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METHOD OF APPLYING INSULATING INCAPSULATION
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This invention relates generally to a method of applying insulating encapsulation and, more particularly, to a method of applying such encapsulation to an electrical unit for obtaining a coating of uniform dielectric strength.

This application is a continuation-in-part of my application Serial No. 821,211, filed on June 18, 1959.

In the construction of electrical units such as dry type transformers, it is essential that the insulation of the coils have uniform dielectric strength. The transformer must be rated at a maximum voltage which corresponds to the weakest point of the insulating coating. A common process for insulating such coils is by wrapping the coils with tape and subsequently impregnating the same with varnish. This process does not result in accurate dielectric thickness, especially so where the coil is of irregular shape, for example, toroidal shape. Furthermore the surface of each turn of tape and the region of lead penetration result in dielectric discontinuity. This process also has commercial drawbacks in that it involves excessive labor and material costs and is therefore costly.

A coating of the coils by a dipping process, while suitable for small coils, is not suitable for large coils, especially those requiring supports in addition to the connections leads themselves. Dipping is limited to the production of thin layers and multiple dips result in discontinuities between adjacent layers.

Coating by conventional casting or molding techniques do not avoid problem areas, that is, areas where the coils are supported during the coating process. In such processes where the supports are made of the same type of insulating material as the coating and embodied in the final coating a discontinuity remains between the independently hardened materials and it has been found that the breakdown voltages at such points are much less than for the rest of the insulation coating. Where several coatings are applied in superposed relation and optionally staggered it has not avoided the problem of uniform dielectric properties and there remained problem points at which insulation breakdown would occur at a lower voltage than characteristic of the remainder of the coating. Thus heretofore there has been no known technique for fully encapsulating a large dry type transformer with a uniform coating of sufficient thickness and dielectric strength to withstand high voltages.

It is accordingly the primary aim and object of the present invention to provide a method for fully encapsulating large transformer coils in a thick insulating coating having uniform dielectric strength over its entire area.

Another object of the present invention is provision of a method of applying insulation encapsulation which is suitable for large coils, for example, above 50 pounds, provides accurate and uniform thickness over the entire area, and which assures against discontinuity of dielectric and other physical properties in the coating.

Another object of the present invention is the provision of a method of applying insulation encapsulation of the aforesaid character which is simple and reliable, and is inherently economical and thus suitable for practice on a commercial scale.

Pursuant to certain embodiments of the present invention, the coil to be encapsulated is supported at several support areas while the coating is applied and the support areas are subsequently coated without any line of demarcation or electrical discontinuity at the boundary zone between the several coated areas.

In other embodiments of the present invention, the coil to be encapsulated is supported at several support areas by tapes or sheets formed of the material of the coating and the remaining areas are coated and intimately integrated with such tapes or sheets without any line of demarcation at the zones between the coated areas and tapes or sheets.

Other objects, features and advantages of the present invention will become apparent as the description thereof proceeds when considered in connection with the accompanying illustrative drawings, in which:

FIG. 1 is a schematic longitudinal sectional view illustrating one embodiment of mold for carrying out the method of encapsulating a large coil pursuant to the present invention;

FIG. 2 is a plan view illustrating another embodiment of mold for carrying out the method of the present invention;

FIG. 3 is a sectional view taken on the line 3—3 of FIG. 2;

FIG. 4 is a sectional view taken on the line 4—4 of FIG. 3;

FIG. 5 is a view similar to FIG. 2 illustrating a companion mold thereto for curing coating areas uncured in the mold of FIG. 2;

FIG. 6 is a sectional view taken on the line 6—6 of FIG. 5;

FIG. 7 is a plan view of a tape or sheet of plastic insulating material utilized in other embodiments of the present invention;

FIG. 8 is a schematic vertical sectional view of a mold for forming the tape or sheet of FIG. 7;

FIG. 9 is a view similar to FIG. 1 illustrating another embodiment of mold for carrying out a modified approach of the method of the present invention;

FIG. 10 is a plan view illustrating still another embodiment of mold for carrying out a modified approach of the method of the present invention; and

FIG. 11 is a sectional view taken on the line 11—11 of FIG. 10.

Briefly, one approach exemplifying the method of the present invention comprises the steps of applying a uniform coating of an uncured heat curing insulating material to a first surface area of the electrical unit to be coated, supporting the unit at a support area adjacent the first area whereby the support area will be covered and inaccessible for coating, heat curing the first surface area coating except at a border zone between the first surface area and support area in which zone the coating gradually diminishes in cure to an uncured region adjacent the support area, supporting the unit at a cured point of the first surface area and exposing the support area which is now coated with the uncured material. The uncured material is intimately merged with the material at the uncured region of the border zone and the latter and support areas are heat cured to encapsulate the unit with an insulating coating of uniform dielectric strength.

The insulating material M used is of a character which will form a solid, rigid or elastomeric, when subjected to heat under requisite pressure and time conditions. Thus the setting or vulcanizing of the material is a function of temperature, pressure and time and such material is generally commercially available and the curing schedules thereof are well known to those skilled in the art and well documented in commercial literature of the vendor—the material M per se forming no part of the present invention. Such materials can be applied to a
surface in any desired manner, as by a manual application using a trowel, or the like, dispensing the material against a surface or mold as in press molding or injection molding, or by casting in a mold. An example of a material found to be eminently suitable for the practice of the present invention is commercial silicone rubber, such as “Silastic” 80, a trademarked product of the Dow Corning Corporation. The properties and curing or vulcanizing temperatures of this material are well known and detailingly documented in commercially available technical literature supplied by the vendor and accordingly such characteristics are not set out here and are considered unnecessary to a clear understanding of the present invention. Suffice it to state that the curing temperature of the material of the exemplified embodiment is of the order of 250 degrees F. plus or minus 10 degrees.

The electrical unit to be coated in the example given in Fig. 1 is a transformer coil 10 which is shown in a complementary mold 12 defining a cavity 14 to accommodate the coil and the insulating coating to be applied thereon. Thus the peripheral gap 16 defined between the coil and walls of the cavity 14 is adapted to receive the insulating material M which forms the encapsulating coating. The mold 12 is a two-part mold having upper and lower mating parts 18 and 20, respectively which separate at parting line 22; the elements being assembled in relational assembly by fasteners 24. The upper mold part 18 is provided with a passage 26 which is adapted to be connected to a source of vacuum through control valve 28. The lower mold part includes a chamber 30 in communication with the space or gap 16, said chamber in turn being in communication with the reservoir 32 through passage 34 defined by conduit 36. Interposed in conduit 36 is a control valve 38 and the reservoir 32 is provided with an inlet fitting 40 controlled by valve 42.

The part 30 includes a pair of spaced supports S disposed in generally radial disposition which extend into the gap 16 to provide a two point support for the coil. The supports S have terminal ends 44 contoured complementary to the surface of the coil supported thereon. The supports S are mounted for axial reciprocation in part 30 between the extended position shown in Fig. 1 and a retracted position in ends 44 are spaced from the coil a distance corresponding to the thickness of gap 16 and the encapsulating coating. The desired axial adjusted position of the supports S are indicated through the use of cooperating index marks 46 and 48 which provide visual indication of position of the supports. The supports are axially reciprocated by suitable pinions 50 in mesh with companion racks 52 of the supports.

The part 54 includes connecting conduits 54, 56, 58 and 60, the conduit 54 having an inlet fitting 62 and the conduit 60 having an outlet fitting 64. A coolant, such as cold water, is admitted through fitting 62, circulates through connecting conduits 54, 56, 58 and 60 and is discharged at fitting 64 for cooling the regions adjacent the supports S for a purpose which will be apparent from the description which follows. The mold and supports are provided with suitable heaters 66 and 68, respectively disposed in companion cavities to cure the insulating material M in adjacent regions of the gap 16. Thermometers are shown at 70 to indicate curing temperature in the regions thereof. It being understood that the various regions may be provided with any suitable temperature indicating devices, as desired.

Curing temperatures may be achieved in any desired manner through heating devices of any well known type which may be manually or automatically controlled to achieve the desired degree of heating for the desired period. In the illustrated embodiment the heaters 66 and 68 shown are of the electrical resistance type.

In practice, the reservoir 32 is charged with uncured heat curing insulating material M of the character afore-referred to. With the valve 38 closed, a suitable source of vacuum is applied to the gap 16 through open valve 28 and passage 26 to draw all the air and moisture from the coil. The conditions of vacuum treatment correspond to the usual vacuum impregnation processes and depend on the character of the coil and are well known to those skilled in the art. In the example given 24 hours are required for approximately 6 hours will free the unit of air and moisture and surrounding contaminants, the vacuum treatment being optional and not critical to the technique of the present invention. Subsequent to this treatment valve 28 is closed and valves 38 and 42 are opened. Compressed air is now admitted through fitting 54 so as to squeeze material M through passage 34, into chamber 30 and into gap 16, the latter being entirely filled by the material except at the support areas defined by the extended supports S in the gap. The pressure may be of the order of 100-500 pounds per square inch, preferably of the magnitude of 460 pounds. After filling of the gap, the curing of the coating is effected except at the border zones adjacent the support areas. More particularly, the heaters 66 are energized to achieve the desired curing temperature and coolant (cold water) is circulated through the conduits 54, 56, 58 and 60 at the border zones adjacent the support areas, the pressure, temperature and moisture being retained in the liquid or resinous state for the requisite period to achieve curing in the region of the heaters. In the example given the curing temperature is 250 degrees F. plus or minus 10 degrees which is maintained for three minutes at the pressure indicated after the filling of the gap. This curing operation will result in a complete cure in the immediate region of the heaters 66 with the border zones adjacent thereto and extending to the supports diminishing in cure steplessly or in infinite increments, the regions immediately adjacent the support areas being uncured. This diminishing of cure is achieved by the coolant flow so as to leave the border zones resulting in a temperature gradient therein. The fully cured regions are solid enough to take over the support of the unit.

The supports S are now axially retracted an amount corresponding to the thickness of coating by actuating the support 44 corresponding to the desired thickness of coating, the fully cured regions taking over the support of the unit which does not change position in the mold. The pressurized material M is now admitted to the exposed support areas below support 44 to fill the same. This material is in the axial position and obeys the uncured material at the adjacent edges of the mold so as to intimately merge therewith. The flow of coolant is shut off and the coolant passages are drained. The heaters 68 are energized to curing temperature to cure the border zone and support area coatings in the manner aforementioned with reference to cured regions adjacent heaters 66. This will result in fully incorporating the unit or coil in a coating of uniform dielectric strength, there being no discontinuities or areas of demarcation in the fully cured coating which in the instant example is ¼ inch thick.

After the pressure is released, valves 38 and 42 are closed and the mold parts are separated so as to permit the uncapsulated coil to be withdrawn from the mold. The material in the region of the support in the injection passages breaks away from the unit as it has not been cured and if a stub remains it may be readily trimmed from the unit. It is in the present invention to encapsulate any desired unit using any desired insulant having the aforementioned properties as will be apparent to those skilled in the art, the above specific embodiment being given by way of example only to illustrate the detail of the invention. The pressures, temperatures and times noted above are also given by way of example only in connection with the use of
"Silastic" 80 to incapsulate unit 10, the pressures, temperatures, and times as related to this incapsulant being a function of the size, shape, and character of unit and the incapsulating layer to be formed thereon. With reference to FIGS. 2-5, there is shown another embodiment of mold for carrying out the method of the present invention, this embodiment differing from the previously described embodiment in the respects which will be noted below. The mold 72 is of annular configuration to accommodate a unit 10' of corresponding configuration, said mold comprising upper and lower mold parts 76 and 77, respectively, which separate on a parting line 78. The mold is releasably retained in assembled relation by fasteners 80. The mold is provided with three equidistantly spaced portions 82 of reduced diametrical extent which define supports for the unit 10' in the mold. Beyond these portions 82, there is defined in the mold a gap 16, corresponding to the gap 16 previously described, to receive the insulating material M in surrounding relation with the unit. The mold is provided with border zones 84 adjacent portions 82 having openings 86 open to atmosphere for a purpose which will be apparent from the description which follows. Thus the mold is open to atmosphere at openings 86 adjacent the support areas of the unit. The major peripheral portions 88 of the mold have heaters 90 extending therearound for curing material M at said portions in the manner previously described. Thus mold 72 is provided with three zones, portions 82 which define curing zones, portions 84 which define support areas, and portions 88 which define border zones in which the cure dimensions in the manner of the border zones of the previous embodiment.

Companion to mold 72 for use in the second and final stage of the process, is a mold 72' shown in FIGS. 5 and 6. Mold 72' has upper and lower mold parts 92 and 94 which define a cavity 96 of uniform cross section to accommodate the incapsulated unit 10". The cavity 96 is closed to atmosphere and major equispaced peripheral portions 98 of the mold have surrounding heaters 100 corresponding to heaters 90.

In practice, the bottom part 76 of the mold 72 is lined with a layer of uncured material M which may be applied in any suitable manner as manually with the aid of a trough, the portions 82 being left uncovered. The coil or unit 10' is lowered into such lined mold part with due care being taken to insure that the gap between the coil and mold part is completely filled. Because of the construction of the mold, the coil is supported at the uncovered portions 82 of the mold which are of reduced cross section. Material M is similarly applied to the upper half of the coil except at the regions in the projected area of portions 82. The upper part 74 is secured on the lower part 76 of the mold, due care being taken to insure that the gap between the coil and mold part 74 is completely filled. The coil will be uncured with the insulating material M at mold portions 82 and while covered at portions 84, the insulant will be exposed to the atmosphere through openings 86. Thereafter the heaters 90 are energized and brought up to vulcanizing temperature for the requisite time. Suitable temperature indicating devices (not shown) will be provided to check the temperature at the gap. In any case, in the case of a gap of the magnitude of 3% of an inch the temperature should be brought up quickly to 260 degrees F. and maintained for 5 minutes. This cures material M at portions or zones 88 to a strength sufficient to carry the weight of the unit. At the border zones 84 the cure diminishes in the manner of the previously described border zones since the heaters 90 provide a temperature gradient thereat and the openings 86 expose said zones to atmosphere.

The unit is now removed from said mold 72 and the uncured portions 82 will now be manually covered with material M to a thickness corresponding to the thickness of the previously applied layer and intimately integrated with the material at the border zones. At this time the unit is supported on the fully cured zones 88 of the incapsulating layer. The now fully incapsulated coil 10" is positioned in mold 72' to register the zones 82 and 84 thereof to be vulcanized with the peripheral portions 98. The heaters 100 are energized and brought up to vulcanizing temperature for the requisite time to fully cure the material at zones 82 and 84. In the example given the temperature is brought up to 260 degrees for five minutes to complete the curing of the incapsulating layer. The mold 72 is also provided with suitable temperature indicating devices (not shown). On full vulcanization the heaters are de-energized and the incapsulated unit is removed from the mold to complete the incapsulating operation.

The method described above has been found suitable for incapsulating relatively heavy coils in an insulating layer of accurate and uniform thickness over the entire area, there being no discontinuity of dielectric or other physical properties in the coating. The method of the present invention is applicable to produce a coating of any desired thickness within the range of practical coating thicknesses. The insulating layer exhibits a substantially uniform resistance to voltage breakdown and does not produce any localization of stress concentration in the dielectric.

Brieify, another approach exemplifying the method of the present invention comprises the steps of providing a sheet of plastic insulating material having a cured portion, an uncured periphery and a border zone defined between the cured portion and periphery in which the cure thereat diminishes towards the periphery, supporting the unit at a support area by the cured portion of the sheet, uniformly coating the unit beyond the periphery of the sheet with the same material in an uncured state and intimately merging the same with the uncured material at the periphery of the sheet, and curing the uncured material of the sheet and coating. The same plastic insulating material M, as previously described, is utilized in this approach which results in the incapsulation of the unit with an insulating coating of uniform dielectric strength corresponding to the coating of the previous embodiments.

With reference to FIGS. 7 and 8, the sheet or tape 102 is of elongated rectangular configuration and is formed of insulating material M, said tape having a longitudinally extending cured portion 104, an uncured periphery 106, and a border zone 108 defined between said cured portion and periphery in which the cure thereat diminishes. The longitudinally extending fully cured portion 104 is adapted for the support of the unit during the incapsulating operation as will be described in detail hereinafter. A mold 110 for forming the tape 102 is schematically illustrated in FIG. 8, said mold comprising a complementary pair of mold parts 112 and 114 which in their closed mating relation defines a cavity 116 therebetween of a size and configuration corresponding to tape 102. The mold parts are releasably retained in assembled relation by means of suitable fasteners 118. The mold parts include passages 120 for a suitable coolant medium and passages 122 for a suitable heating medium, said passages being discreetly located with respect to the cavity 116 for forming the tape 102 having the zones thereon described aforementioned.

The cavity 116 is charged with insulating material M in an uncured condition and with or without the aid of pressure as dictated by the character of the specific insulating material M utilized. A coolant, such as cold water, is admitted through the passages 120 and a heating medium, such as steam, is passed through the passages 122 during the molding or forming operation, it being apparent that the heating medium results in the cure of the material at portion or zone 104 with the cooling medium resulting in an uncured periphery 106. The transition zone between
heating and cooling defines the border zone 108 in which the cure thereat diminishes towards the periphery 106.

With reference to FIG. 9, the mold 124 for encapsulating the transformer coil 10a is of a construction similar to the mold 12 previously described, differing therefrom in the respects to be pointed out hereinafter. The mold 124 is devoid of supports S and associated structure as the initial support for the transformer coil is provided by tapes 102. The mold 124 defines a cavity 126 to accommodate the coil and the insulating coating to be applied thereon for encapsulating the coil. The mold 124 has upper and lower mating parts 128 and 150, respectively which are releasably retained in assembled relation by suitable fasteners 132. As in mold 12, the upper mold part 128 is provided with a passage 134 which is adapted to be connected to a source of vacuum through a suitable control valve 136. The lower mold part includes chamber 138 in communication with the unoccupied space 140 defined between the coil 10a and the walls of the cavity 126, said chamber in turn being in communication with the reservoir 142 through passage 144. A valve 146 is provided for passage 144 and the reservoir 142 has an inlet fitting 148 which is controlled by valves 150. The mold is provided with suitable heaters 152 disposed in companion cavities to cure the insulating material M in the peripheral gap or space 140. From the above it will be apparent that the mold 124 corresponds generally to the mold 12 previously described except that the latter is additionally provided with supports S and associated structure and means for circulating a coolant adjacent to such supports.

In practice, a plurality of tapes 102 are wrapped around the transformer coil 10a in spaced radial fashion and the coil and surrounding tapes are fitted into the cavity 126 of the mold 124. As shown in FIG. 9, the tapes 102 are disposed in the mold in a manner to be described hereinafter. In this way the cured portions 104 of the tapes 102 provide the initial support for the coil in the mold, thereby obviating the need for supports of the character of supports S of the first described embodiment. Accordingly, the tapes provide a supporting medium for the coil, and simultaneously position the latter in the mold so as to secure uniform encapsulation.

The reservoir 142 is charged with uncured heat curing insulating material M and with the valve 146 closed a suitable source of vacuum is applied to the gap 140 through open valve 148 to draw all the air and moisture from the cavity in the manner previously described. Thereafter valve 146 is closed and valves 148 and 150 are opened. Compressed air is injected into the reservoir so as to pressurize the material M for flow into the chamber 138 and into gap 140, the latter being entirely filled by the material. Thus all the unoccupied space defined between the external surface of the coil and the cavity walls of the mold is filled by material M. After the filling operation, the curing of the coating and tapes is effected by energizing the heaters 152 to achieve the desired curing temperature. It will be noted that prior to curing the peripheral edge 106 of the tapes 102 and the added material M of the coating are in an unsealed state and intimately merge without any lines or areas of demarcation. The desired curing temperature is maintained for the requisite curing time as previously described to result in a complete cure of the uncured portions of the tape and the flowed in coating. The unit or coil is thus fully encapsulated in a coating of uniform dielectric strength without physical or electrical discontinuities. The fully encapsulated transformer coil is removed from the mold 124 in the manner previously described. The material in the region of the injection passages may be readily broken away or trimmed from the unit.

With reference to FIGS. 10 and 11, there is shown another embodiment in the form of a mold 156 for carrying out the approach or technique of the present invention exemplified with reference to FIG. 9. The mold 156 is of annular configuration and has a cavity 164 to accommodate an encapsulated unit 160, said mold comprising upper and lower mold parts 158 and 160, respectively which are releasably retained in assembled relation by suitable fasteners 162. There is defined a peripheral gap 150 between the external surfaces of the transformer unit and the cavity walls, said gap being of a uniform thickness corresponding to the thickness of the coating to be formed on the unit. The tapes 102 are wrapped around the unit 10a for the support thereof in the manner described above with reference to the previous embodiment and this assembly is enclosed in the cavity 164. As in the previous embodiment, three tape zones are defined, a support zone in which the unit is supported on cured portions 104, an uncured peripheral zone 106, and a zone 108 having a cure which diminishes towards the peripheral zone. The unit is supported at spaced areas in the mold by the cured portions of the tapes. A cylindrical reservoir 166 is provided in mold part 158, said reservoir having a complementary reciprocating ram 168 for pressurizing the material M disposed therein in an uncured state. The reservoir 166 communicates with the injection passages 160. The coating operation is effected by reciprocating ram 168 downwardly to cause the flow of material M into the unoccupied space or gap 164 in the mold. The material M will intimately merge with the material in like state at the periphery of the tapes.

Surrounding the mold parts are heating chambers 172 having inlets 174. A suitable heating medium, such as steam, is admitted through the inlets 174 to the heating chambers 172 for curing the uncured material of the tapes and coating. Suitable passages 176 may be provided in the mold parts for drainage purposes. On full curing or vulcanization of the material M the heating operation is terminated and the fully encapsulated unit is removed from the mold.

From the above it will be apparent that the fully cured zone of the tapes provide the initial support for the coil during the encapsulating and that the technique exemplified with reference to FIGS. 10 and 11 corresponds to the technique described above in detail with reference to FIG. 9. Thus apparatus of the character of molds 12 or 72 may be utilized in which the mold itself includes support structure for the encapsulating unit, and, if desired, tapes, or the like, having fully cured support zones may be utilized for the initial support of the unit during the encapsulating operation as described in connection with the embodiments of FIGS. 9 through 11.

It will be obvious that the encapsulating method of the present invention may be used for encapsulating electrical equipment, and the like, other than transformer coils. It will also be evident from the foregoing description that those skilled in the art of electrical insulation and of applying insulation coatings will be able to make various changes and modifications in the method without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A method of encapsulating an electrical unit with a coating of uniform dielectric strength, comprising the steps of applying a uniform coating of an uncured plastic insulating material to the surface area of said unit except for a support area adjacent said coated surface area, said coated surface area having a border zone adjacent said support area and defined between said coated and support areas, curing said coated surface area and gradu-
A method of encapsulating an electrical unit with a coating of uniform dielectric strength, comprising the steps of providing a plurality of tapes of plastic insulating material having a cured portion, an uncured peripheral zone and a partially cured border zone defined between said cured portion and periphery in which the cure zone is essentially complete, uniformly coating the remaining surface areas of said unit at spaced support zones by said cured portions of said tapes, uniformly coating said unit beyond said periphery of each tape and filling the space therebetween with said material in an uncured state and intimately merging the same with the uncured material at said periphery, and curing said uncured material of said tapes and coating.

A method of encapsulating an electrical unit with a coating of uniform dielectric strength as defined in claim 8 in which said insulating material is of the heat curing silicone rubber type and in which said coatings and coating are substantially of uniform predetermined thickness and free of dielectric and physical discontinuities.

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