United States Patent

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[45] Patented **Oct. 5, 1971**

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[54] **ENCAPSULATED ELECTRICAL WINDINGS**
3 Claims, 15 Drawing Figs.

[52] **U.S. Cl.** **336/60,** 29/602, 336/96, 336/192, 336/205
[51] **Int. Cl.** **H01f 27/08,** H01f 15/10
[50] **Field of Search** ..... 336/60, 96, 205, 232, 192, 180; 174/52 PR; 264/272

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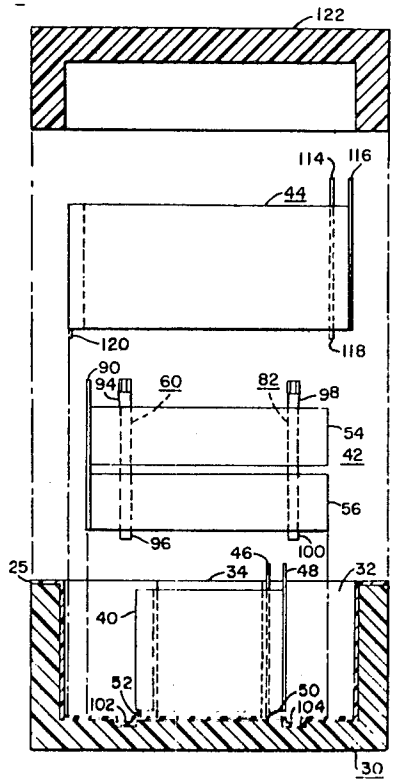
ABSTRACT: Electrical windings encapsulated in a cast solid electrical insulating material. Support means extends from the bottom of the windings to an outer surface of the cast solid insulation, with the support means including extensions on the winding terminals, to space certain of the windings from the outer surface of the insulation.



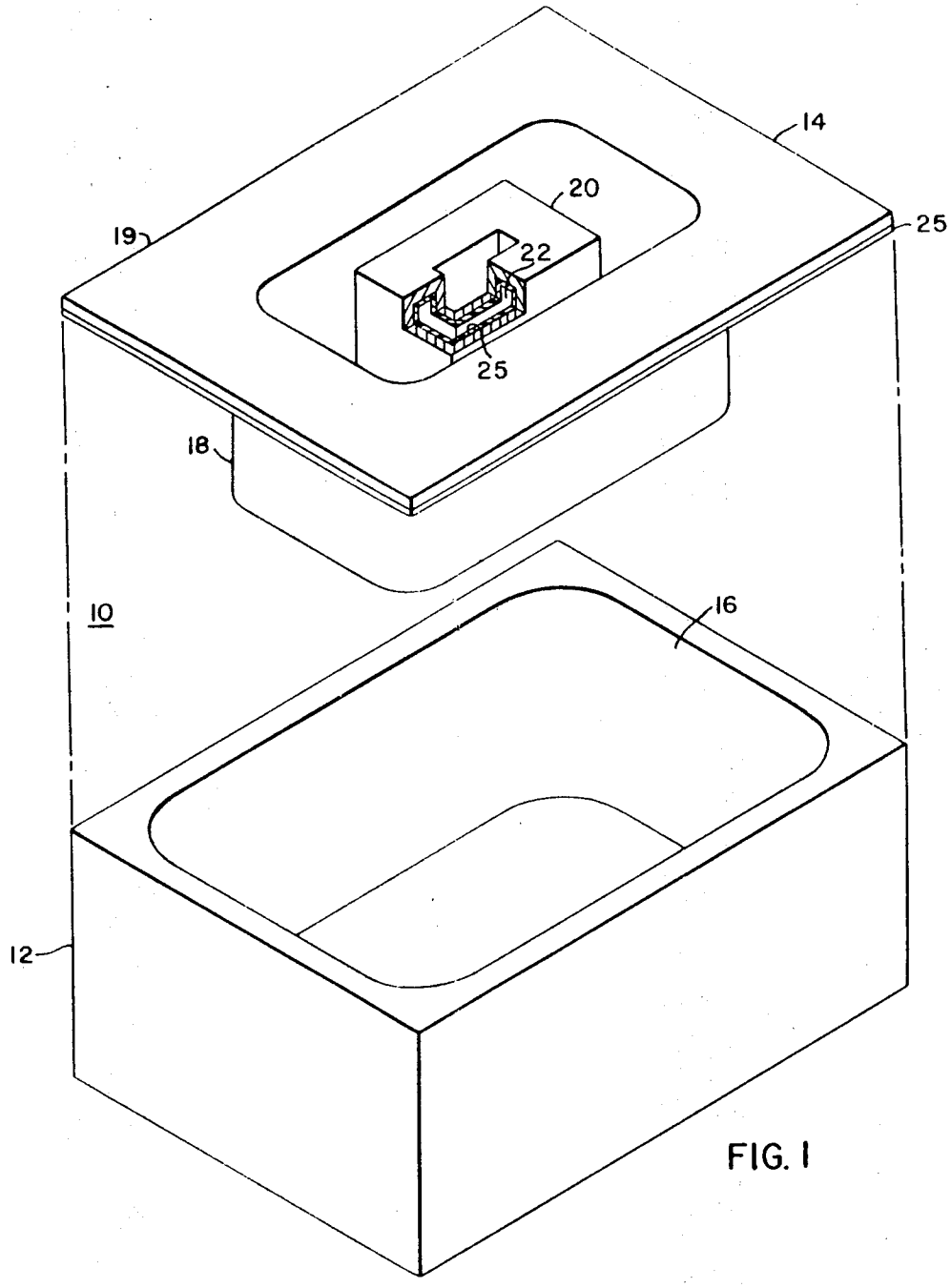


FIG. 1

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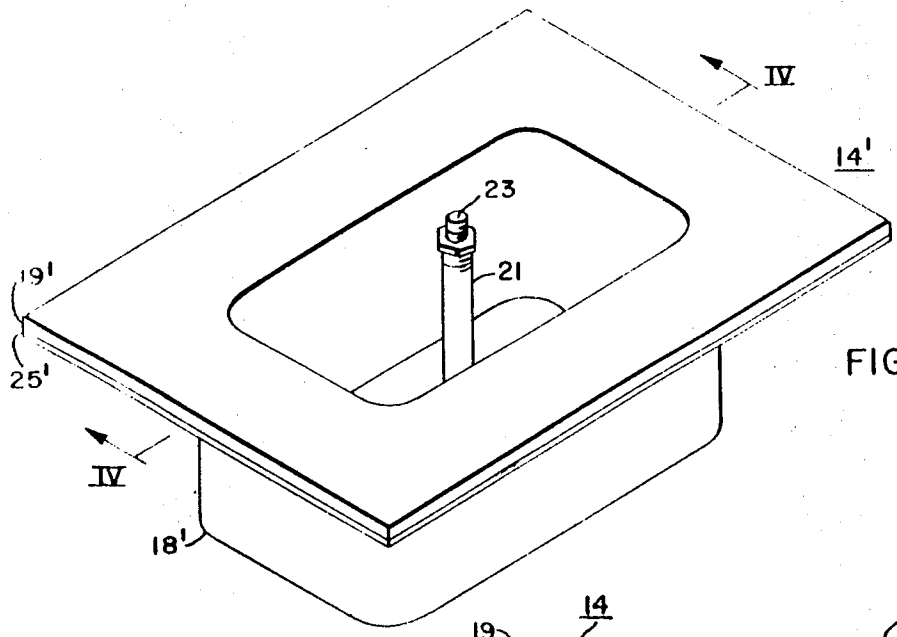


FIG. 4

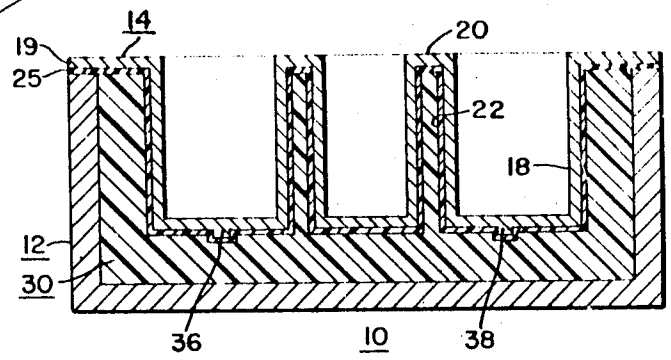


FIG. 2

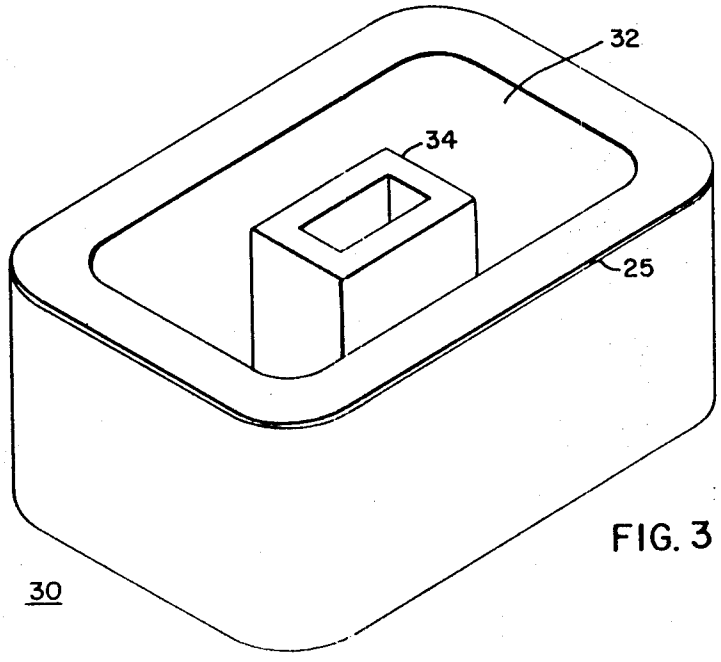


FIG. 3

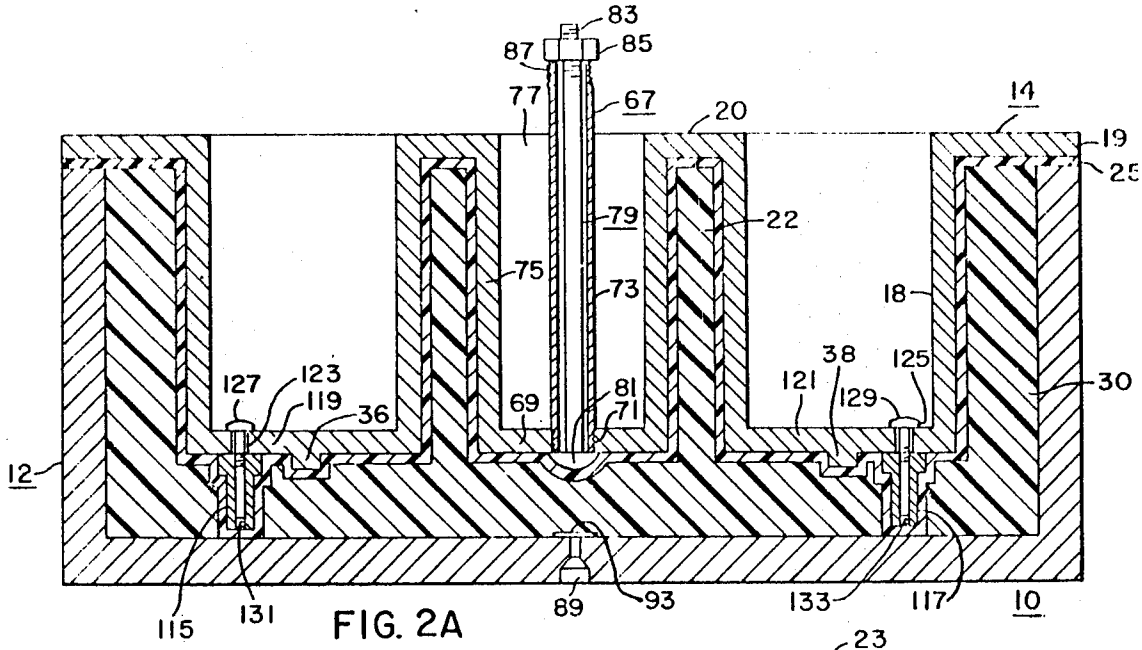


FIG. 2A

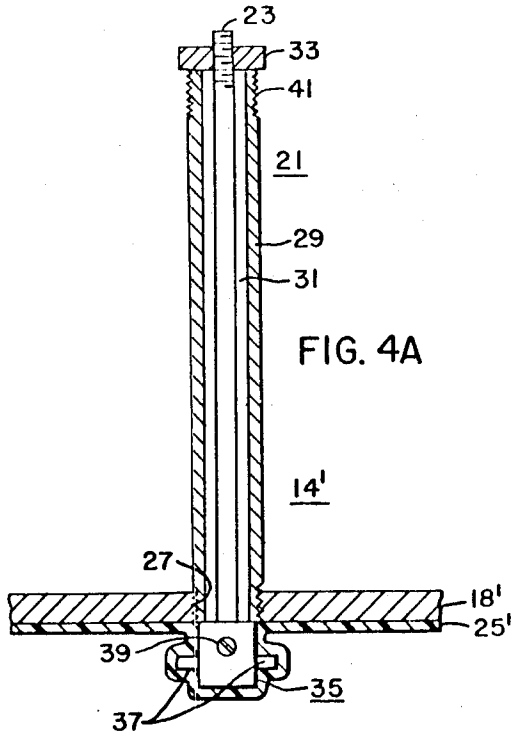


FIG. 4A

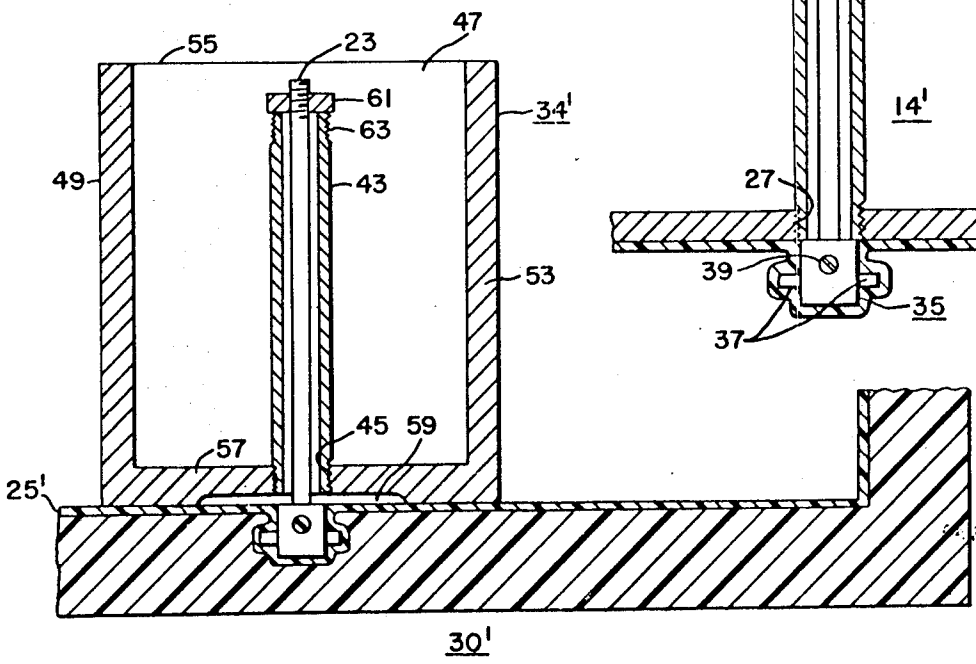


FIG. 5A

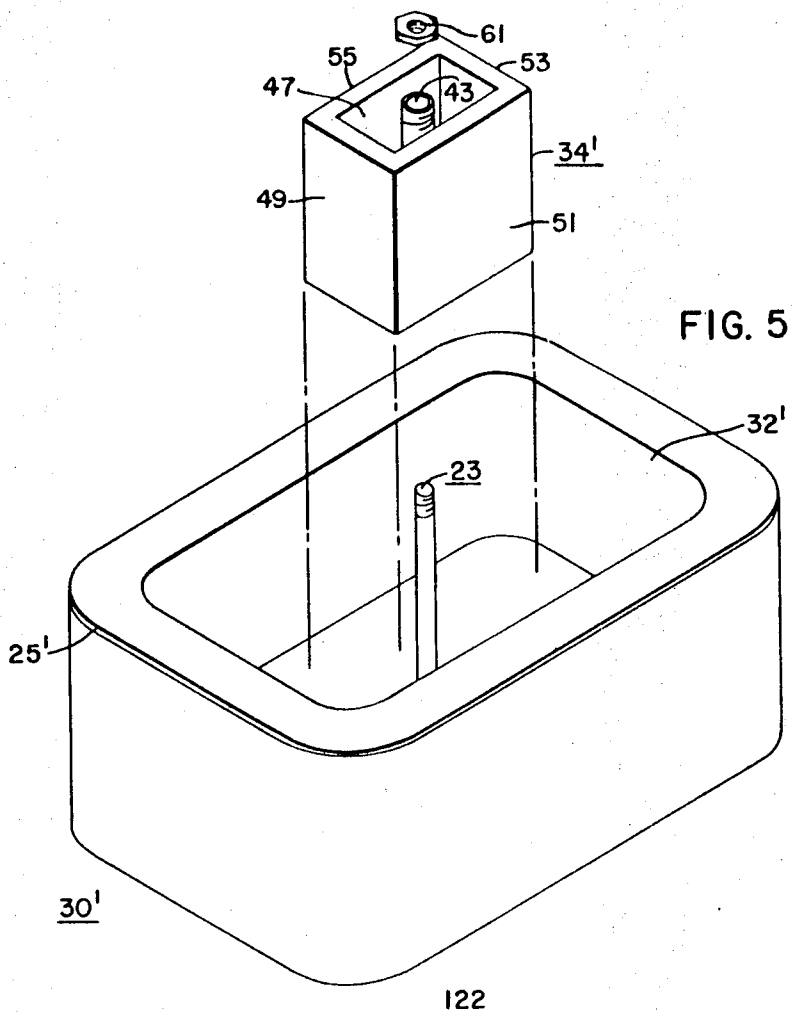

61
55
53
47
43
34'
49
51
32'
23
25'
30'

FIG. 5

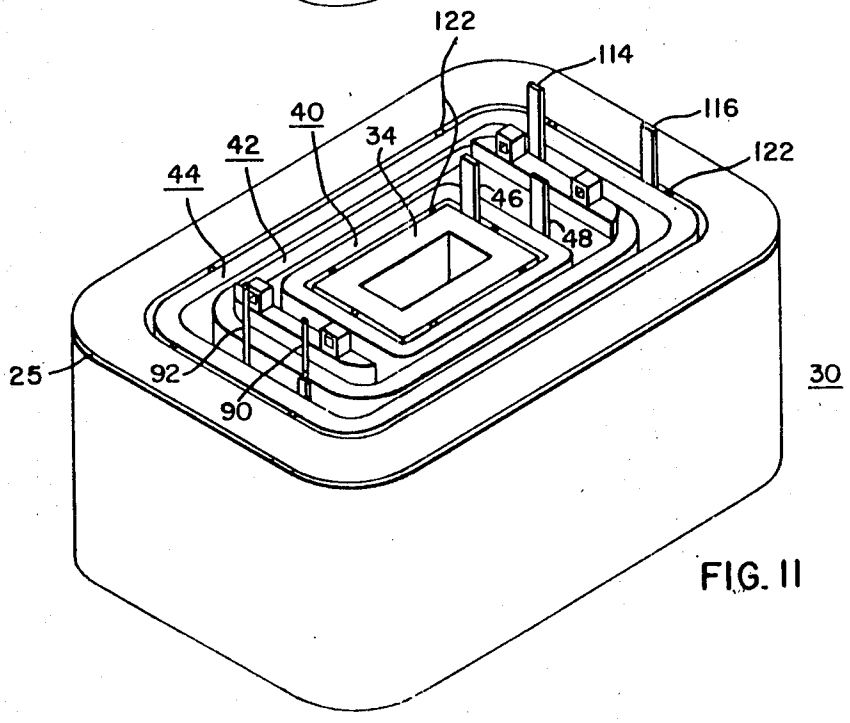
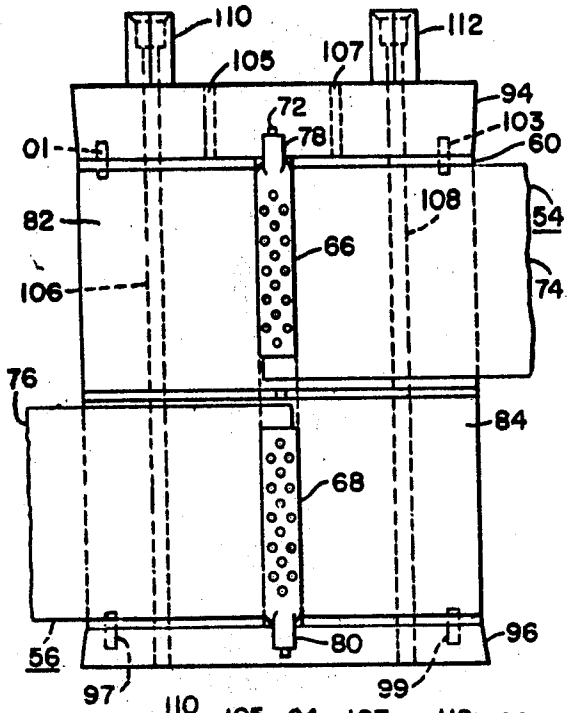

122
114
116
40
42
34
122
44
46
48
25
92
90
30

FIG. 11

FIG. 7



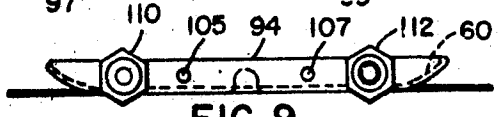


FIG. 9

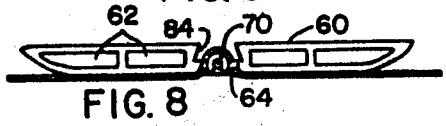


FIG. 8

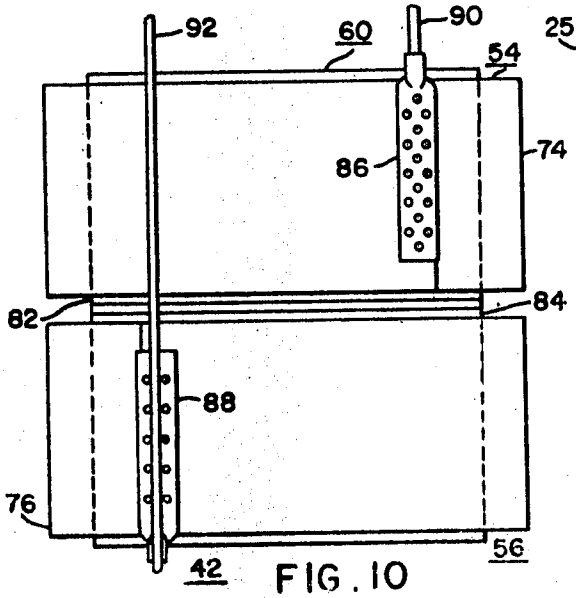


FIG. 10

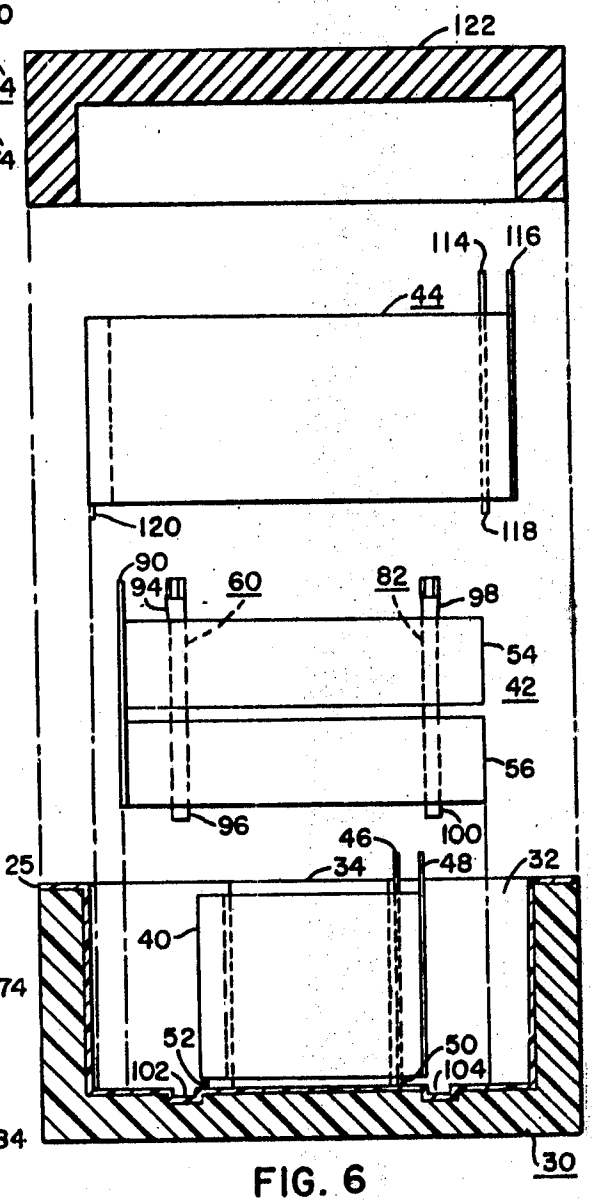


FIG. 6

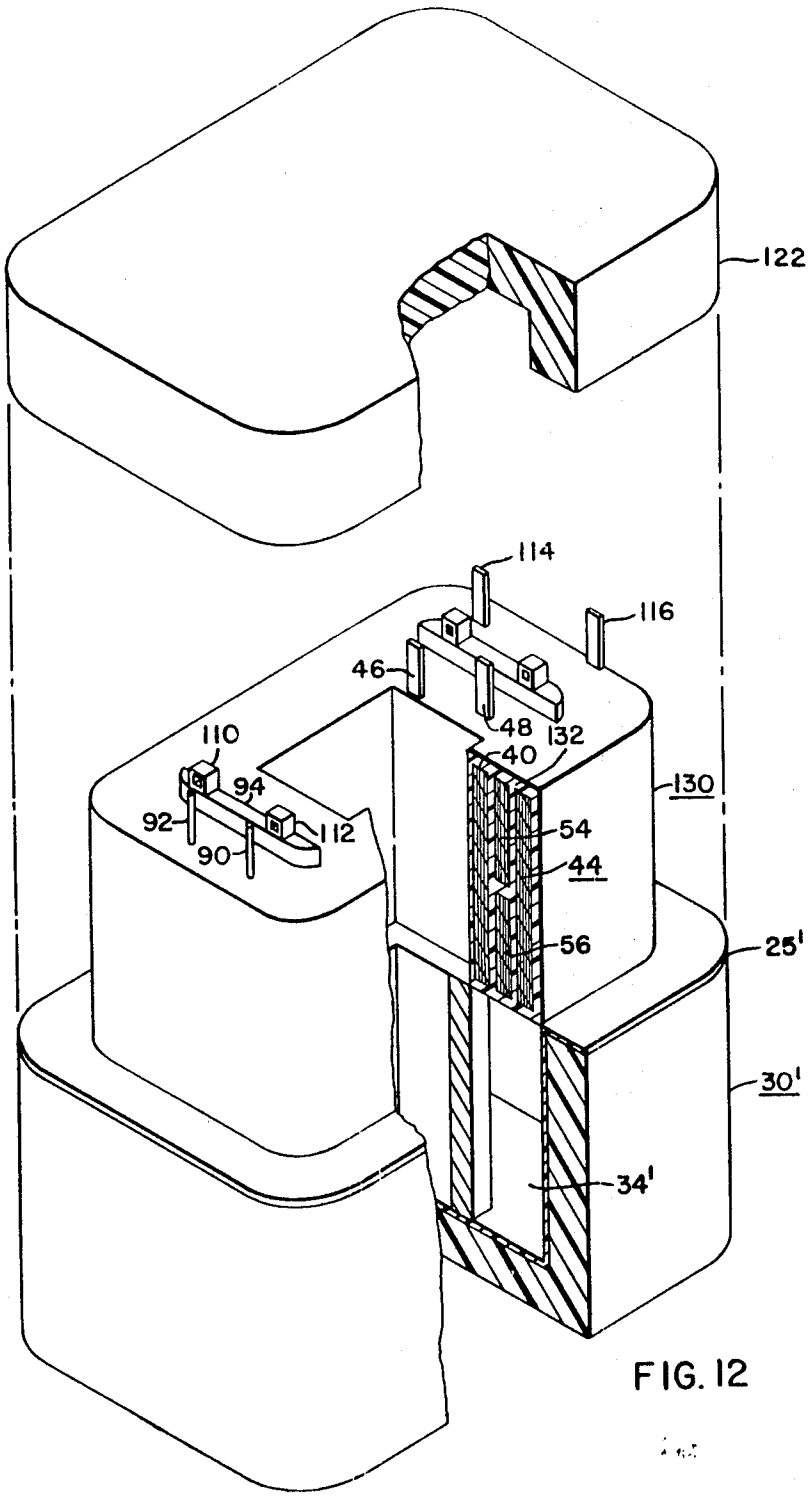


FIG. 12

ENCAPSULATED ELECTRICAL WINDINGS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a division of application Ser. No. 675,840, filed Oct. 17, 1967, now U.S. Pat. No. 3,537,677.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to windings for electrical inductive apparatus, such as transformers, and more particularly to electrical windings encapsulated in a cast resin insulation system.

2. Description of the Prior Art

The development of excellent casting resin systems has made it extremely attractive to encapsulate electrical windings, such as those for electrical transformers, in a pourable resin system, which is subsequently gelled and cured to a solid. It is important that the windings be properly spaced from the bottom and walls of the casting mold cavity, in order to provide the desired thickness of solid insulation about the windings. The spacing of the windings from the sidewalls of the cavity is not difficult, but the spacing of the windings from the bottom of the cavity is more complicated. For example, it is common to pour and gel a layer of casting resin on the bottom of the mold cavity prior to the introduction of the windings, to provide the desired spacing. It would be desirable, however, to be able to quickly and accurately space the windings from the bottom of the mold cavity, without resorting to such time consuming and, therefore, costly procedures.

SUMMARY OF THE INVENTION

Briefly, the invention is a new and improved encapsulated winding assembly, which includes a plurality of concentrically disposed windings formed of electrically conductive foil, strip, or sheet material. The windings are encapsulated in a solid resin system which defines first and second major opposed outer surfaces, the planes of which are substantially perpendicular to the axes of the windings. Electrical terminals are connected to the windings, which extend outwardly from the first major surface of the solid insulation, and support means, for at least certain of the windings, extends between the windings and the second major surface. The support means functions to space these windings from the bottom of the mold cavity when the windings are being encapsulated. The support means is provided by integral extensions of certain of the terminals on the windings, and by insulating members disposed between certain of the turns of windings, as the windings are wound.

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, in which:

FIG. 1 is a perspective view of a pattern mold which may be used to form foam molds for use in encapsulating electrical windings constructed according to the teachings of the invention,

FIG. 2 is a cross-sectional view of the pattern mold of FIG. 1, after a resin system has been foamed therein to form a foam mold,

FIG. 2A is a cross-sectional view of a pattern mold, similar to the view shown in FIG. 2, except modified to enable compressed air to be used to eject the foam mold from the pattern mold,

FIG. 3 is a perspective view of a foam mold which may be used to encapsulate windings constructed according to the teachings of the invention,

FIG. 4 is a perspective view of a portion of the pattern mold shown in FIG. 1, illustrating a modification which may be made thereto,

FIG. 4A is a fragmentary cross-sectional view of the male portion of the pattern mold shown in FIG. 4, taken along the line IV—IV,

FIG. 5 is a perspective view of a foam mold constructed with the pattern mold of FIG. 1, as modified by the portion of the pattern mold shown in FIG. 4,

FIG. 5A is a fragmentary cross-sectional view of the foam mold shown in FIG. 5,

FIG. 6 is an exploded, side elevational view, partially in section, illustrating a foam mold and electrical windings to be encapsulated therein,

FIG. 7 is an end elevational view illustrating the start of electrical windings constructed according to the teachings of the invention, and how they may be interconnected,

FIG. 8 is a plan view of a duct former which may be used with the windings shown in FIG. 7,

FIG. 9 is a plan view of the top duct former plug shown in FIG. 7,

FIG. 10 is an end elevational view of the completed windings, of which the start was shown in FIG. 7,

FIG. 11 is a perspective view of transformer windings disposed in the cavity of a foam mold, and

FIG. 12 is an exploded, perspective view, partially in section, illustrating the completed cast winding assembly, the foam mold, and a foam top for the foam mold.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, and FIG. 1 in particular, there is shown a perspective view of a pattern mold **10**, which may used to make molds suitable for use in encapsulating electrical windings constructed according to the teachings of the invention. Pattern mold **10** has first and second cooperating portions, a female mold portion **12**, and a male mold portion **14**. The female pattern mold portion **12**, which may be formed of any suitable metal such as steel or aluminum, has a cavity **16** formed therein which forms the outer bottom and outer sidewall portions of the foam mold. The male pattern mold portion **14**, which also may be formed of a suitable metal such as steel or aluminum, has a projecting portion **18** sized to enter the cavity **16** of portion **12**, in predetermined spaced relation with the bottom and sidewall portions of the cavity **16**, in order to establish the wall thickness of the bottom and sidewall portions of the foam mold, and to determine the dimensions of the cavity in the foam mold. The projection **18** is connected at its upper end to a flanged portion **19**, which cooperates with the upper surface of portion **12** when portions **12** and **14** are assembled, to seal the cavity of the pattern mold **10**. Since the cast winding requires an opening therein for receiving a magnetic core, the foam mold must have a projection rising from the bottom of its cavity, to form this opening. As shown in FIG. 1, this projection may be integrally formed while forming the foam mold within the cavity of the pattern mold **10**, by a projection **20** which rises vertically upward from the bottom of projecting portion **18**. The projection **20** has an opening accessible from within the cavity of the pattern mold **10**, to allow the foamed resin to rise therein and establish the desired shape for the center post or projection **20**. Thus, as shown more clearly in FIG. **2**, which is a cross section of the pattern mold **10** shown in FIG. **1** with portions **12** and **14** in assembled relation, the projection **20** has a double wall section, with the double wall in this embodiment defining a rectangular cavity **22**, and with the cavity **22** in projection **20** being accessible from within the cavity of the pattern mold **10**.

To form a foam mold from the pattern mold **10** requires that a suitable foam resin system be mixed and introduced into the cavity **16** of the female portion **12** of the pattern mold **10**. The cavity **16** of the female pattern mold portion **12** may have a suitable mold release material uniformly applied to its surfaces, such a polytetrafluoroethylene, commonly called "-TEFLON," and the female pattern mold portion is preheated to a predetermined temperature, which depends upon the particular foam resin system utilized. The male portion **14** of the pattern mold **10** may also have a mold release material on the surfaces which enter the cavity **16**, and is also preheated to a predetermined temperature. The resin is mixed, introduced into the heated female portion **12** and the heated male portion

14 is disposed in assembled relation with the female portion. The resin system, as it foams and rises, fills the cavity between the male and female molds, and the cavity 22 in the center of projection 20, forming the foam mold 30 shown in FIGS. 2 and 3. The pattern mold 10, along with the foamed resin, may then be heated to a predetermined elevated temperature for a predetermined period of time, to cure the foam mold, and then the foam mold 30 may be removed from the pattern mold. The foam mold 30 has a cavity 32 and a projection or center post 34 rising from the floor of the cavity, as shown in the perspective view in FIG. 3.

While the foam mold 30 may be used to encapsulate electrical apparatus by applying a mold release material to its cavity surfaces, the foam mold 30 may alternatively be formed with a smooth, tight-fitting plastic liner 25 disposed in the cavity 32, and on the surfaces of the projection 34.

As shown in FIG. 1, the plastic liner 25 is disposed on at least the surfaces of the male pattern portion 14 which will come into contact with the foamed resin, including the surfaces within the cavity 22 of its center post or projection 20. Liner 25 is preferably formed of a thermoplastic material, having a softening temperature consistent with the pouring temperature of the encapsulating resin, such as polyvinylchloride, polyethylene, or polypropylene. Thermosetting materials would, in general, be unsuitable, as the cast resin system for encapsulating the electrical windings may stick thereto, while a thermoplastic material may be selected which will soften and secrete enough plasticizer to act as a mold release. The liner resin may be applied to the male portion 14 of pattern mold 10 by heating the male portion 14 to a predetermined temperature and dipping it into an appropriate resin system. The resin may be powdered, and applied by fluidized bed coating techniques, or it may be an emulsion; or, it may be sprayed, for example, by electrostatic methods. If dipped, the temperature of the male portion will determine the thickness of the resulting plastic liner.

The plastic liner on the male pattern mold portion 14 will serve as the mold release for the male portion of the pattern mold. Then, when the resin system is foamed in the pattern mold, the foamed resin will adhere tenaciously to the liner 25. The bond between the foam mold and the liner 25 is much stronger than the bond between the liner 25 and the male portion of the pattern mold. Thus, when the foam mold 30 is removed from the pattern mold 10, the liner 25 will also be removed as an inseparable portion of the foam mold 30, and it will be in the desired position on the foam mold 30.

Liner 25 functions as a mold release, aiding in the removal of the foam mold 30 from the male portion of the pattern mold, it functions to provide a smooth coating on the cast resin which is subsequently cast therein, it functions as a non-contaminating mold release for the cast resin system, and it allows the life of the foam mold to be extended. Instead of scrapping the foam mold after a single casting, it may be used to form a plurality of additional cast windings, before it deteriorates to a point which necessitates scrapping.

As hereinbefore stated, the resin of which the foam mold 30 is formed may be any suitable resin which is capable of standing the temperatures at which the casting resin system is poured and cured. In general, it should preferably be a thermosetting, rigid foam of sufficient density to provide the requisite strength. Examples of suitable foamed resin systems are the urethanes, epoxies, phenolics and the silicones.

The rigid, closed-cell polyurethane foams have been found to be excellent as they may be foamed in place, and they provide good adhesion to the plastic liner on the male portion of the pattern mold. They may also be used at the elevated temperatures at which the casting resin system is poured, they are chemical resistant, their density may be easily controlled, and they may be blown with fluorocarbons, which give them the excellent thermal insulating qualities necessary to use the molds as gelling and curing containers. Rigid polyurethane foams, which are the reaction product of a polyisocyanate and a polyhydroxyl material, may also be blown with carbon dioxide, and produced by a water and isocyanate reaction. Since the foam material per se is not part of the invention, and since suitable plastic foams, their compositions, and the methods for producing them, are well known in the art, such, for example, as disclosed in U.S. Pat. No. 3,072,582 issued Jan. 8, 1963, and entitled "Polyether-Urethane Foams and Method of Making Same," and in the "Handbook of Foamed Plastics," Rene J. Bender, Editor, Lake Publishing Corporation, Libertyville, Ill., 1965, they will not be described in detail.

An example of successful methods and apparatus for forming foam molds of polyurethane is to construct the male and female pattern molds of aluminum, heat the male portion of the mold to 165° C. and dip it into an emulsion of polyvinylchloride, which coats the male portion of the mold with a plastic liner approximately one-sixteenth of an inch thick, heat the male mold and liner to 180° C. for 90 minutes to cure the liner, spray a mold release material on the surfaces of the cavity of the female mold, heat the male and female mold portions to 85° C., mix a rigid polyurethane fluorocarbon blown resin system, pour the resin system into the female portion of the pattern mold, and place the male portion of the pattern mold into assembled relation with the female portion, cure the foamed resin at 180° C. for 30 minutes, remove the male portion of the pattern mold from its assembled position, which leaves the polyvinylchloride liner on the foam mold, and remove the foam mold from the female portion of the pattern mold.

As shown in FIG. 2, the male portion 14 of the pattern mold 10 may have locating means, such as projections 36 and 38 therein, which form depressions for accurately locating certain of the windings to be encapsulated therein.

The removal of the foam mold 30 from the pattern mold 10 may be facilitated by the strategic application of compressed air. FIG. 2A is a cross-sectional view of the pattern mold 10, with its portions 12 and 14 in assembled relation, and a foam mold 30 shown in the cavity of the pattern mold 10. FIG. 2A is similar to FIG. 2, with like reference numerals indicating like components, except modified according to an embodiment of the invention which utilizes compressed air.

More specifically, the male portion 14 is modified to include a stud, pipe, and nut assembly 67. The center post forming projection 20 of the male portion 14 includes a bottom section 69 which has threaded opening 71 therein. The bottom section 69, along with the inner wall sections of the projection 20, such as wall section 75, define a cavity 77. A tubular member or pipe 73 is disposed within the cavity 77, with one of its ends being threadably inserted into the opening 71, and its other end extending perpendicularly outward from the bottom section 69. A bolt or stud 79, having a flanged head portion 81 and a threaded end portion 83, is inserted, threaded end first into the opening 71 and then into the pipe 73. The length of the stud 79 is selected to allow its threaded end 83 to extend past the upper end of the pipe 73, when the flanged head 81 is covering the opening 71, allowing a nut 85 to secure the stud 79 in this position. Assembly 67 is completed prior to the step of applying the liner 25 to the male portion 14, in order to apply the liner over the exposed head portion 81 of the stud 79. The exposed head portion 81 is preferably dome-shaped, in order to facilitate its removal from the liner 25 after the male portion 14 of the pattern mold is removed from its assembled position. Instead of constructing stud 79 to be free of the mold 30, it may also be constructed with a larger end 81 which will enable the stud 79 to be embedded in the foam mold, in a manner which will be hereinafter described relative to another embodiment of the invention. This will then provide a suitable anchoring point for holding down any portion of the electrical apparatus to be encapsulated which would otherwise "float" on the heavier resin system when it is poured.

When the mold 30 is ready for removal from the pattern mold 10, the nut 85 is removed from the end of the stud 79, and a compressed air fitting is coupled to the upper end of pipe 73. The upper end of pipe 73 may be threaded, as shown

at 87, to facilitate the connection. Compressed air will be directed between the stud 79 and the pipe 73, the O.D. and I.D. of which were selected to provide an annular space therebetween, past the flanged head 81 of the stud 79, and outwardly between the liner 25 and male portion 14. The compressed air quickly and effectively breaks the bond between the liner 25 and male portion 14, transferring the liner 25 to the foam mold 30.

The foam mold 30 may then be removed from the female mold portion 12 by compressed air. An opening 89 may be disposed through the bottom section of the portion 12, which is sized at the outer access end of the opening to receive the end of a compressed air nozzle. The end of the opening 89 which is within the pattern mold cavity may be temporarily sealed, to enable the foaming process to be performed within the cavity of the pattern mold 10; by gluing a small piece of aluminum foil 93, or other suitable material, over this opening.

The modulus of elasticity of the foam mold 30 allows the compressed air to minutely and nondestructively flex the foam mold to break the bond between itself and the pattern mold 10. The mold 30 may be nondestructively flexed in a mechanical fixture after the electrical apparatus is cast, to break the bond between the cast resin system and the liner 25. Or, as shown in FIG. 2A, the male portion 14 of the pattern mold 10 may be further modified to provide strategically located access ports through the foam mold 30 which will allow compressed air to be used for this function.

More specifically, prior to applying the liner 25 to the male portion 14, tubular metallic members 115 and 117, each having an opening therein which is threaded near each axial end, may be removably secured to the surface of the male portion 14 which will be within the cavity of the pattern mold 10. For example, sections 119 and 121 of the male portion 14 may have openings 123 and 125 disposed therein, which will receive bolts 127 and 129. Bolts 127 and 129 are adapted to threadably engage the internal threads near one end of the tubular metallic members 115 and 117, respectively, securing tubular members 115 and 117 in a depending position from the bottom sections of the male portion 14. Threaded insert members 131 and 133 may be disposed in the remaining ends of the tubular members 115 and 117, in order to seal their openings and prevent entry of liner material therein. Thus, when the liner 25 is applied to the male portion 14, it will also coat the tubular members. When the foam mold 30 has been formed, the bolts 127 and 129 are removed, and the tubular members 115 and 117 will remain in the foam mold 30 when it is removed from the pattern mold 10. The coating of the liner material about the embedded tubular members 115 and 117 will strengthen the bond between the mold 30 and tubular members 115 and 117. Tubular members 115 and 117 are selected to have a length such that the liner 25 on their extreme ends will be visible on the bottom portion of the foam mold when it is removed from the pattern mold 10. This facilitates the location of the tubular members 115 and 117, and the removal of the portion of the liner material, as well as the inserts 131 and 133. The same threads on tubular members 115 and 117 which receive inserts 131 and 133 may be used to accept compressed air fittings. The compressed air is applied to both tubular members simultaneously from a common header, in order to apply a uniform force to both ends of the cast electrical apparatus.

Instead of forming the center projection 34 of the foam mold 30 of foam, simultaneously with the formation of the main portion of the mold, the male portion of the pattern mold may be simplified by eliminating projection 20, which would then form a male pattern mold , 14', as shown in FIG. 4. Pattern mold 14' has a projection 18', flanged portion 19', and a plastic liner 25', similar to the male pattern portion 14, but it is easier to manufacture as it does not have the projection 20. The male pattern mold 14' shown in FIG. 4, cooperating with the female pattern mold portion 12 shown in FIG. 1, will provide a foam mold 30' as shown in FIG. 5, having a cavity 32' lined with a plastic liner 25'. The center post or projection 34', which in this instance may be formed of metal, such as aluminum, is mechanically secured in the desired position within the cavity 32' of the foam mold, such as by a nut and bolt combination 21.

The bolt or stud of the combination 21 may be cast into the foam mold at the time of foaming, by disposing a stud 23 in the male portion 14' of the pattern mold in a manner which will allow it to be transferred to the mold 30', as shown in FIG. 5. This function may be accomplished, as shown in FIGS. 4 and 4A, with FIG. 4A being a fragmentary cross-sectional view of FIG. 4. A threaded opening 27 is provided in the bottom section 18' of the male mold portion 14'. An upstanding tubular member or pipe 29, having a central opening 31, is threaded into opening 27. The stud 23 is then inserted through the opening 31 in the pipe 29, with the stud 23 being of sufficient length to extend past the upper end of the pipe. The upper end of the stud 23 is threaded, and a nut 33 is disposed thereon, to secure the stud 23 to the male portion 14'. The lower end of the stud 23 has a flanged portion 35, which has a larger diameter than the opening in the pipe 29, allowing the nut to draw the flange against the bottom of the male pattern mold portion 14'. The flanged end portion 35 is constructed to extend outwardly for a predetermined distance which will enable it to be deeply embedded in the foam mold 30' when it is formed, and it may have a plurality of projecting portions 37 which will strongly resist any force attempting to pull the stud 23 from the mold 30'.

The stud 23 is placed in assembled relation with male portion 14' prior to applying the liner 25', in order to coat the flanged end 35 with the liner material, which will strengthen the embedment of the stud in the mold. An opening 39 may be provided through the flanged portion 35, which will allow the liner material to enter and provide still additional strength for holding the metallic center post 34' in assembled relation with the foam mold 30'.

Compressed air may also be used to aid in the removal of the foam mold from the pattern mold, and also to aid in the removal of the cast electrical apparatus from the foam mold 30'. The nut, bolt, and pipe assembly 21, shown in FIG. 4A, lends itself to providing a suitable access for the compressed air. The I.D. of the pipe 29 and the O.D. of the stud or bolt 23 are selected to provide an annular airspace therebetween. Then, by threading the upper end of pipe 29 at 41, a compressed air fitting may be attached thereto, following the foaming of the mold, and the removal of the nut 33. The compressed air will break the bond between the liner 25' and the male portion 14', facilitating the removal of the male portion 14 from the foam mold 30'. As hereinbefore explained relative to FIG. 2A, compressed air may then be used to break the bond between the female mold portion 12 and the foam mold, by providing a suitable opening through the bottom section of the female portion 12.

When the foam mold 30' is removed from the pattern mold, the stud 23 will be in the upstanding position shown in FIG. 5. The metallic center post 34' may have an upstanding pipe 43 secured thereto, as shown in FIGS. 5 and 5A. FIG. 5A is a fragmentary cross-sectional view of the foam mold 30', shown in FIG. 5, after the center post 34' is in assembled relation with the foam mold 30'.

Center post 34' is substantially rectangular in shape, having a blind opening or cavity 47 therein which is defined by four wall sections 49, 51, 53 and 55, and a bottom section 57. Pipe 43 is disposed within cavity 47, and it has a threaded end which is disposed in a threaded opening 45 in the bottom section 57. Thus, the center post 34' may be placed within the cavity 32' of the mold 30', with the pipe 43 being telescoped over the upstanding stud 23. The threaded upper end of the stud 23 extends past the upper end of the pipe 43, for receiving a nut 61, which is tightened to securely hold the center post 34' in position during the casting step of the process.

Compressed air may also be conveniently used to break the bond between the cast electrical apparatus and the liner 25, by

providing a slightly concaved surface on the bottom section **57** of the center post **34'**, to provide a cavity **59** between the bottom section **57** and the liner **25'**. Thus, when it is desired to remove the cast electrical apparatus from the foam mold **30'**, the nut **33** is removed from the end of the stud **23**, and compressed air applied between the stud **23** and the pipe **29**. The upper end of the pipe **29** may be threaded at **41**, in order to secure a compressed air fitting. The compressed air is directed between the I.D. of the pipe **43**, and the O.D. of the stud **23**, into the cavity **59**, and between the cast electrical apparatus and the inner **25'**. The compressed air breaks the bond and gently lifts the casting partially from the mold. The center post **34'** may be removed from the cast electrical apparatus by a press. In this embodiment of the invention, the center post **34'** may be used as an anchor point to hold down any of the electrical apparatus to be encapsulated which would "float" out of position in the resin.

The pipe-stud-nut assembly **21**, therefore, may provide the functions of securing the center post **34'** in assembled relation with the foam mold **30'**, it may be used with compressed air to break the bond between the cast electrical apparatus, and the stud **23** may cooperate with a similar pipe and nut to break the bond between the male portion **14'** of the pattern mold and the liner **25'**, the time the foam mold is formed.

After the foam mold, such as mold **30** shown in FIG. **3**, is formed, the coils or windings to be encapsulated are placed in the desired position within the cavity **32** of the mold, the windings are heated to a predetermined temperature, the mold and windings are evacuated, and the cast resin system is vacuum poured. The vacuum is retained after pouring for a predetermined period of time to remove as much air from the resin system as possible. An insulating top is then placed on the mold, and the foam mold and top contain the heat of the poured resin system to effect the gelling of the resin. After the resin has gelled, the cast windings are removed from the foam mold, with the liner **25** providing a smooth surface on the cast windings, and also functioning as a noncontaminating mold release agent.

FIG. **6** is an exploded elevational view, partially in section, of a specific embodiment of the invention, illustrating electrical apparatus, such as the windings for a transformer, having an inner low voltage winding **40**, a high voltage winding **42**, and an outer low voltage winding **44**, FIG. **6** illustrates how these windings or coils may be telescoped into position about projection **34** within the cavity **32** of the foam mold **30**. The foam mold **30** is formed in accordance with the teachings of the invention, having a plastic liner **25** therein, such as shown in FIG. **3**.

The inner low voltage winding or coil **40** is formed of a plurality of superposed turns of sheet or foil conductor, such as aluminum or copper, having a coating of enamel insulation on at least one side thereof in order to insulate adjacent turns, or a continuous sheet of insulating material may be disposed between the turns. Terminals **46** and **48** are connected to the ends of winding **40**. The center projection **34** of the foam mold **30** locates and positions the inner low voltage winding. Since the cast insulating system should be disposed beneath the windings, one of the terminals, such as terminal **46**, may be arranged to extend below the bottom of the coil assembly, to form an extension **50** which supports the terminal end of the winding. A support **52** may be provided for the opposite end of the winding by disposing suitable insulating means, such as polysulfone, between certain turns of the coil as it is being wound. Thus, when the inner low voltage coil **40** is telescoped over the center post or projection **34**, the lower extension **40** of terminal **46**, and the insulating insert **52**, provide supports for holding winding **40** above the bottom of the foam mold.

The high voltage windings **42**, in this embodiment of the invention, is formed of first and second serially connected, axially aligned sections **54** and **56**. Each coil section is formed of a plurality of turns of electrically conductive foil or strip material, with the strip thickness being less than the thickness of the strip of which the inner low voltage winding was would. For example, a transformer rated 50 kva., 7,200 to 120/240 volts, may have low voltage coils **40** and **44** wound from an aluminum strip 6½ inches wide and 0.032 inch thick, and the high voltage coil **42** may have its sections wound from an aluminum strip 3 inches wide which is 0.0025 inch thick.

Since vertical ducts are necessary through the completed cast winding assembly in order to circulate a cooling medium therethrough, to aid in removing the heat from the encapsulated coils, the ducts and high voltage coil sections **54** and **56** may be constructed as shown in FIG. **7**, to properly locate and hold the duct former, and to locate and axially position and electrically interconnect the high voltage coil sections **54** and **56**.

More specifically, as shown in FIG. **7**, a metallic duct former **60**, having an end view as shown in FIG. **8**, is used to start the inner turns of the high voltage winding sections **54** and **56**. Duct former **60** has two major, substantially flat, opposed surfaces separated by a plurality of openings **62** which extend between its ends, and one of its major surfaces has a depression **64** therein which extends between its ends midway between its outer edges. This depression is sized to receive crimp-type terminals or connectors **66** and **68**. Duct former **60** also contains a slot **70** in the depression **64**, sized to allow an electrical conductor, such as a copper wire **72**, to be axially threaded therein. The connectors **66** and **68**, in addition to being crimped to the ends of the electrically conductive strips **74** and **76**, which form coil sections **54** and **56**, respectively, are also connected to the ends of wire **72**, to electrically connect the two coil sections **54** and **56** in series. The portion of the connectors which slips over the ends of the wire **72**, such as portion **78** of connector **66**, and portion **80** of connector **68**, fits snugly against the ends of the duct former **60**, to axially locate the coil sections. Suitable insulating means, such as sheets **82** and **84** of adhesive backed insulating paper may be placed on the duct former **60** to prevent the ends of the first turn of both coil sections from being shorted. The duct former **82**, disposed at the opposite side of the high voltage coil sections **54** and **56**, as shown in FIG. **6**, may also use adhesive backed insulating means to properly start and hold the first turns of the two coil sections in the proper axial relationship. The duct formers, such as duct former **60** shown in FIG. **8**, may also have a slot or depression **84** on its other major surface for fixing it to the winding mandrel. Thus, to wind the high voltage coil assembly **42**, the duct formers **60** and **82** are slipped into place on the winding mandrel, the adhesive backed insulation is placed in the proper positions on the duct formers, the connectors **66** and **68** are crimped to the ends of the electrically conductive strip material **74** and **76**, respectively, the wire **72** is threaded into slot **70** in duct former **60**, the ends **78** and **80** of connectors **66** and **68** are slipped over the ends of wire **72** and brazed, soldered, or otherwise suitably connected thereto, and the winding mandrel may be rotated slowly one turn to stick the strips **74** and **76** to the adhesive on the duct former **82**, and the mandrel may then be rotated to build up the desired number of turns. When the winding sections **54** and **56** are completed, crimp type terminals **86** and **88** may be connected to the ends of the strip material **74** and **76**, respectively, and wires **90** and **92** fastened to the terminals **86** and **88**, respectively, as shown in FIG. **10**, which is an end elevational view of the completed high voltage winding assembly **42**.

In order to prepare the duct formers **60** and **82** for the subsequent casting step, and prevent the casting resin from filling the opening **62** in the duct formers, duct plugs may be placed over the ends of the duct formers, as shown in FIGS. **6**, **7** and **9**. Duct plugs **94** and **96** may be placed at the top and bottom, respectively, of duct former **60**, and duct plugs **98** and **100** may be placed at the top and bottom of duct former **82**. The bottom duct plugs **96** and **100**, which may have upwardly extending locating pins, such as pins **97** and **99** in plug **96**, are used as supports to provide space below the winding section **56** for the cast resin system, and are also used to properly locate the high voltage winding section **42** by fitting into the

depressions **102** and **104** in the bottom of the foam mold **30**, which were formed by the projections **36** and **38** in the male portion of the pattern mold, as shown in FIG. **2**.

The top duct plug, such as plug **94**, has downwardly extending locating pins **101** and **103**, and airholes **105** and **107** which allow air to be removed from the ducts during the vacuum step of the process.

The top and bottom duct plugs, such as plugs **94** and **96**, as shown in FIG. **7**, may be interconnected by suitable rods **106** and **108**, which extend through the opening **62** in the duct former **60**. The rods may be threaded into suitable threaded openings in the bottom plug, and the assembly secured by nuts **110** and **112** which are threaded onto the upper ends of the rods. Nuts **110** and **112** may have suitable transverse openings therethrough to allow them to be used as lifting eyes during the handling of the high voltage winding assembly. The duct plugs have a suitable mold release material applied thereto, to prevent the poured cast resin system from adhering to the plugs.

After the high voltage winding assembly **42** is telescoped into position about the inner low voltage coil **40**, and positioned by fitting the lower duct plugs into the depressions in the bottom of the foam mold, the outer low voltage coil **44** is telescoped over the high voltage winding assembly **42**. The outer low voltage coil **44** is located by the inside surface of the cavity of the foam mold. The outer low voltage coil **44** may be formed in a manner hereinbefore described relative to the inner low voltage coil **40**, having terminals **114** and **116** connected to the ends of the electrically conductive strip material of which the coil is formed, and the supporting means for providing the clearance between the coil and the bottom of the foam mold may be provided by an extension **118** on one of the terminals, such as terminals **114**, and by a polysulfone inert **120** at the end of the winding opposite to the terminal end of the winding.

FIG. **6** also illustrates an insulating cover **122** which may be used to cooperate with the foam mold to contain the heat of the poured resin system for gelling the resin system. The insulating cover **122** may be formed of a foamed plastic resin system, similar to the foam mold **30**.

FIG. **11** is a perspective view of the foam mold **30**, with the inner low voltage coil **40**, the high voltage winding assembly **42**, and the outer low voltage coil **44** disposed within its cavity, about the center post **34**, ready for the casting step of the encapsulating method. In order to provide a thin coating of the cast resin system on the outside turn of the outer low voltage coil **44** and on the inside turn of the inner low voltage coil **40**, small insulating rods **122**, such as glass fiber rods one-sixteenth inch in diameter, may be placed between the foam mold and the outer low voltage coil **44**, and between the center post **34** and the inner low voltage coil **40**, at predetermined spaced intervals. These spacer rods may be removed after vacuum casting, or they may be left in place.

After the windings or coils are placed within the foam molds, as shown in FIG. **11**, and the spacing rods **122** placed into position, the assembly is ready for vacuum casting. The first step of the casting method is to heat the coils to approximately the same temperature as the cast resin system, for example, 150° C. plus or minus 5° C. for certain epoxy resin systems. This heating step may be accomplished electrically by shorting the terminals of each low voltage coil, and connecting the high voltage winding section to a source of electrical potential. The high voltage coil will be heated resistively, and the low voltage coil will be heated inductively. The mold and heated coils are then placed in a vacuum chamber, where the air is removed, and the cast resin system is then poured at a predetermined elevated temperature, while the mold and coils are held under vacuum. For example, the cast resin system may be poured at a temperature of 105° C. plus or minus 5° C. The vacuum is retained after pouring for a predetermined period of time, and then the mold is removed from the vacuum chamber. Copending application Ser. No. 675,841, filed Oct. 17, 1967, now U.S. Pat No. 3,529,320, which is assigned to the same assignee as the present application, discloses a production casting machine and method which may be used to encapsulate the electrical coils in the foam mold disclosed in this application. Any suitable casting resin system may be used, such as the epoxy resin systems disclosed in copending applications Ser. Nos. 447,237, now abandoned 456,038, now abandoned and 645,320, now U.S. Pat. No. 3,434,087, filed Apr. 4, 1965, May 6, 1965, and June 12, 1967, respectively, which applications are assigned to the same assignee as the present application.

After the foam mold and its contents are removed from the vacuum chamber, an insulating top **122**, as shown in FIG. **6**, is placed on the foam mold **30** to contain the heat of the poured resin system. Because of the excellent thermal insulating qualities of the foamed plastic, the cast resin system will gel without any additional heat, allowing the cast coils to be removed from the mold after approximately 2 hours, as shown in the exploded perspective view of FIG. **12**. The foam mold **30** may be used again and again, until it deteriorates to the point where it may no longer be efficiently used as an encapsulating mold.

The cast coil or winding assembly **130**, shown in FIG. **12**, may then be placed in an oven to cure the cast resin system **132**, or the cast winding assembly **130** may be again electrically heated, for example to 150° C., by shorting the low voltage coils and applying an electrical potential to the high voltage winding sections, and the heated cast winding assembly may then be placed in an enclosure or box formed of a foamed plastic for the post-cure cycle. The foamed plastic enclosure may be made from the same pattern molds used for forming the foam molds, but in this instance it will not be necessary to provide a liner, or a special master mold may be used to provide the post-cure enclosures, if desired. A typical post-cure time is 6 hours.

In summary, there has been disclosed new and improved encapsulated electrical windings, including a plurality of electrical windings formed of electrically conductive sheet material cast in a solid resin system. Electrical terminals are secured to the windings, which extend outwardly from the cast solid insulation, and support means for the windings extends from one end of the windings to one of the surfaces of the solid insulation, which provides the function of spacing the windings from the bottom of the mold cavity when the windings are cast in the insulation. The support means is provided for little additional cost by integral extensions on certain of the terminals and by insulating members disposed between the turns of the windings when they are wound.

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.

We claim as our invention:

1. An encapsulated electrical winding assembly comprising:
   - electrical windings having a plurality of superposed turns of insulated electrically conductive sheet material,
   - cast solid resinous insulating means disposed to encapsulate said electrical windings, providing a cast solid winding structure having first and second major opposed outer surfaces perpendicular to the axis of the electrical windings,
   - electrical terminal means connected to the ends of said electrical windings which extend outwardly from the first major surface of said cast solid winding structure,
   - and support means which extend from said electrical windings to substantially the second major surface, but not beyond, for supporting said electrical windings while they are being encapsulated, said support means including integral extensions on at least certain of said electrical terminal means.

2. The encapsulated electrical winding assembly of claim 1 wherein the support means also includes insulating members disposed between certain turns of the electrical windings.

3. An encapsulated electrical winding assembly comprising:
electrical windings having a plurality of superposed turns of insulated electrically conductive sheet material, with at least one of the electrical windings being divided into first and second axially separated sections, cast solid resinous insulating means disposed to encapsulate said electrical windings, providing a cast solid winding structure having first and second major opposed outer surfaces perpendicular to the axis of the electrical windings, terminal means connected to the ends of said electrical windings which extend outwardly from the first major surface of said cast solid winding structure, a duct former disposed through the cast solid winding structure, between the first and second major opposed outer surfaces, with the inner ends of said first and second axially separated winding sections being adjacent to said duct former, said duct former having an electrical conductor which extends therethrough, with the ends of the electrical conductor extending past the ends of said duct former, and means electrically connecting the ends of said first and second axially separated winding sections to the ends of the electrical conductor extending through the duct former, to serially connect said first and second axially separated winding sections.