such a manner that the induced voltage due to the leakage flux in one coil group opposes the induced voltage due to the leakage flux in another coil group. The resulting opposition of leakage flux voltages substantially reduces the circulating currents flowing between the conductor groups. The heat generated in the winding is reduced and the efficiency of the apparatus is improved.

BRIEF DESCRIPTION OF THE DRAWING

Further advantages and uses of this invention will become more apparent when considered in view of the following detailed description and drawing, in which:

FIG. 1 is an orthographic view of the winding and core structures of a shell form type power transformer;

FIGS. 1A, 1B, and 1C are sectional views taken at the area "A" of FIG. 1 illustrating conductor strand grouping arrangements which are taught by this invention;

FIG. 2 is a schematic diagram of a coil interconnection arrangement as taught by this invention;

FIG. 3 is a schematic diagram illustrating the relationship between the leakage flux induced voltages for the coils of FIG. 2;

FIG. 4 is a diagram illustrating an arrangement for interconnecting coils having six strands as taught by this invention;

FIG. 5 is a diagram illustrating an arrangement for interconnecting coils having five strands as taught by this invention;

FIG. 6 is a diagram illustrating an arrangement for interconnecting a winding having four strands as taught by this invention;

FIG. 7 is a partial orthographic view of coils interconnected according to this invention;

FIG. 8 is a partial plane view illustrating the finish-finish connection between two coils as taught by this invention; and

FIG. 9 is a partial elevational view illustrating the finish-finish connection between two coils as taught by this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Throughout the following description similar reference characters refer to similar members in all figures of the drawing.

Referring now to the drawing, and FIG. 1 in particular, there is shown the electric and magnetic structures of a shell-form type power transformer. The laminated magnetic core **10** includes the legs **12**, **14** and **16** and the yokes **18** and **20**. The legs and yokes are formed from a plurality of laminations which are assembled around the winding structure **22**.

The winding structure **22** includes a low voltage winding group **24**, a high voltage winding group **26** and a low voltage winding group **28**. Each winding group comprises substantially flat rectangular coils wound with conductors spirally disposed around the core leg **14**. The coils of the low voltage winding group **24** are separated from each other by the insulating washers **30**. The coils of the low voltage winding group **28** are separated from each other by the insulating washers **32**. The coils of the high voltage winding group **26** are separated from each other by the insulating washers **34**.

The conductors forming the coils may comprise one or more insulated strands or layers of strands. The strands may be transposed within the coil to reduce the effects of leakage flux. Interconnection between coils within a winding group, although not illustrated, may be made by alternate start-start and finish-finish conductor connections. Winding group leads are used for connecting each winding group to an external circuit and/or other winding groups. The leads **36** and **38** of the winding group **24**, the leads **40** and **42** of the winding group **26**, and the leads **44** and **46** of the winding group **28** are all used for connecting their respective winding groups to other groups or circuits.

The leads **38** and **44** are brazed together at position **50** to form a series connection **48** between the low voltage winding groups **24** and **28**. The conductors forming the series connection **48** are divided into at least two groups. Four groups are shown in FIG. **1** to illustrate the possible methods of dividing. The group **52** is brazed to the conductor group **54**, the conductor group **56** is brazed to the conductor group **58**, the conductor group **51** is brazed to the conductor group **53**, and the conductor group **55** is brazed to the conductor group **57**. Each conductor group may contain one or more conductor strands.

FIG. **1A** is a cross-sectional view of the series connection **48** at the area "A" in FIG. **1** and illustrates the division of the conductor strands to reduce the effects of both the horizontal and vertical components of the leakage flux. FIG. **1B** illustrates a division of the conductor strands which would be used to reduce the effects of the vertical component of the leakage flux. The conductor is divided into the conductor groups **59** and **61** and are brazed to similar conductor groups from the lead **44**. FIG. **1C** illustrates a division of the conductor strands which would be used to reduce the effects of the horizontal component of the leakage flux. The conductor is divided into the conductor groups **63** and **65** and are brazed to similar conductor groups from the lead **44**.

The conductors are bent as shown so that the conductor groups of the low voltage winding group **24** are electrically connected to the conductor groups of the low voltage winding group **28** which are at opposite radial and axial positions. This effectively provides a transposition of the conductor groups by the series connection **48**. The result is that the voltages which are developed in the conductor groups of each low voltage winding group due to the leakage flux oppose each other. This reduces the circulating currents, the heating of the winding, and the losses of the transformer.

Electrical connections for serially interconnected winding groups are illustrated in FIG. **2**. The coils **60**, **62**, **64** and **66** are shown moved to the side of each other for clarity. Physically, the coils would be aligned over each other. This can be visualized by moving the coil **62** to the left so that is is directly over the coil **60**, by moving the coil **64** so that it is directly over the coils **62** and **60**, and by moving the coil **66** so that it is directly over the coils **64**, **62** and **60**. The coils **60** and **62** are interconnected by the start-start connection **68**, the coils **64** and **66** are interconnected by the start-start connection **70**, and the coils **62** and **64** are interconnected by the finish-finish connection **72**.

The coils **60**, **62**, **64** and **66** are shown wound with the conductors **74**, **76**, **78** and **80**, respectively. Each conductor may comprise a plurality of insulated strands or layers of strands. The coils of FIG. **2** each have six strands. Although not illustrated, the coils may contain conductor strand transpositions. Methods for making the transpositions within the coils are described in U.S. Pat. No. 3,283,280, patented Nov. 1, 1966, and in pending application Ser. No. 876,769, filed Nov. 14, 1969, now U.S. Pat. No. 3,602,860, both being assigned to the same assignee as this invention. The coils **60**, **62**, **64** and **66** may comprise more than one coil turn. However, the single coil turn shown in FIG. **2** is sufficient to illustrate the invention.

The conductor strands **90**, **92**, **94**, **96**, **98** and **100** of the coil **60** are electrically connected at the braze position **102**, to which is connected a winding lead **104**. The conductor strands **106**, **108**, **110**, **112**, **114** and **116** of the coil **66** are electrically connected at the braze position **118**, to which is connected a winding lead **120**. The braze positions **122** and **124** electrically divide the conductor **74** into two conductor groups, **126** and **128**, respectively. The braze positions **130**, **132**, **134** and **136** electrically divide the conductor **76** into two conductor groups **138** and **140**. The braze positions **142**, **144**, **146** and **148** electrically divide the conductor **78** into two conductor groups, **150** and **152**. The braze positions **154** and **156** electrically divide the conductor **80** into two conductor groups, **154** and **156** respectively.

Ideally, conductor strand transpositions, such as described in U.S. Pat. No. 3,283,280, would eliminate the circulating currents due to one component of the leakage flux and the pattern of the remaining component would result in negligible losses. In reality, the transpositions cannot be placed at the ideal location for zero losses due to one component of the leakage flux and the pattern of the other component deviates considerably from the ideal case. Therefore, the voltages induced in the conductor groups **126** and **128** of the conductors **74** are not equal. A similar relation exists between the conductor groups **138** and **140** of the conductor **76**, the conductor groups **150** and **152** of the conductor **78**, and the conductor groups **154** and **156** of the conductor **80**. By transposing the finsh-finish connection **72**, as shown, the difference voltages substantially cancel each other.

FIG. **3** schematically represents the conductors of FIG. **2**. The conductor group **128** may, at an instant of time, have an induced voltage with an amplitude different than the voltage induced in the conductor group **126**. The difference is denoted by e_1 with the polarity as shown. At the same instant of time, similar voltages are induced in the conductor groups **138**, **150** and **160** and denoted as e_2, e_3 and e_4, respectively. Since e_1, e_2, e_3 and e_4 are substantially equal in amplitude, the reversal characteristic furnished by the finish-finish connection **72** causes the closed loop voltage to be approximately equal to zero. Thus, circulating currents between the conductor groups are effectively reduced.

FIG. 4 illustrates, in abbreviated form, an interconnection arrangement for coils having conductors comprising six strands or strand groups. The leads **162** and **164** are connected to the finish conductor turns of the coils **166** and **172**, respectively. The coils **166** and **168** are interconnected by the start-start connection **174** and the coils **170** and **172** are interconnected by the start-start connection **176**. The start-start connections **174** and **176** are made so that the conductor groups of adjacent coils are electrically connected to each other at the same radial position within the conductor. The finish-finish connection **178** interconnects the coils **168** and **170** so that the conductor groups are transposed.

FIG. 5 illustrates, in abbreviated form, an interconnection arrangement for coils having conductors comprising five strands or strand groups. The leads **180** and **182** are connected to the finish conductor turns of the coils **184** and **190**, respectively. The coils **184** and **186** are interconnected by the start-start connection **192** and the coils **188** and **190** are interconnected by the start-start connection **194**. The start-start connections **192** and **194** are made so that the conductor groups of adjacent coils are electrically connected to each other at the same radial position within the conductor. The finish-finish connection **196** interconnects the coils **186** and **188** so that the conductor groups are transposed.

FIG. 6 illustrates, in abbreviated form, an interconnection arrangement for coils having conductors comprising four strands or strand groups. The leads **198** and **200** are connected to the finish conductor turns of the coils **202** and **216**, respectively. The coils **202** and **204** are interconnected by the start-start connection **218**, the coils **206** and **208** are interconnected by the start-start connection **220**, the coils **210** and **212** are interconnected by the start-start connection **222**, and the coils **214** and **216** are interconnected by the start-start connection **224**. The start-start connections **218**, **220**, **222** and **224** are made so that the conductor groups of adjacent coils are electrically connected to each other at the same radial position within the conductor. The coils **204** and **206** are interconnected by the finish-finish connection **226** and the coils **212** and **214** are interconnected by the finish-finish connection **230**. The coils **208** and **210** are interconnected by the connection **228**, which may be either a finish-finish connection or a series connection. The connection **228** would be a finish-finish connection if the coils **202**, **204**, **206**, **208**, **210**, **212**, **214** and **216** are all contained within the same winding group. The connection **228** would be a series connection if the coils **208** and **210** are contained in different winding groups.

FIG. 7 is a simplified view of four coils which are interconnected as taught by this invention. All insulating members are eliminated from the figure to show the interconnections more clearly. For the same reason, the coils are shown having a larger separation distance than they would normally have in a power transformer winding.

The coil **232** is shown wound with four turns of the conductor **234**. The conductor is electrically divided into the conductor groups **236** and **238**. Each conductor group may contain more than one insulated strand. The coils **232** and **234** are interconnected by a start-start connection which is not shown in the figure. A similar start-start connection interconnects the coils **236** and **238**. The conductor groups **240** and **242** of the coil **234** are electrically connected to the conductor groups **244** and **246** of the coil **236** at the positions **248** and **250**. This finish-finish connection serially interconnects the four coils **232**, **234**, **236** and **238** and transposes the conductor groups according to this invention.

FIG. 8 is a plane view of an arrangement for making the finish-finish connection between adjacent coils. The conductor forming the upper coil **251** as shown in FIG. 8 consists of the insulated strands **252**, **254**, **256** and **258**. The conductor forming the lower coil consists of the strands **260**, **262**, **264** and **266**. The conductors are grouped into pairs and are brazed as pairs at the positions **268** and **270**. The strands which are near the braze positions are secured by a means such as the tie **272**. The spacer blocks **276** are attached to the insulating washer **274**, which is notched to make the interconnection of the conductor groups more convenient.

FIG. 9 is an elevational view of the interconnecting arrangement of FIG. 8. The conductor groups from the upper coil **251** and the lower coil **253** are bent and pulled toward each other and brazed at the positions **268** and **270**. Although not shown, the exposed braze positions **268** and **270** may be wrapped with an insulating material.

In summary, there has been described interconnection arrangements which may be used to reduce the circulation currents in a winding. This is accomplished by interconnecting the winding groups and/or the coils within a winding group so that the leakage flux induced voltages oppose each other.

We claim as our invention:

1. A power transformer comprising a shell-form type laminated magnetic core, a pancake-type winding structure disposed in inductive relationship with said laminated magnetic core, said winding structure having a plurality of winding groups which are physically separated by at least one other winding group, said separated winding groups each having first, second, third and fourth pancake-type coils, each of said coils having at least one conductor spirally wound for a plurality of coil turns, said conductor having a plurality of insulated strands, said insulated strands being grouped together to form a plurality of conductor groups with the conductor groups positioned at different radial positions in said conductor, each of said conductor groups having a plurality of insulated strands said conductor groups having said strands electrically connected together at the beginning position of the start turn of said coil and at the ending position of the finish turn of said coil, said second and third coils being electrically interconnected by a finish-finish connection, said first and second coils being electrically interconnected by a start-start connection, said third and fourth coils being electrically interconnected by a start-start connection, said finish-finish connection serially interconnecting said coils, said finish-finish connection electrically connecting together all of the conductor groups from said second coil to the conductor groups from said third coil which are at radially opposite positions within the conductors when the conductors have an even number of conductor groups, said finish-finish connection electrically connecting together all of the conductor groups from said second coil, except a middle conductor group, to the conductor groups from said third coil which are at radially opposite positions within the conductors when the conductors have an odd number of conductor groups, said start-start connections electrically connecting together all of the conductor groups from one coil to the conductor groups from the other coil which are radially at the same position within the conductors.

2. The power transformer of claim **1** wherein the winding groups are electrically interconnected by a series connection which electrically connects together conductor groups which are at radially opposite positions within the conductors of the winding groups.

3. The power transformer of claim 1 including an insulating washer which separates coils that are electrically interconnected by a finish-finish connection, said insulating washer having at least one notch therein, the conductor groups of the finish-finish connection extending through said notch with selected conductor groups being electrically connected together.

* * * * *