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Martincic et al.

[11] **3,708,875**

[45] **Jan. 9, 1973**

[54] **METHODS OF CONSTRUCTING ELECTRICAL INDUCTIVE APPARATUS**

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

[22] Filed: **Sept. 17, 1971**

[21] Appl. No.: **181,480**

Related U.S. Application Data

[62] Division of Ser. No. 12,704, Feb. 19, 1970, abandoned, which is a division of Ser. No. 815,035, April 10, 1969, Pat. No. 3,548,355.

[52] **U.S. Cl.** **29/605,** 29/602, 336/60, 336/185

[51] **Int. Cl.**.....**H01f 7/06**

[58] **Field of Search** 29/605, 602; 336/185, 60, 96, 336/223, 232

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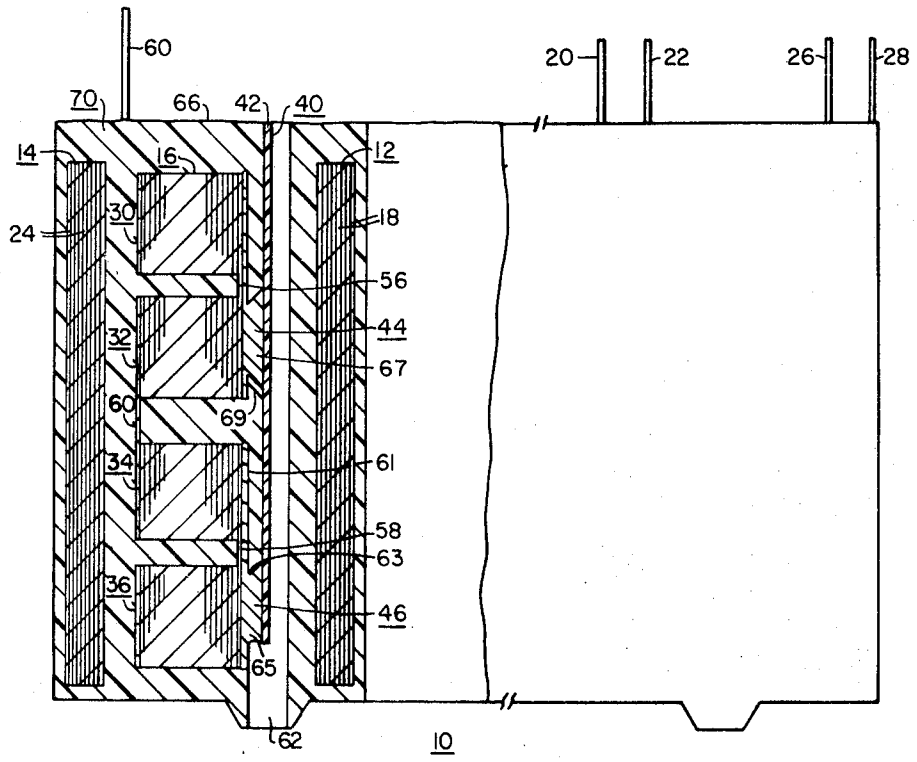
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Assistant Examiner—Carl E. Hall
Attorney—A. T. Stratton et al.

[57] **ABSTRACT**

Methods of constructing electrical inductive apparatus of the type having a plurality of electrical windings encapsulated in cast solid electrical insulation. At least one of the windings has a plurality of spaced electrically connected coil sections each formed of electrically conductive foil or strip, with the coil sections being fixed to metallic coil back plate members, which are supported on spaced insulating support members.

7 Claims, 20 Drawing Figures



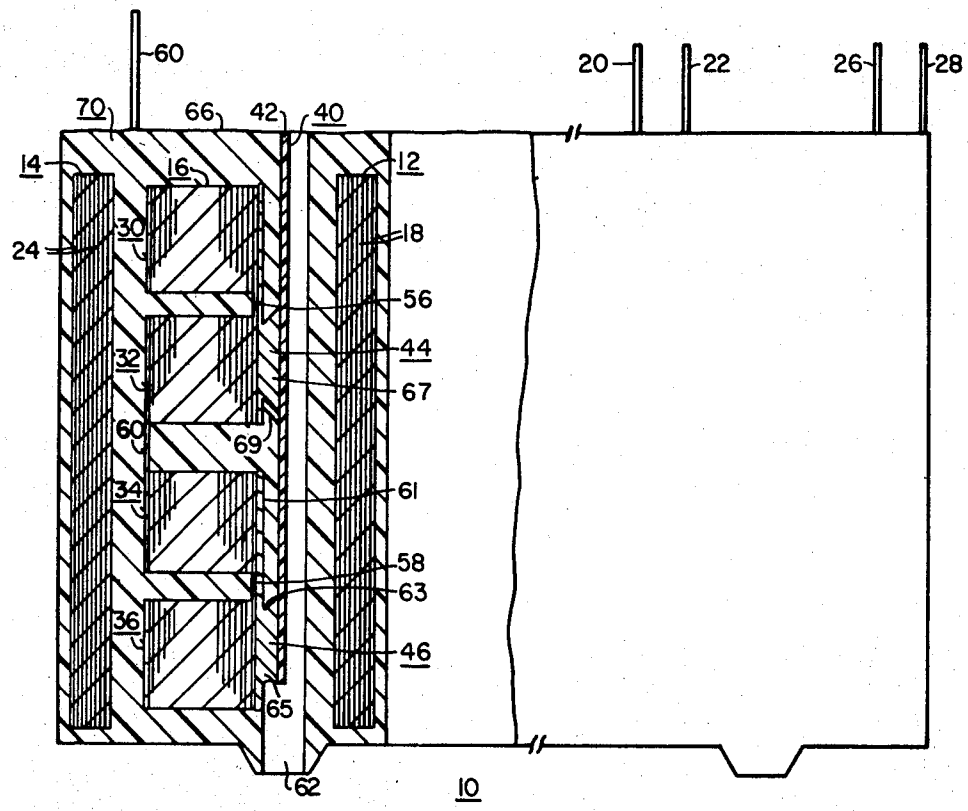


FIG.1

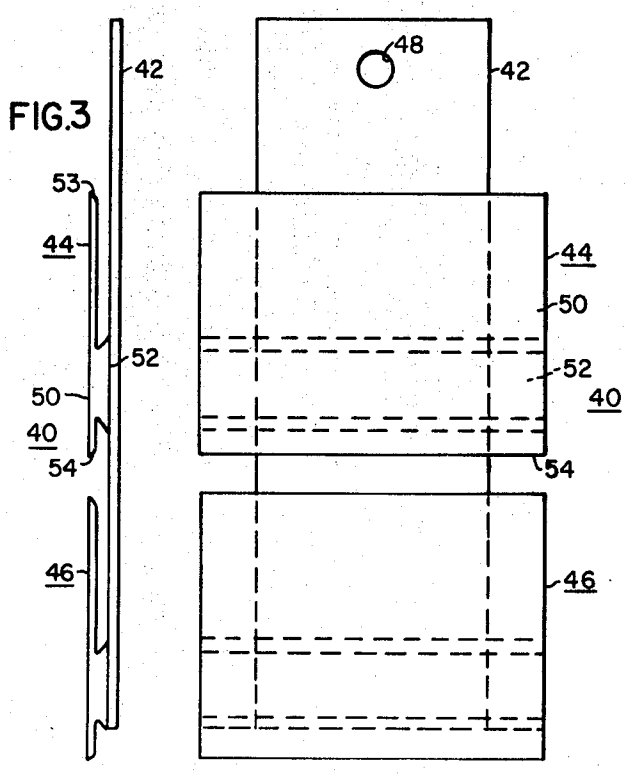


FIG.3

FIG.2

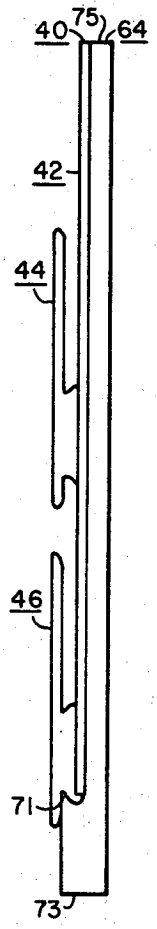


FIG. 5

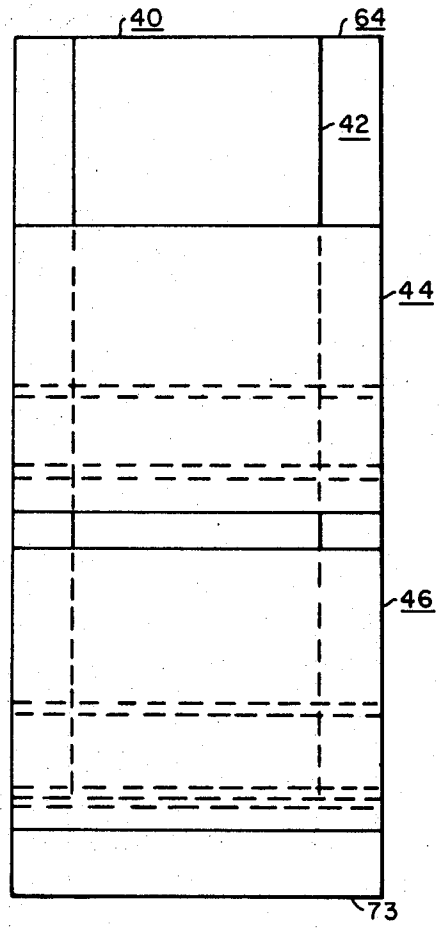


FIG.4

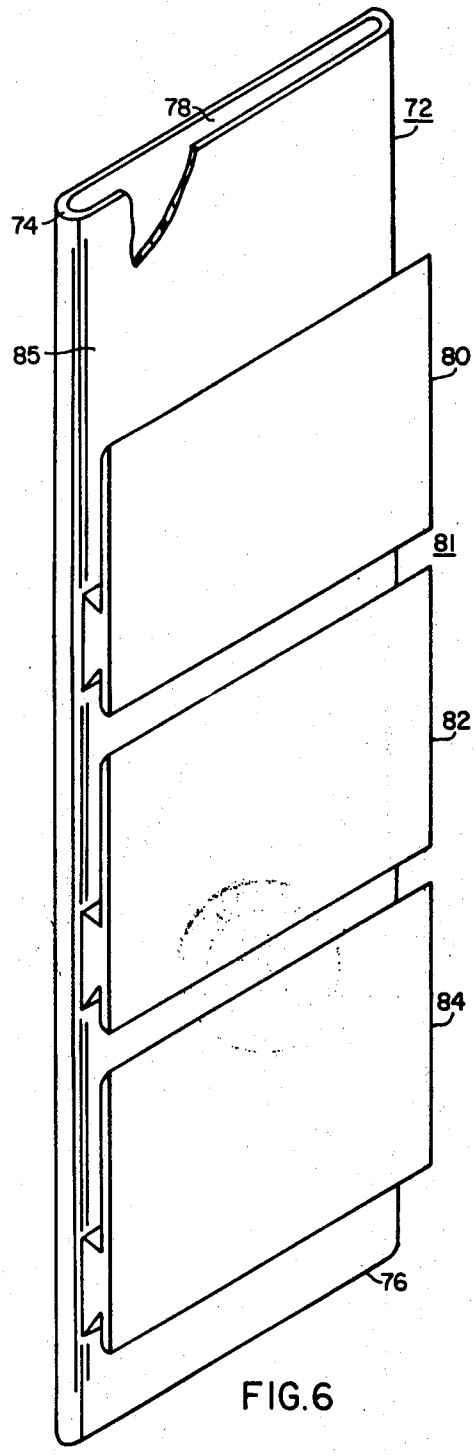


FIG.6

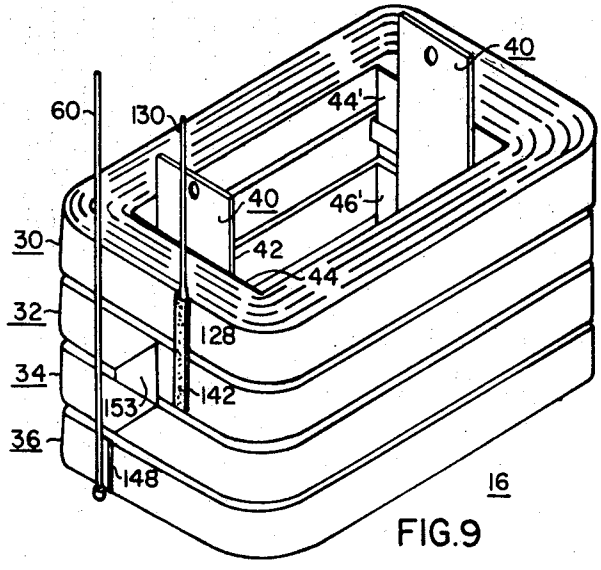


FIG.9

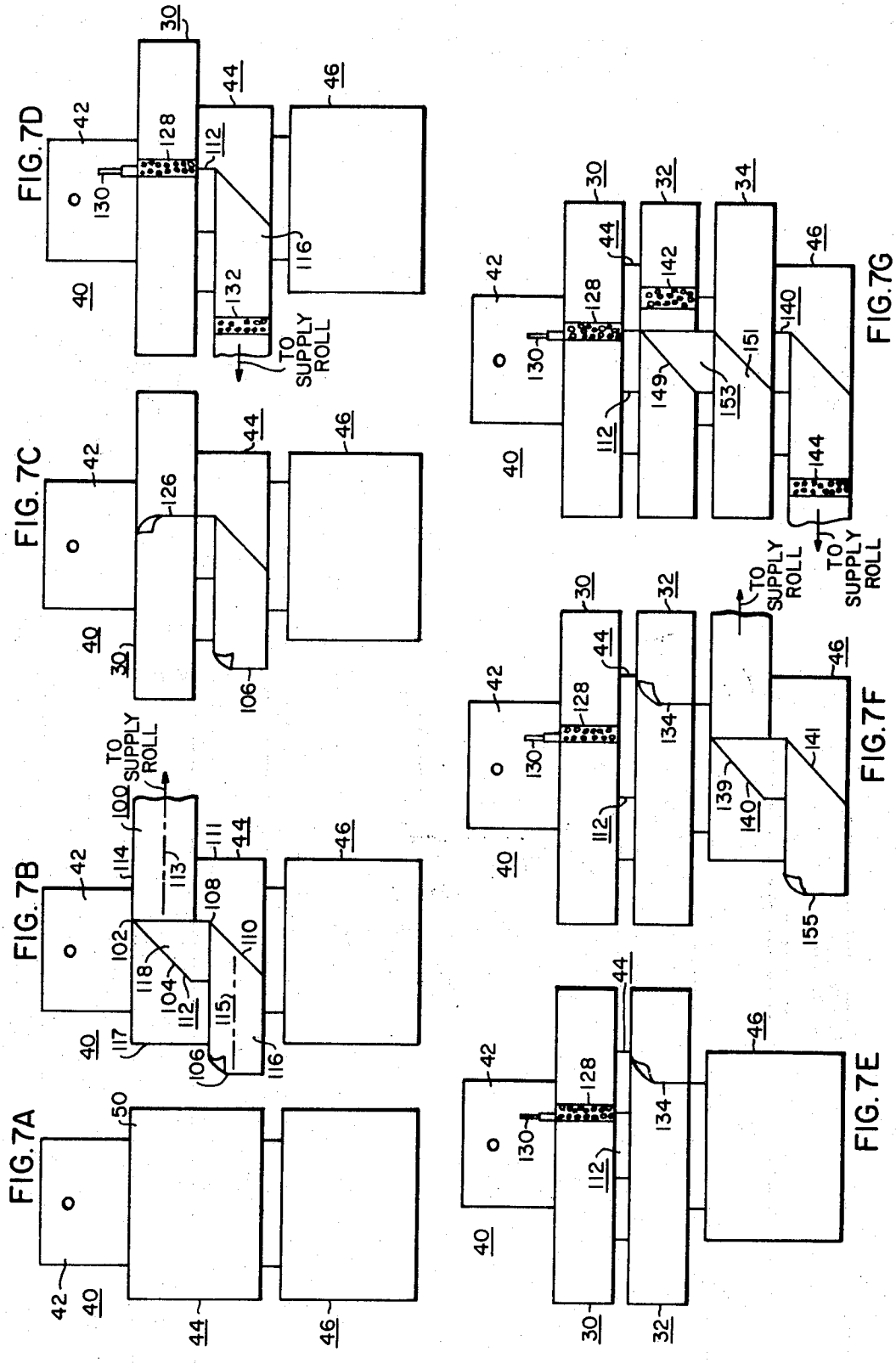

FIG. 7A
FIG. 7B
FIG. 7C
FIG. 7D
FIG. 7E
FIG. 7F
FIG. 7G
TO SUPPLY ROLL

FIG. 10

FIG. 7I

FIG. 7H

FIG. 8C

FIG. 8B

FIG. 8A

METHODS OF CONSTRUCTING ELECTRICAL INDUCTIVE APPARATUS

CROSS REFERENCE TO RELATED APPLICATION

This application is a division of application Ser. No. 12,704, filed Feb. 19, 1970, now abandoned, which was a division of application Ser. No. 815,035, filed Apr. 10, 1969, now U.S. Pat. No. 3,548,355.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to electrical inductive apparatus, such as transformers, and more specifically to new and improved methods of constructing winding assemblies therefor.

2. Description of the Prior Art

Castable solid electrical insulation systems, such as those of the epoxy type, provide superior insulation systems which may be used for encapsulating electrical windings, such as windings for electrical distribution transformers. Cast solid insulation has insulating qualities approximately 100 times better than air. Thus, the use of cast solid insulation systems to encapsulate transformer windings, allows the size of the transformers to be reduced, as the insulating clearances may be reduced. Solid insulation may fail by "puncture" through the body of the solid material, or by "creep" around the edges of the solid insulation. The resistance of most solid insulation systems to failure by puncture is far greater than their resistance to failure by creep, particularly if the creep path can be contaminated by moisture or conductive particles. Therefore, the electrical apparatus should be designed to stress the solid insulation primarily in puncture, with creep paths either being eliminated, or made sufficiently long.

Encapsulating windings with solid insulation, which are of the type having wire conductors, with many conductor turns per layer, creates problems due to the difficulty in uniformly impregnating the winding turns with viscous encapsulating material. Voids in the solid insulation about the winding turns, in addition to creating barriers to the flow of heat away from the windings, produce places for air to ionize under the high voltage stresses present, causing corona discharges with their accompanying radio interference and degradation of the insulation. Wire-type conductors also provide a poor space factor. Thus, in order to solve these problems, the electrical windings which are to be encapsulated are usually constructed of electrically conductive metallic foil or strip material. Metallic strip or foil provides an excellent space factor, and eliminates high layer-to-layer stress and special layer insulation. With strip or foil type windings, each coil is formed of a plurality of radially superposed turns, with the foil or strip usually having a thin layer of insulating enamel on one or both of its major sides, which provides the turn-to-turn insulation required for the relatively low turn-to-turn stresses. Since there is only one turn per layer, and the turn-to-turn stresses are low, air entrapment between the turns is not a serious problem.

Problems arise in transformer design when using foil or strip type conductor, which makes it desirable to construct at least the high voltage winding with a plurality of axially spaced, electrically connected coil sections. The high and low voltage windings of a selected transformer rating each require a certain amount of

conductor material. The low voltage windings, having a higher magnitude of current flowing therein, may use fairly thick conductive strip material, such as 32-mil aluminum strip having a width of 6.5 inches. Since the insulating coating on the strip is only about one-half mil per side, the conductor to insulation ratio is high, resulting in good space factor. The high voltage winding, however, requires much less volume of conductive material. For example, if foil having the same width as the strip of which the low voltage coils are wound, is used for the high voltage coil, the foil thickness required may be a mil or less. It is undesirable, however, to utilize such thin foil because it is difficult to handle and wind. Further, the ½-mil coating of insulation on each side of the foil becomes a major portion of the total winding volume, resulting in a very poor space factor, and the large amount of insulation compared to active conductor volume impedes heat transfer from the winding turns.

Thus, economies in space and cost may be realized by constructing the high voltage winding with axially spaced electrically connected coil sections or "part coils". This practice decreases the width of the foil used for each part coil, and the sum of the widths of all of the part coils is less than the width of the low voltage coils, thus increasing the thickness of the foil required for each part coil to a more practical value. An example of such construction is disclosed in U.S. Pat. No. 3,537,677, which is assigned to the same assignee as the present application. This patent discloses a high voltage winding having two spaced coil sections, which are insulatingly fixed to metallic cooling ducts, with the "starts" or inner ends of the inner turns of the coils being electrically connected to connect the two part coils in series, and provide substantially no difference in potential between the inner turns of the two coils.

In some instances, however, a better space factor may be obtained, and also a more favorable electrical impedance, by constructing the high voltage winding with more than two part coils. The construction disclosed in the hereinbefore mentioned U.S. Pat. No. 3,537,677, while suitable for two part coils, does not lend itself to three or more part coils, as there would then be a substantial voltage difference between the inner or start turns of certain adjacent coils, which may cause failure of the winding assembly due to creep across the surface of the solid insulation disposed between the two coils which is in contact with the metallic duct.

Therefore, it would be desirable to be able to take advantage of the improved space factor and impedance obtainable by the use of three or more part coils, if these advantages may be obtained without encountering excessive corona and construction problems. Further, since the plurality of part coils must be electrically connected, it would be desirable to be able to wind and interconnect the coils with a new and improved method which will reduce the time for manufacturing the coils, and therefore their cost.

SUMMARY OF THE INVENTION

Briefly, the present invention includes new and improved methods of constructing electrical inductive apparatus of the encapsulated type, wherein a plurality of electrical windings are disposed in concentric adjacent

relation. At least one of the windings has a plurality of axially spaced, electrically connected coil sections, each having a plurality of radially superposed turns formed of electrically conductive strip or foil. The coil sections, or part coils, are connected with successive start-start, finish-finish connections. For example, the ends of the inner turns of the first two coils are electrically interconnected, which is called a start-start connection, and the ends of the outer turns of the second and third coils are electrically interconnected, which is called a finish-finish connection. This sequence is repeated across the axially spaced coils, until all of the coils are serially connected.

The plurality of part coils are held in assembled relation by metallic coil back plates, and the metallic coil back plates are fixed to two spaced insulating support members. Electrical coils which are connected by start-start interconnections may be fixed to a common metallic coil back plate on each insulating support member, while the coils which are interconnected by finish-finish connections are fixed to different spaced metallic coil back plates. The metallic coil back plates have a cross sectional configuration which allows the coils fixed to adjacent metallic back plates, interconnected with the finish-finish connections, to be closely axially spaced, while still providing a long creep path between them.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages and uses of the invention will become more apparent when considered in view of the following detailed description of exemplary embodiments thereof, taken in connection with the accompanying drawings, in which:

FIG. **1** is an elevational view, partially in section, of encapsulated electrical inductive apparatus which may be constructed according to the teachings of the invention;

FIG. **2** is an elevational view of a coil support structure for use with windings which have a plurality of part coils, which may be constructed according to the teachings of the invention;

FIG. **3** is a side elevational view of the coil support structure shown in FIG. **2**;

FIG. **4** is an elevational view of the coil support structure shown in FIG. **2**, modified to include a removable duct former;

FIG. **5** is a side elevational view of the coil support structure and removable duct former shown in FIG. **4**;

FIG. **6** is a perspective view of a coil support structure which includes a permanent duct former incorporated as part of the support assembly;

FIGS. **7A** through **7I** illustrate steps in a method of constructing a winding according to the teachings of the invention, which has a plurality of axially spaced start-start, finish-finish connected part coils;

FIGS. **8A** through **8C** illustrate alternate steps which may be used in constructing a winding according to the teachings of the invention, which has a plurality of axially spaced electrically connected part coils;

FIG. **9** is a perspective view of the winding shown in FIG. **7I**, and

FIG. **10** illustrates another method which may be used to form intercoil connections.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, and FIG. **1** in particular, there is shown an elevational view, partially in section, of a transformer **10** which may be constructed according to the teachings of the invention. Transformer **10**, in this instance, includes inner and outer low voltage coils **12** and **14**, respectively, and a high voltage winding assembly **16**. The inner and outer low voltage windings **12** and **14** and high voltage winding assembly **16**, are all disposed in concentric, adjacent relation about a common center line, with the high voltage winding assembly **16** encircling the inner low voltage winding **12**, and with the outer low voltage winding assembly **12** encircling the high voltage winding assembly **16**. The inner low voltage winding assembly **12**, may be constructed of a plurality of radially superposed turns **18** of conductive strip material, such as copper or aluminum, which has a coating of electrical insulating material on at least one of its major sides, or which has a separate sheet of insulating material, such as a polyester film, bifilarly wound with the conductive strip material at the time the coil **12** is wound. The inner low voltage coil **12** has electrical leads or terminals **20** and **22** connected to its inner and outer ends, respectively.

In like manner, the outer low voltage coil **14** may be constructed of a plurality of radially superposed conductor turns **24**, formed of a sheet or strip of electrically conductive material, with the inner and outer ends of coil **14** being connected to terminals **26** and **28**, respectively.

The high voltage winding assembly **16** has a special construction, wherein the winding, in this instance, has four axially spaced coil sections or part coils, **30**, **32**, **34** and **36**. The part coils are supported on a special support structure or assembly, disposed at predetermined opposite ends of transformer **10**, such as the support assembly **40** shown in FIG. **1**. Since the support assembly at each predetermined end of transformer **10** is similar in construction, and since a cross-sectional view of transformer **10** on each side of the opening for receiving a magnetic core would be similar, transformer **10** is sectioned only at one end thereof. When describing the construction of the support assembly **40** shown in FIG. **1**, FIGS. **2** and **3** will also be referred to, which illustrate front and side elevational views, respectively, of support assembly **40**.

In general, support assembly **40** includes an upstanding insulating plate or support member **42**, which may be made of any suitable insulating material, such as a glass polyester, and a plurality of metallic coil back plate members **44** and **46**, with the number of metallic coil back plate members used depending upon the number of part coils utilized in the transformer.

The insulating plate member **42** has an opening **48** disposed near the top thereof, which, along with a similar opening in the other support assembly, provides means for receiving a shaft which facilitates handling of the completed assembly, as well as means for supporting and locating the winding assembly in a mold.

The metallic coil back plate members have a unique cross-sectional configuration which enables a plurality of coil sections to be closely axially spaced, taking advantage of the excellent strength of solid insulation, in puncture, in which the coils will be subsequently en-

capsulated, while still providing generous creep distances.

More specifically, as shown most clearly in FIG. 3, each of the metallic coil back plate members, such as coil back plate member **44**, has first and second parallel opposed sides **50** and **52**, in which the area of the first major side **50** is much larger than the area of the second major side **52**. The second surface or side **52** provides the base for the coil back plate, which is secured to the insulating support member **42**, such as by a pressure sensitive thermosetting adhesive, and the first surface or side **50** provides a surface which cooperates with a surface on a similarly disposed coil back plate member on the other support assembly, to hold one or two of the part coils. The second surface **52** may extend across the complete width W of the back plate, but it extends only partially across the height dimension H thereof, preferably starting near the lower edge **54** as shown, and extending about midway across the height dimension. In other words, the coil back plate members are relatively thin adjacent most of the first surface **50**, and they may be thought of as being formed of a thin plate-like member of which the first major surface **50** forms one side thereof, and having a trapezoidal shaped bar-like member attached to the other side thereof, with the large base of the trapezoid forming the second surface **52**.

The coil back plate members may be conveniently constructed by extruding a member, such as of aluminum, which has a cross-sectional configuration as illustrated in FIG. 3, and then cutting the extruded member at predetermined measured locations along its length, to provide the desired number of back plate members. In manufacturing the high voltage winding assembly **16**, a support assembly, such as support assembly **40** shown in FIG. 1, is disposed at each end of a winding mandrel, such as in the manner disclosed in U.S. Pat. No. 3,454,237, which is assigned to the same assignee as the present application, with the part coils being wound on the first surfaces **50** of the coil back plate members. One coil back plate member may be provided for each of the part coils, or as illustrated in FIG. 1, alternate pairs of part coils may be connected with start-start connections, which enables these pairs of coils to be disposed on a common coil back plate at each predetermined end of the transformer **10**. Thus, an external terminal would be connected to the outer turn of the first coil section **30**, and the circuit would then spiral inwardly in a predetermined circumferential direction until reaching the inner turn, the end of which is connected via conductor **56** to the end of the inner turn of the next adjacent coil section **32**. Thus, there will be no potential difference between the inner turns of part coils **30** and **32** and they may be conveniently disposed on the same coil back plate member **44**. A thin sheet of electrical insulation may be disposed, such as by a suitable adhesive, on the first surface **50**, which, in addition to the enamel disposed on the electrically conductive strip material, will insulate the coils from the metallic back plate members. The coils may be held in position on the first major surface **50** by a pressure sensitive thermosetting adhesive. Since the electrical circuit will spiral outwardly in part coil **32**, instead of inwardly, it should be wound in a circumferential direction opposite to that of which part coil **30** was wound, in order to provide a magnetomotive force which will be additive to that provided by a part coil **30**. The part coils **34** and **36** may be constructed in a manner similar to part coils **30** and **32**, having their inner turns electrically interconnected by a conductor **58**, with these part coils being disposed on coil back plate member **46**. The ends of the outer turns of part coils **32** and **34** are electrically interconnected by a conductor **60**, which completes the series connection of the plurality of part coils. The end of the outer turn of part coil **36** is connected to an external electrical terminal **60**, thus providing a complete series circuit between the end of the outer turn of part coil **30** and the end of the outer turn of part coil **36**, with the electrical circuit from one terminal to the other traversing each of the part coils in the same circumferential direction.

The coil back plate members **44** and **46** are oriented in a similar manner and fixed to the insulating support member **42** in spaced relation, such that part coils **32** and **34** are disposed in relatively close spaced relation. The inner turns of part coils **32** and **34** are at different electrical potentials, but they may be spaced fairly close together due to the excellent insulating qualities of cast solid insulation material in puncture. It should be noted, however, that even though the coils are closely spaced, that due to the cross-sectional configuration of the coil back plate members, that there is a very long creep path between the inner turns of part coils **32** and **34**. In order for the voltage to flashover between the inside turns of part coils **32** and **34** over the surface of the cast solid insulation, a path would have to be established which includes the inner surface **61** of the thin portion of the back plate member **46**, which is adjacent the outer surface **50**, it would have to proceed all the way to the junction **63** of the trapezoidal portion **65** of back plate member **46** with the thin section, and then proceed along the interface between the solid insulation and the insulating plate member **42** until reaching the trapezoidal portion **67** of back plate member **44**, and then proceed along the side of the trapezoid to the junction **69** between the thin section and the trapezoidal section of the back plate member, until reaching the inner turn of coil **32**.

In addition to supporting the part coils during manufacturing and assembly thereof, the support structure **40**, with its metallic coil back plates, also has the function of providing corona shielding means for the high-low space between the high voltage winding **16** and the inner low voltage winding **18**, and any cooling ducts which may be disposed through that high-low space, such as cooling duct **62**. If the support assembly **40**, including the insulating plate member **42** and the coil back plate members **44** and **46** were to be constructed of an insulating material, in the shape or configuration illustrated in FIG. 1, it would still be necessary to provide a conductive surface at the location of surface **50**, in order to provide this corona shield.

Certain transformer constructions require cooling ducts, while others do not. In those instances where a cooling duct is not required, it is only necessary to dispose the high and low voltage coil assemblies in adjacent concentric relation, within a suitable mold, and introduce the cast insulation system, which is gelled and cured to a solid, such as the solid insulation **70**

shown in FIG. 1. In those instances where a cooling duct or ducts are required through the solid insulating material 70, they may be provided by disposing the supporting structures 40 on a tapered removable metallic duct forming member, such as the duct former 64 shown in FIGS. 4 and 5. FIGS. 4 and 5 are front and side elevational views, respectively, of the support structure 40 shown in FIGS. 2 and 3, modified to include the removable duct former 64. The removable duct former 64 has a suitable mold release material disposed thereon, such as polytetrafluoroethylene, and is driven out of the cast transformer assembly after the winding assemblies have been encapsulated with a solid insulation system. Thus, as illustrated in FIGS. 4 and 5, the lower coil back plate member 46 may have its trapezoidal portion 65 resting on a step 71 formed on the lower end of duct former 64. The lower end 73 of duct former 64 will rest on the mold, and its upper end 75 will extend above the upper surface 66 of the cast solid insulation 70. Thus, after the windings are encapsulated, and the solid insulation is gelled and cured, the tapered duct former 64 may be driven from its assembled location by force applied to end 75, which provides a duct 62 through the solid insulation 70. The upper end of the insulating plate member 42 will also extend above the upper surface 66 of the solid insulation 70, and is cut flush with surface 66, after the solid insulation 70 is cured, as illustrated in FIG. 1.

The solid insulation 70 which is used to encapsulate the electrical windings of the transformer 10 may be of any suitable formulation which will be highly resistant to cracks which has a high mechanical strength, both at the low and elevated temperatures to which the transformer 10 may be subjected, and which is impervious to attack from insulating fluids which may be used to cool the transformer. Examples of suitable encapsulating materials which may be used are disclosed in U.S. Pat. Nos. 3,434,087, 3,493,531 and 3,547,871, which are assigned to the same assignee as the present application. In general, encapsulating resins of the epoxy type, having a filler selected to enable the cast resin system to closely match the coefficient of thermal expansion of the windings embedded therein, have been found to be very successful.

As hereinbefore stated, certain applications for distribution transformers require that ducts be disposed through the solid insulation for facilitating the removal of heat from the transformer windings. While the method of using a removable duct former has been found to be satisfactory for transformers in which the duct length is in the order of 8 to 10 inches, the removal of a duct former when the duct length exceeds these dimensions becomes extremely difficult. Therefore, instead of utilizing a removable duct former, in certain applications it may be desirable to utilize a preformed insulating duct former, to which the metallic coil back plate members may be secured. A coil support arrangement 81 having an integral, permanent duct forming member, constructed according to another embodiment of the invention, is illustrated in FIG. 6. FIG. 6 is a perspective view which illustrates a continuous duct forming member 72 which may be formed of a glass polyester, or other suitable insulating material. Duct forming member 72 has first and second major outer sides, such as side 85, first and second ends 74 and 76, respectively, and an opening 78 which extends between its ends. The dimension of duct former 72 between its first and second ends 74 and 76 is selected such that the duct forming member 72 will extend slightly above the upper surface of the solid insulation after it has been cured. A plurality of metallic coil backup plates 80, 82 and 84 may be disposed in spaced relation across one of the major sides, such as side 85, of the duct former 72, and secured thereto, such as with a pressure sensitive, thermosetting adhesive. The configuration and design of these metallic coil back plate members may be the same as hereinbefore described relative to the embodiment of the invention shown in FIGS. 1, 2 and 3.

Before the encapsulation of the windings, the openings at the ends 74 and 76 of the duct forming member 72 are sealed with a high temperature tape, the high voltage part coils are wound on the major outer surfaces of metallic coil back plates, after fixing a suitable sheet of insulation to these surfaces, and a thermosetting adhesive is disposed between the duct former 72 and the coil back plates 80, 82 and 84 which is cured when the part coils are heated while still on the winding mandrel, to consolidate their turns. The consolidation of the turns of a coil formed of electrically conductive sheet or strip material, is disclosed in U.S. Pat. No. 3,555,670, which application is assigned to the same assignee as the present application. After the electrical coils of the transformer are encapsulated with solid insulation and the solid insulation is gelled, the portion of the duct former 72 which extends above the upper surface of the cast portion of the transformer may be cut flush therewith, and the tape removed from the bottom end 76 of the duct former 72.

The construction of the high voltage winding 16 shown in FIG. 1, wherein two coils are fixed to a common coil back plate member, requires that the coils be interconnected with successive start-start, finish-finish connections. In other words, the first pair of coils have the ends of their inner turns electrically interconnected, and the next pair of coils have the ends of their outer turns electrically interconnected. Thus, alternate pairs of coils are electrically interconnected with start-start connections, and the remaining pairs of coils are electrically interconnected with finish-finish connections. It should be noted that the start of a coil is the end of its inner turn, regardless of where the electrical circuit first enters the coil.

The electrical interconnection between the part coils of the high voltage winding assembly 16 are difficult to make, using conventional techniques. FIGS. 7A through 7I illustrate the steps in manufacturing a high voltage winding, such as high voltage winding assembly 16, in which the making of the interconnections between the part coils is greatly facilitated, reducing the time and therefore the cost involved in the manufacture of such part coil windings. Specifically, FIG. 7A is an elevational view of the support assembly 40 shown in FIG. 1, with a similar support assembly being disposed in spaced relation directly in back of it. As hereinbefore stated, the support assemblies are connected to opposite ends of a winding mandrel. The major surfaces 50 of the metallic coil back plate members 44 and 46 are covered with a thin sheet of electrical insulation, which may be fixed thereto with a pres-

sure sensitive, thermosetting adhesive, and the outer surface of the thin sheet of insulation may also have a thin coating of pressure sensitive, thermosetting adhesive disposed thereon.

The next step in the construction of winding **16** is to form a start-start connection **112** between the first two coils **30** and **32**. This may be accomplished by providing a preformed Z shaped piece, but this requires two crimp type connectors. It would be preferable to eliminate one or both of these connectors. One of the connectors may be eliminated, as illustrated in FIG. 7B, by folding the foil or strip material of which the coils are to be wound at first and second spaced points near the end of the roll of foil material, and disposing the resulting interconnection **112** against the pressure sensitive adhesive on back plate member **44**. The foil **100**, from which the first part coil **30** is to be wound, is folded at a first point **102**, perpendicular to the sides or edges of the foil **100**, which provides a diagonal fold **104**, and the foil **100** is folded at a point between fold **104** and the end **106** of the foil, such as at point **108**, with the fold again being made perpendicular to the sides of the foil, which provides a diagonal fold **110**. As illustrated in FIG. 7B, the two spaced folds **104** and **110** should be made in a direction which will continue the original direction of the foil. In other words, the start-start interconnection, shown generally at **112** has a substantially Z configuration, or a backward Z configuration, with the folds **104** and **110** being parallel with one another. The foil **100** enters one side of the back plate member, such as side **111**, it is then offset from its original axial location, indicated by broken line **113**, into a second axial location indicated by broken line **115**, and it then proceeds away from the coil back plate member **44** on the opposite side **117** thereof. The start-start interconnection **112** thus has two parallel portions **114** and **116** and a perpendicular interconnecting portion **118**. The supply roll of electrically conductive foil is integrally connected to portion **114**, eliminating a connector between the interconnection **112** and the first part coil. As illustrated in FIG. 7C, the first part coil or coil section **30** may then bewound from the supply roll with the edges of the radially superposed turns of coil section **30** being aligned with the edges of the first section **114** of the start-start connection **112**. After the requisite number of conductor turns has been obtained for part coil **30**, the foil is severed to provide an end **126**, to which a terminal **128** may be connected, as illustrated in FIG. 7D. Terminal **128** may be a crimp type terminal which has a plurality of sharp tangs which bite into the foil **100** and penetrate any coating of enamel or electrical insulation disposed on the foil, when the terminal is crimped on the foil. A wire **130** may be fixed to terminal **128** which will extend outwardly from the transformer and provide a terminal for making an electrical connection to the high voltage winding assembly **16**.

As illustrated in FIG. 7D, the end of the supply roll is now connected to the end **106** of portion **116** of the start-start connection **112**, such as with a crimp type connector **132**, and the second coil section **32** is wound, in a circumferential direction which is opposite to that of the first coil section **30**. After the required number of turns have been achieved in part coil **32**, the foil is severed to provided an outer end **134**. Instead of folding the foil from the supply roll to form a Z shaped connector, it may also be prepared with a single fold, such as fold **104**, such that the end of the foil coincides with the bottom edge of coil back up plate **44**. The end of the supply roll of which part coil **32** is wound may then be connected to this L shaped interconnection with a crimp type connector. This embodiment of the invention is illustrated in FIG. **10**, which shows an L shaped interconnection **112'** formed with a single fold **104'**. The connection of the foil used to start part coil **32** is illustrated in phantom, using a crimp type connector **132'**.

The next steps are to wind part coils **34** and **36**, and they may be wound in a manner similar to part coils **30** and **32**. As shown in FIG. 7F, a start-start connection **140** is provided, having spaced parallel folds **139** and **141**, similar to the start-start connection **112** shown in FIG. 7B, with start-start connection **140** being fixed to coil back plate member **46**. The third coil section **34** is then wound in the same circumferential direction as part coil **30**. After completing the outer turn of part coil **34**, as illustrated in FIG. 7G, the outer end of the foil may be folded twice on spaced parallel fold lines **149** and **151**, to form Z shaped finish-finish connection **153**, the extreme end of which is connected to the end **134** of part coil 32 with a crimp type connector **142**. Alternatively, the outer turn of part coil **34** may be severed in a conventional manner, with the outer turn of part coil **32** being constructed to provide enough material to allow it to be folded twice into a Z shaped finish-finish connection, in which event the pressure type connector **142** would be aligned with part coil **34**. Or, a preformed Z shaped piece may be used, which is connected to the ends of both coils with crimp type connectors. The next step is to connect the end of the supply roll to the free end **155** of the start-start connection **140**, such as with a crimp type connector **144**, and wind part coil **36** as shown in FIG. 7H. The end **146** of the outer turn of coil **36** may then be connected to a crimp type terminal **148** as shown in FIG. 7I, which has a wire **60** attached thereto having a length sufficient to extend above the surface of the cast solid insulation, to provide the other external connection to the high voltage winding assembly **16**. FIG. **9** is a perspective view of the high voltage winding assembly **16** as completed in FIG. 7I, which more clearly illustrates the construction of the winding assembly with its two spaced support structures **40** and **40'**.

Two of the crimp type terminals required in the method illustrated in FIGS. 7A through 7I may be eliminated if the foil is obtained in two connected rolls. The method of constructing the part coils according to this embodiment of the invention is illustrated in FIGS. **8A** through **8C**. FIG. **8A** illustrates the forming of a start-start connection **160**, similar to the start-start connection **112** shown in FIG. 7B, except that it is formed with the portion of the foil which interconnects the two supply rolls. The second supply roll may be secured to the winding mandrel and the first coil section **30** wound from the first supply roll to provide the first coil section **30**, as shown in FIG. **8B**. The winding direction of the mandrel may be then reversed and the second coil section **32** wound from the second supply roll, to provide coil section **32** as shown in FIG. **8C**. Coil sections **34** and **36** may then be formed in a similar manner, with

the outer end of coil section 32 or coil section 34, being folded twice as illustrated in FIG. 7G, to form the finish-finish connection between the part coils 32 and 34.

In summary, there has been disclosed new and improved encapsulated inductive apparatus which facilitates the manufacturing of high voltage windings having a plurality of axially spaced part coils. The disclosed construction is arranged to stress the solid encapsulating resin primarily in puncture, with the creep paths between adjacent coils being long compared with the close axial spacing of the coils. The disclosed construction is not limited to two axially spaced part coils, but may be extended to any number of coil sections. Also disclosed are new and improved constructions for obtaining cooling ducts through the solid insulation. New and improved methods of winding the part coils, with start-start, finish-finish connections are also disclosed, which greatly facilitate the manufacturing of these types of winding assemblies, which reduces the manufacturing time and the cost of such assemblies.

We claim as our invention:

1. A method of constructing an electrical winding assembly, comprising the steps of:

providing first and second spaced insulating support members,

attaching first and second metallic members to the first insulating support member,

attaching third and fourth metallic members to the second insulating support member,

winding first and second electrical coils of electrically conductive strip material about the first and third metallic members, respectively, with the first and second coils being wound in opposite circumferential directions, to provide a plurality of radially superposed turns in each,

electrically connecting the ends of the innermost turns of the first and second electrical coils,

winding third and fourth electrical coils of electrically conductive strip material about the second and fourth metallic members, respectively, in the circumferential directions of the first and second electrical coils, respectively, to provide a plurality of radially superposed turns in each,

electrically connecting the ends of the innermost turns of the third and fourth electrical coils, and

electrically connecting the ends of the outermost turns of the second and third coils.

2. The method of claim 1 including the step of encapsulating the first, second, third and fourth electrical coils in cast solid insulation.

3. The method of claim 2 including the step of providing cooling ducts through the cast solid insulation.

4. The method of claim 3 wherein the step of providing cooling ducts in the cast solid insulation includes the steps of mounting the first and second insulating support members on first and second duct forming members, respectively, and removing the first and second duct forming members following the encapsulating step.

5. The method of claim 3 wherein the step of providing cooling ducts through the cast solid insulation includes the step of providing the first and second insulating members with openings which extend between their ends.

6. The method of claim 1 wherein the steps of electrically connecting the innermost turns of the first and second electrical coils, and the innermost turns of the third and fourth electrical coils, include the steps of folding the strip material of which the first and third coils are formed, prior to the winding steps, to provide substantially Z shaped start-start connections, with the free ends of the Z shaped start-start connections being connected to the innermost turns of the second and fourth electrical coils, respectively.

7. The method of claim 1 wherein the steps of electrically connecting the outermost turns of the second and third electrical coils includes the steps of folding the strip material of which one of the coils is formed to provide a substantially Z shaped finish-finish connection, and connecting the free end of the Z shaped finish-finish connection to the end of the outermost turn of the other of the coils.

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