Dec. 15, 1970 R. L. PECKHAM 3,548,357

ENCAPSULATED ELECTRICAL INDUCTIVE APPARATUS

Filed May 13, 1969 2 Sheets-Sheet 1

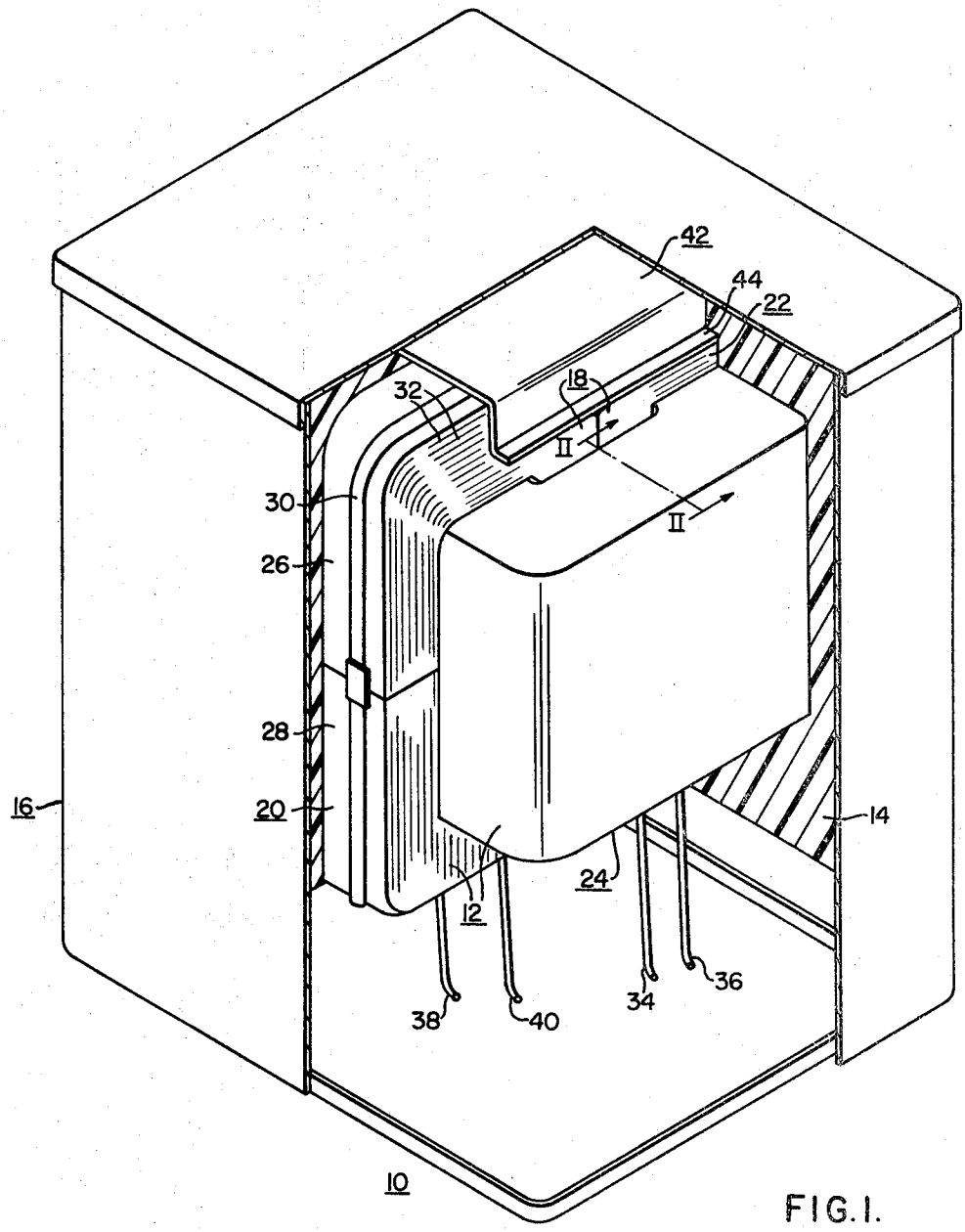


FIG. I.

WITNESSES

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Filed May 13, 1969 2 Sheets-Sheet 2

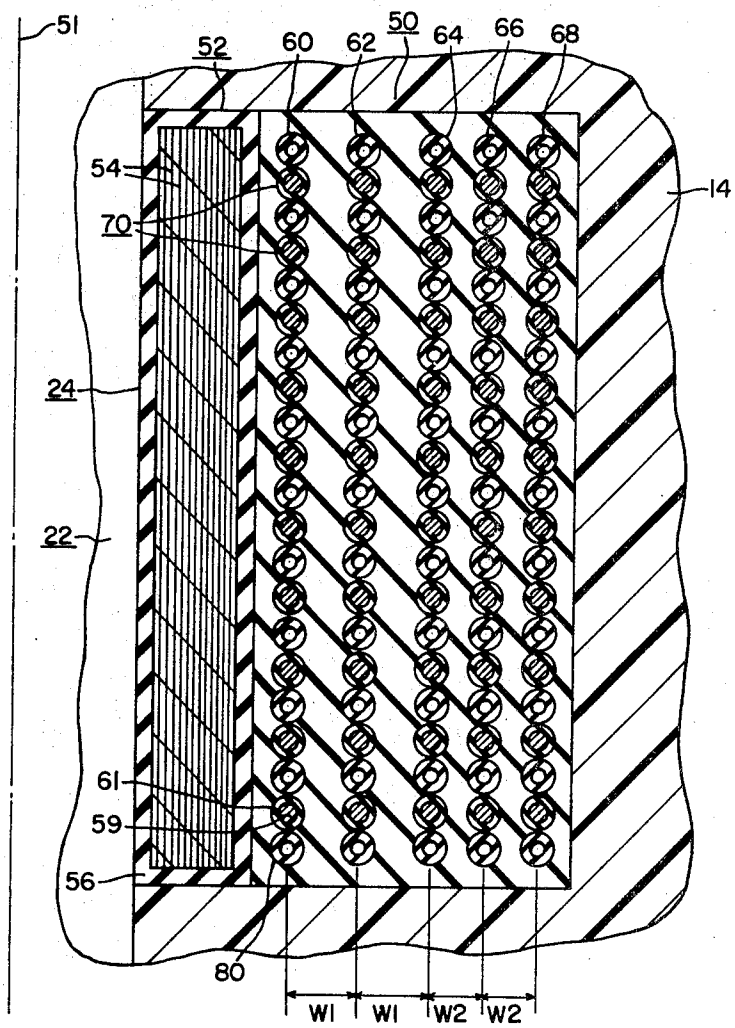


FIG. 2.

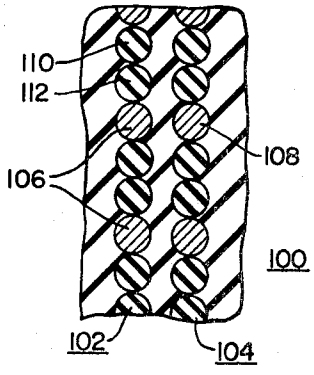


FIG. 3.

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ENCAPSULATED ELECTRICAL INDUCTIVE APPARATUS

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U.S. Cl. 336—205 7 Claims

ABSTRACT OF THE DISCLOSURE

Encapsulated electrical apparatus wherein at least one electrical winding has a plurality of radially superposed layers of conductor turns. The turn-to-turn insulation in at least certain of the layers is at least partially provided by a discrete continuous insulating filament, solid or tubular, which separates the conductor turns of those layers.

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 transformers of the type which are encapsulated in a cast solid resinous insulation system.

(2) Description of the prior art

Basic insulation levels (BIL) are reference levels expressed in impulse crest voltage with a standard wave not longer than $1\frac{1}{2} \times 40$ microseconds. The rated withstand voltage is the crest value of the impulse wave that the apparatus will withstand without disruptive discharge. The crest value of the rated withstand curve is the same as the BIL.

When electrical transformers are designed with BIL's starting at about 60 kv., it has been customary to utilize oil filled construction because of the excellent insulating properties of oil. Dry type transformers have been constructed to meet higher BIL's, but they have required special parts and constructions which differ from established manufacturing techniques for dry type transformers, and thus have made them unattractive from a cost viewpoint. Therefore, it would be desirable to be able to increase the BIL of dry type transformers when the need arises, without special parts, special machines and/or manufacturing techniques, which would make the dry type transformer of higher BIL ratings more competitive with similarly rated oil filled transformers.

SUMMARY OF THE INVENTION

Briefly, the present invention is a new and improved dry type transformer of the encapsulated or potted type, in which the BIL is increased while utilizing the same manufacturing apparatus and techniques which are used for conventional dry type transformers. Further, the new and improved dry type transformer does not require the manufacture of special insulating shapes or members, or other specially designed or manufactured components of the type which would unduly increase the manufacturing cost.

The critical turn-to-turn insulation of the high voltage winding of the transformer, at least in the layers of conductor turns immediately adjacent the high voltage terminal, is provided by one or more continuous, discrete insullating filaments or strands, either solid, or tubular, such as insulating sleeving, disposed between the conductor turns. The discrete continuous insulation is selected to have about the same diameter as the wire of which the conductor turns are formed, with the number of discrete filaments disposed between the adjacent conductor turns depending upon the electrical strength of the insulating

strands and the particular BIL required. Insulating sleeving or tubing is readily available, and it may be wound on the coil form at the same time the conductor turns are wound, similar to winding a plurality of conductors together at the same time. Therefore, the same winding machines and techniques may be used to achieve the required barrier dimension between conductor turns, as are presently used to manufacture conventional dry type transformers.

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 and drawings, in which:

FIG. 1 is a perspective view, partially cut away, of a dry type encapsulated transformer which may utilize the teachings of the invention;

FIG. 2 is a cross sectional view of the winding assembly of the transformer of FIG. 1, taken along a plane which cuts vertically through the assembly along a line between arrows II—II, illustrating the high voltage winding constructed according to an embodiment of the invention; and

FIG. 3 is a fragmentary cross-sectional view of a high voltage winding constructed according to other embodiments of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, and FIG. 1 in particular, there is illustrated a dry type encapsulated transformer **10**, of the type which may utilize the teachings of the invention.

In general, transformer **10** includes a magnetic core-winding assembly **12** embedded in a cast solid insulation system **14**, with the potted magnetic core-winding assembly and solid insulation being disposed in a suitable casing or housing **16**.

The magnetic core-winding assembly **12** comprises a magnetic core structure **18**, which in this instance comprises first and second magnetic cores **20** and **22**, respectively, disposed in side-by-side relation, with their adjacent portions providing a winding leg about which a winding assembly **24** is disposed. As illustrated, each of the magnetic cores **22** and **24** may be formed of a pair of wound C-cores, such as C-cores **26** and **28**, which are held in assembled relation by banding means **30** to provide the first magnetic core **20**. Each of the C-cores have a plurality of nested metallic laminations, such as laminations **32**, which are bonded together to provide a coherent structure.

The winding assembly **24** includes concentrically disposed high and low voltage windings, with the high voltage winding having electrical leads **34** and **36**, and the low voltage winding having electrical leads **38** and **40**. Transformer **10** may have additional concentrically disposed windings, as required by specific applications.

The solid insulation system **14** may be of any suitable type, such as a filled epoxy resin. The filler material may be finely divided silica, such as sand, or any other inorganic non-friable material. Suitable resin systems for encapsulating dry type transformers are disclosed in U.S. Pat. 3,030,597, which is assigned to the same assignee as the present application.

The magnetic core-winding assembly may be positioned within the casing **16** by a bracket member **42** which is welded to the inside of the casing. The bracket member **42** may also be used to maintain the potted magnetic core-winding assembly within the casing **16**, by virtue of integral winged projections **44**.

FIG. 2 is a cross-sectional view of the winding assembly **24** shown in FIG. 1, taken on a vertical plane through the assembly along a line between arrows II—II. Wind-

ing assembly **24** includes high and low voltage windings **50** and **52**, respectively, constructed according to the teachings of the invention, to increase the BIL of the transformer to 60 kv., or even higher, such as 75 or 95 kv.

The low voltage coil **52** is formed of metallic strip or foil, having a plurality of radially superposed insulated conductor turns, shown generally at **54**, which are wound on a mandrel or coil having a center line **51**. Since there is only one conductor turn per layer in a foil or strip wound coil, the BIL of the low voltage coil **52** may be increased by increasing the thickness of the insulation between adjacent conductor turns. Conservatively, normal insulation thickness between the turns may be doubled, and should not be less than about 1.5 mils. The insulation between conductor turns may be provided by a coating of insulation, such as enamel, disposed on one or both sides of the foil, or by a separate strip or sheet of insulation which is wound with the metallic foil or strip, such as a polyester film. The thickness of the insulation between the conductor turns **54** of the low voltage winding **52** is selected to protect the low voltage winding from high voltages which may be capacitively coupled into the low voltage winding from the high voltage winding **50** during a surge condition.

The high-low insulation **56** is also increased in thickness by utilizing a plurality of layers of an impervious film, such as a polyester film. Since a polyester film has a withstand rating of about 4000 volts per mil, a conservative safety factor of 10:1 would dictate about 150 mils of polyester film for a BIL of 60 kv.

The thickness of the solid insulation **14** adjacent the ends of the high and low voltage coils **50** and **52** is also increased, to about one inch for a 60 kv. BIL, and an additional 50 mils of insulation, such as a polyester film, is added between the ends of the winding assembly adjacent the yoke portion of the magnetic core structure **20**.

The construction of the high voltage coil **50** is especially critical when BIL's of 60 kv. and higher are desired, as a surge voltage applied to the high voltage terminal doesn't distribute itself across the winding inductively, but according to the capacitive structure of the winding. Thus, instead of a uniform distribution of the surge voltage across the winding, it is very non-linear between layers across the winding, between turns of the layers, and from the high voltage winding to the low voltage winding and magnetic core, with the non-linearity being such that the electrical stress is concentrated at the portion of the winding connected to the line terminal to which the surge is applied. Thus, the stress concentration is extremely high between the end turns of the layers of turns connected to the line terminal, and between the end turns of the first two layers of turns, with most surge failure occurring at these locations.

The present invention teaches how the high voltage coil **50** may be constructed to BIL's of 60 kv., 75 kv. and 95 kv., as required for rated system voltages of 2.5 kv. to 15 kv., without requiring special shapes of insulating members or special manufacturing or process steps. Thus the dry type encapsulated transformer may be constructed such that it is competitive costwise with oil filled types, for similar rated voltages and BIL ratings.

More specifically, high voltage winding or coil **50** is formed of a wire type conductor **59**, such as copper, which is wound about the same center line **51** as the low voltage coil **52**, to form a plurality of layers, such as layers **60**, **62**, **64**, **66** and **68**, of conductor turns, such as conductor turns **70** in layer **60**. The conductor turns of the first layer **60** progress axially from the first end of the winding assembly **24** to the second end, and then the next layer is radially superposed over the first layer, with its conductor turns progressing axially from the second to the first ends of the winding assembly. The winding progresses in this manner until all of the required layers of turns are provided.

The conductor **59** of which the conductor turns **70** are wound may have a layer or coating **61** of insulation disposed thereon, such as an insulating enamel.

The critical turn-to-turn insulation is provided by a discrete continuous filament or strand of insulating material, which in the embodiment of the invention shown in FIG. 2 is a length of insulating sleeving or tubing **80**, having an outside diameter which is substantially the same as the diameter of the wire conductor **59** with its layer or coating **61** of insulation disposed thereon. Preferably, the diameter of the insulating tubing **80** should be the same as, or slightly greater than the diameter of the insulated conductor.

Insulating tubing or sleeving **80** is readily available commercially, and it may be wound side-by-side with the insulated conductor **59**, similar to winding two conductors side-by-side. The material of which the insulating sleeving **80** is formed should be selected such that the electrical strength presented by twice the wall thickness is higher than the BIL required. For example, a length of polyester tubing having a wall thickness of 10 mils will provide a 20-mil barrier turn-to-turn. If a solid strand of insulation is used, the dimension of the strand from conductor turn to conductor turn should provide the electrical strength required. If the conductor of which the conductor turns is formed is rectangular, such as metallic strap, the insulating filament or strand may also be substantially rectangular in shape, if desired.

The thickness of the layer insulation is increased to that required by the particular BIL specified, with the layer insulation being graded, if desired, as shown in FIG. 2. In other words, since the greatest electrical stress appears between the first few layers adjacent the line terminal, more layers of insulation may be used between the first few layers than between the remaining layers of the winding. The dimension W1 between the centers of the conductors of layers **60** and **62**, and between the centers of the conductors of layers **62** and **64**, is greater than the dimension W2 between the centers of the conductors of layers **64** and **66**, and layers **66** and **68**, due to the grading of the layer insulation. For example, in a transformer constructed according to the teachings of the invention for a BIL of 60 kv., 20 mils of polyester film was provided between adjacent layers for the first four layers, and then the layer insulation was reduced to ten mils for the remaining layers.

FIG. 3 is a fragmentary view, in section, of a high voltage winding **100** for a dry type encapsulated transformer, which is constructed according to other embodiments of the invention. FIG. 3 illustrates layers **102** and **104**, each of which have a plurality of conductor turns, such as conductor turns **106** in layer **102**, which are formed of a conductor **108**. In this embodiment, conductor **108** is bare, i.e., it does not have an integral coating or wrapping of electrical insulation thereon, as the turn-to-turn and layer insulation is completely provided by other insulating materials. Further, as illustrated in FIG. 3, each conductor turn may be separated by a plurality of discrete insulating strands or filaments, with two strands **110** and **112** being illustrated. The number of discrete strands disposed between adjacent conductor turns will depend upon the electrical strength of the insulation used, the BIL requirements of the transformer, and the dimensions of the insulating strands. Still further, the insulating strands **110** and **112** are illustrated as being solid, instead of tubular in cross-sectional configuration. Solid insulating strands are preferable over the tubular type because for a given outer diameter the solid strand has a greater electrical strength than a tubular strand. The final choice, however, may be dictated by the fact that the tubular strands are more readily available commercially than solid filaments of electrical insulation having the required dimensions.

In addition to grading the layer insulation, it would also be possible to grade the turn-to-turn insulation by using more discrete filaments or strands between the turns of

the layers which are immediately adjacent the line terminal, than between the turns in the remaining layers.

The start and finish leads of the high voltage winding **50** of transformer **10** shown in FIG. 2, are insulated with suitable insulating sleeving, and although it is not shown in the figure, the leads may be terminated in bushing members which may be cast into the solid insulation system **14**.

An outer wrap of insulation is disposed about high voltage winding **50**, such as about 150 mils of polyester film for a BIL of 60 kv.

After the winding assembly **24** is completed, the C-cores may be assembled about the winding assembly, and the connections from the high voltage winding **50** may be made to the bushing members, if used, and then the complete assembly is disposed within casing **16**, after first inverting the casing from the position shown. The magnetic core-winding assembly **12** is oriented within the casing **16** with the bracket **42**, which insures that the assembly will maintain the proper position relative to the casing while the magnetic core-winding assembly is being encapsulated. The casing **16** and magnetic core-winding assembly is then heated to a predetermined temperature, such as 135° C., preparatory to receiving the liquid casting resin, and then the casting resin is introduced into the casing to a predetermined level. A finely divided filler material, such as sand, is then introduced into the casing until the resin level rises above the top of the magnetic core assembly. The casing may be vibrated while the resin and sand are introduced, to assure complete impregnation of the core-winding assembly with the liquid resin, and uniform dispersion of the filler material through the liquid resin.

In summary, there has been disclosed a new and improved dry type encapsulated transformer which may be constructed for BIL's of 60, 75 and 95 kv., without requiring special assemblies or members to be manufactured, which would otherwise make the dry type transformer uncompetitive costwise with oil filled transformers. The increased insulating clearances from the high voltage winding to the magnetic core and to the low voltage winding, are provided by additional layers of solid insulating films, the layer-to-layer insulation thickness in the high voltage winding is provided by additional layers of solid insulating films, and the critical turn-to-turn insulation in the high voltage winding is provided by discrete lengths of insulating material, either tubular or solid, which separate adjacent conductor turns in each layer of turns. Thus, the BIL of the dry type encapsulated transformer may be increased for approximately the cost of the additional insulation required, with the additional insulation being of the same general type which is already used in the dry type transformer, such as impervious solid insulating films and insulating sleeving or tubing.

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 or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. An electrical transformer comprising

magnetic core means having a winding leg,

high and low voltage windings disposed about the winding leg of said magnetic core means, to form a magnetic core-winding assembly, said low voltage winding including a plurality of radially superposed, insulated conductor turns formed of electrically conductive strip material,

said high voltage winding including at least one electrical conductor wound to provide a plurality of radially superposed layers of conductor turns, insulating means disposed between the adjacent layers of conductor turns, and at least one discrete, continuous insulating filament, the conductor turns of at least certain of the layers being axially separated by said at least one insulating filament, to provide turn-to-turn insulation,

and solid insulating means, said solid insulating means capsulating said magnetic core-winding assembly.

2. The electrical transformer of claim **1** wherein the insulating filament has a tubular cross-section.

3. The electrical transformer of claim **1** wherein the insulating filament has a solid cross-section.

4. The electrical transformer of claim **1** wherein the electrical conductor has a coating of electrical insulation disposed thereon.

5. The electrical transformer of claim **1** wherein the electrical conductor is free of electrical insulation, with the turn-to-turn insulation being completely provided by the insulating filament.

6. The electrical transformer of claim **1** wherein the radial thickness dimension of the insulating means disposed between the layers of conductor turns is graded, with the radial thickness dimension of the insulation between certain layers exceeding that of the insulation disposed between other layers.

7. The electrical transformer of claim **1** wherein the conductor turns of at least certain of the layers are axially separated by a plurality of continuous insulating filaments.

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