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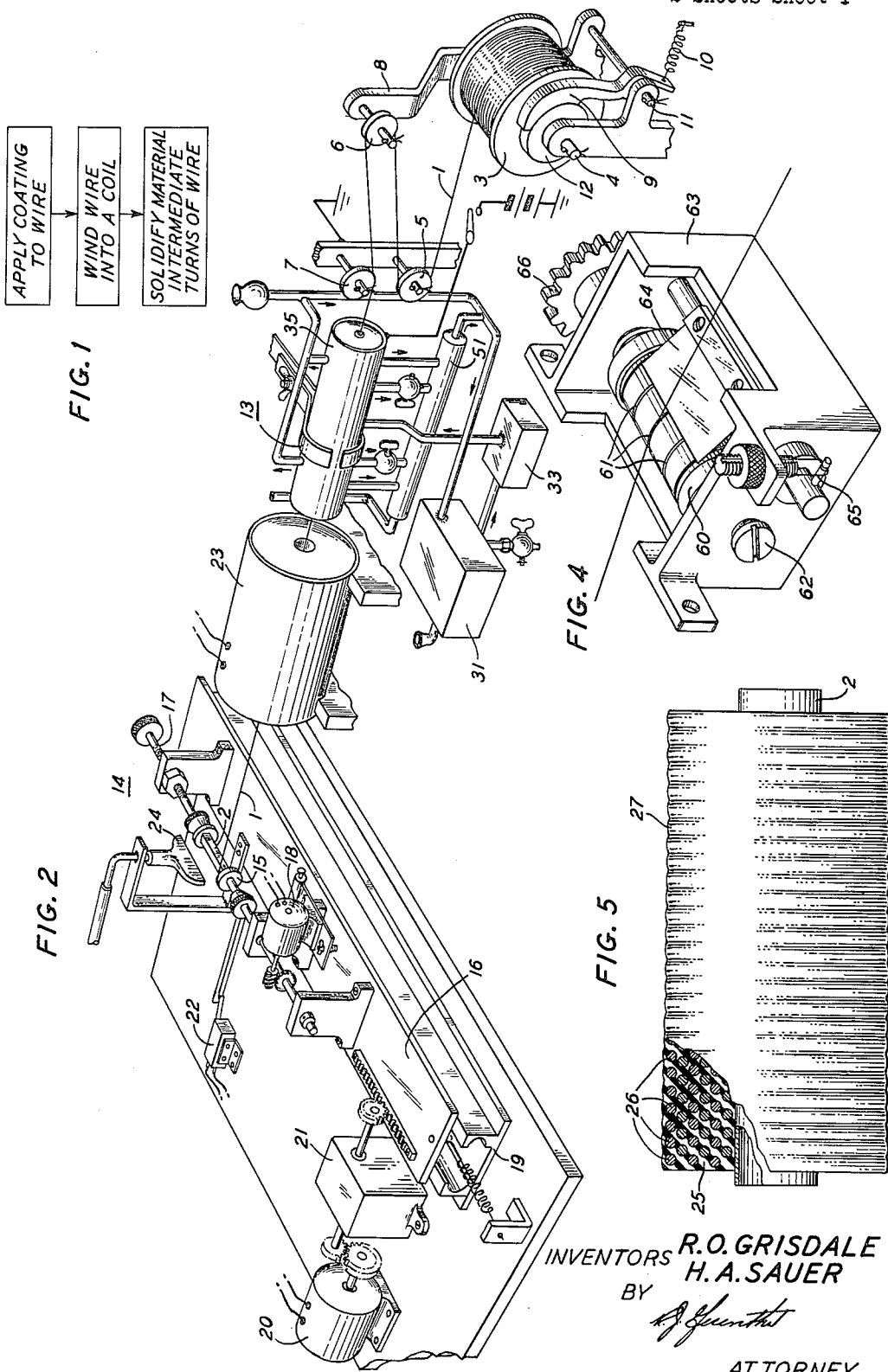
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METHOD FOR PRODUCING CONDUCTING COILS

Filed Aug. 4, 1951

2 Sheets-Sheet 1



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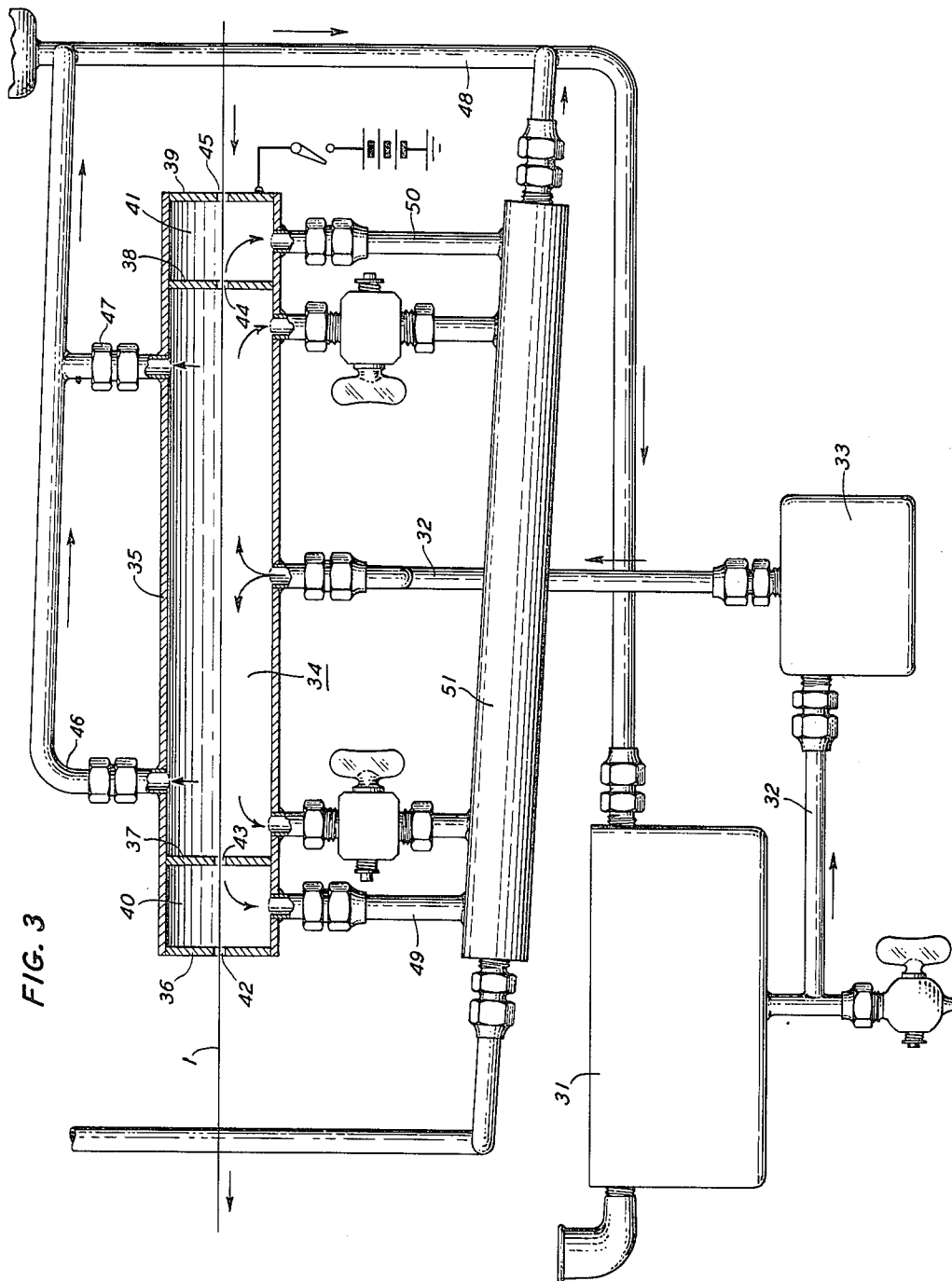
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2,739,371

METHOD FOR PRODUCING CONDUCTING COILS

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This invention relates to coils and methods of their manufacture and more particularly to coils having their turns embedded in a matrix, otherwise known as filled coils, and their methods of manufacture.

Heretofore in the manufacture of high quality electrical coils it has been common practice to insulate and provide for the mechanical separation of the individual turns, and then to impregnate the entire coil structure with a filler in operations which are separate and distinct from that of winding the coil. Thus, the conductor employed for the winding usually is coated with a relatively high quality coating which is sufficiently tough and abrasion resistant so that it can be respooled and otherwise handled prior to the winding operation without damage. In effecting the mechanical separation of adjacent turns and layers of coil turns made up of the coated conductor, the coating and sheets of insulating material between adjacent layers are usually relied upon. Following the winding operation, the coil is impregnated with filler material which is injected in its interstices and mechanically set to improve the insulation between turns and to bond the coil into a unitary structure.

It has also been suggested that the separate impregnating step can be eliminated in the manufacture of high quality coils by employing a conductor which has been covered with a porous material such as asbestos, paper, cotton or other fibrous material, or with a layer which is impermeable to liquids such as insulating enamel and by applying a plastic coating to the covered conductor immediately preceding the winding of the coil. The plastic coating of this construction, due to its initial fluidity, replaces the filler impregnant of the coils described above in that it fills the coil interstices, improves the electrical insulation between turns and when solidified bonds adjacent turns and layers of turns together, while the initial conductor covering provides the means for insuring mechanical spacing between turns.

Objects of this invention are to improve and simplify the manufacturing process for and the construction of coils having their turns embedded in a substantially solid matrix.

A more specific object is to eliminate in the manufacture of coils the separate operations of insulating, mechanically spacing, and bonding together of the conductor turns and of filling the coil interstices. Another object is to reduce the number of handling, prefabricating and storing steps in manufacturing coils.

Other objects of this invention are to reduce the number of elements in coil structures, to reduce the size of coil structures without any sacrifice in their rated capacities or their operating qualities, to reduce the cost of coils, to increase their thermal conductivities, and to improve their copper efficiencies.

In accordance with features of this invention, a series of manufacturing steps are so combined that they produce filled coils in a single continuous series of operations. The initial operation in this process is the coating of the

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bare conductor which is to be utilized as the turns of the coil. The conductor at the instant it is incorporated into the coil by the winding operation bears a coating which is of such a nature that it mechanically separates the adjacent turns of conductor, yet is sufficiently fluid to fill the interstices between adjacent coil turns and to coalesce with the coatings on adjacent turns into a homogeneous matrix. This condition of the coating is achieved by a combination of factors including its composition, its method of application and its treatment in the interval between its application and the winding of the conductor into the coil.

A feature of this invention resides in producing coils embedded in a substantially solid matrix, in a continuous operation beginning with a bare conductor.

Another feature resides in utilizing resins applied as coatings to the conductor immediately preceding its being wound into a coil as the means for maintaining the mechanical separation, the electrical insulation and the bonding together of adjacent coil turns and as a coil filler whereby a more compact and continuous mass of embedded coil turns is produced.

In accordance with one feature of this invention, the mechanical separation of the coil turns by the coating is insured by imparting sufficient mechanical set to at least a portion thereof so that it will maintain itself between the coil turns.

This condition can be advantageously achieved by applying a plurality of coating layers to the bare conductor, the initial coating layer or layers being solidified or set mechanically as by heating or other curing techniques prior to the application of subsequent layers. When the process is practiced in this manner, the outer portion of the conductor coating provides sufficient fluid material to fill the interstices between the turns and to bond adjacent turns together as the winding progresses. After the conductor is incorporated in the coil structure all of the coating material is solidified.

In accordance with another feature of this invention, the conductor turns of a coil are maintained mechanically separate by finely divided solid insulating particles positioned between them. These separating particles may be incorporated into the structure by applying them to the conductor in a fluid vehicle which also serves as the filling and bonding material of the finished coil. This combination permits the mechanical setting of the fluid, at least to any extent in excess of that necessary to maintain the spacing particles on the conductor, to be delayed until the coil has been wound, thereby insuring the free flow of filler into the interstices of the coil and the establishment of a homogeneous matrix comprising a dispersion of the spacing particles in the solidified vehicle.

Another feature of this invention resides in curing or otherwise effecting a solidification or a mechanical set of the filler material in the coil structure as it is built up so that the turns of the coil are embedded in a solid mass which requires no further treatment when they are removed from the winding machine.

A further feature of this invention resides in a coil structure composed of adjacent turns embedded in a substantially homogeneous matrix. This matrix which is continuous and uninterrupted through the structure provides a more rapid conduction of heat to the exterior than is characteristic of those prior structures containing multiple insulating layers on the conductors, voids between the conductors and interleaving between layers of conductor turns.

The invention, together with the above-noted and other objects and features thereof, will be more fully understood from the following detailed description when read

with reference to the accompanying drawings in which:

Fig. 1 is a block diagram of the method of this invention;

Fig. 2 is a representation of an apparatus used in carrying out the method of this invention;

Fig. 3 is a front view, partially in section, of the coating cell shown in Fig. 2;

Fig. 4 is a perspective view of a roller applicator which may be used in lieu of the coating cell shown in Fig. 3; and

Fig. 5 is a partially sectioned view of a coil constructed by the method of this invention.

As is illustrated in the block diagram of Fig. 1, in manufacturing a winding or coil according to this process, a continuous series of operations is practiced starting with an uninsulated conductor and terminating with a completed rigid self-supporting winding. These operations broadly comprise applying one or more resinous coatings to a bare conductor to produce thereon a surface which insures that the turns of the conductor, when it is wound into a coil, will be electrically insulated and mechanically separated from each other and which also filled the interstices between the turns and bonds them together to form a unitary structure, winding the conductor into the desired coil form, coalescing the coatings of adjacent turns, and solidifying the coatings.

In producing a coil structure of the filled type from bare conductor four basic problems present themselves; first, that of maintaining mechanical separation of the adjacent turns of bare conductor in the coil structure; second, that of establishing a continuous electrically insulating coating between adjacent conductors; third, that of filling the interstices of the coil with insulating material, and; fourth, that of bonding the spaced and insulated turns into a unitary structure. Mechanical separation of adjacent turns can be maintained even where surface tension effects of the fluid filler material and the pressures applied by the winding operation tend to pull or otherwise force the turns together if a form of solid spacer is placed between all turns as the structure is built up. In embodiments of the present invention, two forms of mechanical spacer have been provided, each of which is uniformly distributed over the conductor surface to insure its separation from all adjacent turns, and each of which is applicable to bare conductor at a rate equal to the winding speed of the coil in which it is to be employed.

One form of mechanical spacer functioning as outlined above comprises a layer of insulating material applied by one of the processes and of one of the types discussed hereinafter. Several layers of coating material are employed when this type of spacing means is utilized, the initial layer or layers being solidified sufficiently so that the mechanical rigidity thereof is sufficient to maintain a coherent coating on the conductor throughout the subsequent coil forming operations. Solidifying to this extent can be accelerated in a convenient manner such as the application of heat or a solidifying agent. Immediately following the solidifying of the initial coating, more material of the same or a different kind is applied and maintained in fluid form until the conductor is wound to provide for the filling and bonding of the coil.

Alternatively, finely divided solid insulating material located between the coil turns can be employed as mechanical spacing means. Particles of this material insure a separation between turns at least as great as their diameter and thereby permit a layer of fluid at least equally thick to remain between the adjacent turns in the wound structure. Solid spacing particles can be applied and maintained on the conductor by several means. For example, the particles can be applied from a suspension and maintained by an adhesive applied to the bare conductor, the particles can be attracted to and maintained on the conductor by electrostatic means, or a suspension of the particles in a fluid vehicle can be applied. The first two methods of application require the addition of a fluid

bonding and filling material which also forms an insulating film on the conductors between the spacing particles. This fluid coating can be applied either before or after the spacing particles and advantageously is of a nature that it further aids in maintaining the particles on the conductor. The latter method of application is advantageous in that it eliminates the step of separately applying the fluid. When the spacing of the turns is accomplished by finely divided particles the coating material can be applied in a single coating step, it can be incorporated in the coil in a more fluid form thereby insuring more complete filling of the interstices, and the space factor of the coil can be increased through increase in copper cross section relative to coil cross section. Since no continuous solidified film exists on the conductor turns, no extra layer providing for the bonding of adjacent turns is necessary, the fluid between the solid particles performing the bonding and filling functions in addition to providing a continuous insulating film over each conductor turn.

In preparing a bare conductor for use in certain embodiments of this process, a minimum of cleaning is necessary, since after the process is initiated there is no further handling of the conductor other than by the apparatus for practicing the process and therefore the mechanical properties of the coating and the bond between it and the conductor are not subject to the stresses that ordinary insulated conductor encounters. It has been found practicable, when the coating is applied electrophoretically, to employ conductor as it is supplied from the manufacturer and to embody an electrolytic cleaning as one step in the continuous sequence of operations.

Both thermosetting and thermoplastic materials generically referred to as resinous materials can be employed as the basic coating and are applicable either to the bare conductor or to conductor which, in a previous step of continuous process, has been insulated with a cured layer of resinous material which may or may not be similar to that of the bonding layer. Both the thermosetting and the thermoplastic materials are suitable vehicles for suspended solid spacing particles.

Thermosetting material is usually in liquid form when applied although it can also be applied as a finely divided solid which is coalesced by moderate heating; this process involves the cross-linking of polymerization of the material. Suitable thermosetting materials include fast curing phenolics, and epoxy resins when cured in the presence of oxygen.

Thermoplastic materials can be applied as heated liquids or as finely divided solids which are coalesced by heat. These materials should have softening temperatures above the operating temperatures of the coils in which they are employed. Polyamides, polyvinyl chloride, polyethylene, butadiene-styrene-acrylonitrile copolymers, butadiene-styrene copolymers, acrylic resins, and fluorocarbon resins such as polytetrafluoroethylene and polymonochlorotrifluoroethylene all have acceptable thermoplastic characteristics.

Solid insulating materials which can be employed conveniently in finely divided form as spacer bodies between adjacent conductor turns may include among other substances finely divided silica, aluminum silicate, magnesium silicate, mica, lead chromate, lead titanate, titanium dioxide, zinc oxide, iron oxide, aluminum oxide, copper oxide, talc, and cellulose nylon or other filamentary floc. Any of these materials either singly or in combination may be suspended in a fluid vehicle providing the coil filling and bonding, and such vehicles hereafter will be referred to as "loaded fluids."

Any suitable coating method can be employed for applying the coating materials in either the loaded or unloaded state to the conductor. Thus, when in a finely divided solid state, they can be applied from a liquid or gaseous suspension by electrophoretic or other suitable means. When the suspending fluid is water it can

be removed from the deposited coating by moderate heating of the conductor prior to the winding operation. Suspending fluids such as divinyl benzene and acrylonitrile need not be removed when employed for example, with polyester and butadiene-styrene co-polymers, respectively, since they cross-link or polymerize with the suspended material to become a part of the coating. Materials which are in the liquid state can also be electrophoretically applied by suspending them as globules in a suitable immiscible liquid. However, the more common practice with liquid coating materials is to apply them by a drag, dip, or spray technique, for example, by a die-wipe process or by a roller coat process.

After a coating has been applied to the wire it may be solidified. Where a plurality of layers is employed each layer may be solidified or partially solidified prior to the application of further layers. Thermosetting coating materials are conveniently solidified by the application of heat while thermoplastic materials are first coalesced by heat and are then cooled below their melting temperatures. Either type of coating must be conditioned so that its mechanical stability is sufficient to maintain it and any solid spacing particles suspended therein on the wire surface when the conductor is subjected to the next step in the coil manufacturing process.

When the bonding layer has been applied to the conductor, the conductor is wound into a coil with the coatings of adjacent turns in contact in the usual manner. A bond is formed between the coatings on adjacent turns of the winding either by virtue of the tackiness or fluidity of the partially set coatings or by applying heat to soften the coatings thereby coalescing them. The coalesced coatings are then completely set by freezing the thermoplastic material or by heating the thermosetting material to cure it. The coil is then in condition to be assembled with the core, terminals, mounting means and other elements with which it is employed. An armoring coat of plastic material can be applied over the outer layer of turns before the final curing or as the final assembly step if desired.

An example of the product resulting from the above-described steps is shown in Fig. 5 from which it can be seen that the overlying layers of turns of conductor 26 are embedded in a substantially continuous matrix 25 of homogeneous material which maintains the turns mechanically separate and electrically insulated from each other in a rigid body 27. "Homogeneous" as applied here to the material of the matrix describes a mass of material which is essentially uniform in composition throughout although it may be composed of a resinous mixture or such a mixture with solid insulating particles uniformly distributed therein. It is to be noted that no insulating interleaving is employed between the layers of turns. The absence of interleaving improves the thermal conductivity of the structure since it is more compact, the heat paths being shorter and more nearly continuous than heretofore. This improved thermal characteristic provides a higher rate of heat dissipation, thus making the coil structure suitable for operation at higher loads than for the usual coils of similar size. Another advantage of this construction resides in the increased ratio of the cross-section area of bare conductor to the total cross-section area of the coil to improve the copper efficiency. Further, voids are unlikely in this structure since the impregnating material is applied to each portion in the proper amounts as it is built up and need not be forced into the completed structure, thus resulting in an increased electrical breakdown strength. A solid construction as achieved here also creates a more rugged body which can withstand high compressive forces.

Referring now to Fig. 2, typical apparatus is shown for constructing a coil from bare wire in a continuous operation according to this invention. A wire 1 which is to be wound upon a core or core tube 2 into a coil is contained in or stored upon a spool 3 which is mounted

upon a shaft 4. The wire 1 is properly tensioned and aligned as it comes from the spool by the pulleys 5, 6, and 7 and a brake mechanism comprising the pulley 6, the bracket 8, the brake 9, and the spring 10. The bracket 8 is mounted to rotate about the shaft 4 and is coupled by means of gears (not shown) to the shaft 11 to which the brake 9 is attached. As the tension in the wire 1 tends to increase, the force exerted by the wire 1 upon the bracket 8, transmitted through the pulley 6, causes a diminution in the pressure between the brake 9 and the brake disc 12 whereby the tension in the wire is decreased. On the other hand, as the tension in the wire 1 tends to decrease, the pressure on the brake band 12 is increased whereby the tension in the wire is increased.

The wire is passed through an electrophoretic applicator 13 whereby a coating or a layer of a coating material is applied thereto. This applicator is shown in detail in Fig. 3. The coating material is pumped from the reservoir 31 through the pipe 32 by the pump 33 into the chamber 34 of the applicator 13. The applicator 13 essentially comprises a cylindrical tube 35 which, with the walls 36, 37, 38, and 39, defines the chambers 34, 40, and 41. The wire 1 is passed through the apertures 42, 43, 44, 45 in the walls 36, 37, 38, and 39. The coating material rises in the pipes 46 and 47 until the overflow point is reached and then flows back to the reservoir 31 via the pipe 48. A portion of the coating material flows from chamber 34 through the apertures 43 and 44 into the chambers 40 and 41 from where it flows under the influence of gravity through the pipes 49 and 50 and the manifold 51 to the reservoir 31. In coating the wire as it passes through the chamber 34, advantage is taken of the electric charge on the dispersed particles of the coating material. For example, if the particles in the dispersion are positively charged, that is, cationic, the wire may be grounded, for example, by grounding the pulley 7 if this pulley is of a conducting material, and the cylindrical portion 35 of the applicator 12 charged positively by means of a battery. Under the influence of the electrostatic field thereby set up between the wire 1 and the cylindrical portion 35 the particles of the dispersion will be attracted toward and adhere to the wire 1. Similarly, if the particles are negatively charged, that is anionic, the cylindrical portion can be biased negatively with respect to the wire 1 and the particles will likewise adhere to the wire 1.

The electrode position type of applicator shown in Fig. 3 is further advantageous in that it affords a convenient method of providing an electrical connection to the coil at prescribed points in the winding. The momentary destruction of the electrostatic field between the wire 1 and the cylindrical portion 35 for example by disconnecting the battery by means of a switch in the battery circuit, will result in a short length of wire passing through the applicator 12 without being coated. A bare section of the wire formed in this manner can be brought out as a loop from the winding to the terminal block of the coil and secured to it. Only the insulated portions of the loop are within the body of the winding.

The wire 1 is pulled from the spool 3, over the pulleys 5, 6, and 7 through the applicator 13 and wound about the core or core tube 2 into a coil by the winding machine 14. The core tube 2 is seated on the arbor 15 which is mounted for rotation upon the platform 16. The arbor shaft 17 is appropriately coupled to the driving motor 18 also mounted upon the platform 16. The platform 16 oscillates laterally, riding upon the track 19 and being actuated by the motor 20, which acts through the gear box 21 and is controlled by the reversing switch 22. Thus the arbor 15 moves laterally to and fro as the winding proceeds and the coil is wound in layers producing a structure such as is shown in Fig. 5.

The coating may advantageously be partially solidified prior to the actual winding of the coil in order that it

may have sufficient rigidity to provide the essential mechanical separation of adjacent turns of the coil. This partial solidification may be accomplished in the case of a thermosetting resin, among other means, by passing the wire through a heating element 23, which subjects the wire to a gaseous atmosphere at a temperature which may be as high as 800° C. depending on the chemical nature of the resin and the speed of wire travel. Other solidifying processes, partial or complete, may include the freezing of a thermoplastic resin applied from a molten fluid bath or the coalescing of a powder by heat followed by freezing.

The final solidification of the coatings in the coil results in a bonding of the adjacent turns, producing a coil having a rigid structure. This solidification is accomplished by the application of heat to the coil as the winding proceeds. This heating is advantageously produced, among other possible means, by directing a jet of a gas, such as nitrogen, of a temperature of the order of 120° C. toward the arbor 15 by means of a nozzle 24 as the winding proceeds.

The nozzle 24 is so mounted that it can follow and at all times be directly over the coil arbor during the entire coil winding process. This situation is conveniently accomplished by mounting the nozzle on the platform on which the coil arbor is mounted. The partially wound coil acts as a heat reservoir in which heat transferred from the hot gas jet is stored to be subsequently transferred to the more recently wound turns of the coil. The final curing produces a fusion or bonding of adjacent layers of coating resulting in a rigid mass of insulating material 25 with the turns 26 of the coil 27 distributed therein as shown in Fig. 5.

It is understood that the entire process, that is, the coating and winding, proceeds at coil winding speeds.

After the coil is completed, the core or core tube 2 having the coil 27 wound thereon is removed from the arbor and is ready for further assembly, if required, prior to installation.

Another type of applicator which may conveniently be employed with the apparatus of Fig. 2 is the roller coater shown in Fig. 4 which comprises a roller 60 having a plurality of different sized grooves 61 therein, mounted upon a shaft 62 for rotation within a housing 63. A scraper 64, tensioned against the roller 60 by the spring 65, removes the excess of coating material from the roller 60 as it rotates partially immersed in a bath of coating material contained in the housing 63. The wire 1 is passed through one of the grooves 61, as the roller 60 is rotated by some external drive coupled to the gear 66, which is mounted, with the roller 60 on the shaft 62.

In another embodiment of this invention utilizing a primary insulating coating the wire is coated, for example, by a roller type applicator such as is shown in Fig. 4 with a coating of resinous material such as polyester containing 30 per cent styrene to which is added 1 per cent of a catalyst such as 50 per cent benzoyl peroxide, 50 per cent tricresyl phosphate, which plastic is cured by passing the wire through a heating element similar to the heating element 23. The wire, having the cured plastic coating thereon, is then passed through another applicator which applies a coating of a casting resin such as polyester-styrene solution containing about 1 per cent of a catalyst such as 50 per cent benzoyl peroxide, 50 per cent tricresyl phosphate, over the plastic coating. The above-indicated casting resin is cured by heating the coil as it is wound upon the core tube 2 on the winding machine 14, for example, by a jet of nitrogen of a temperature of substantially 120° C. emitted by nozzle 24.

The resulting coil has a rigid structure, the essential mechanical separation and electrical insulation being afforded by the cured plastic coating while the rigidity of the structure is effected by the bonding of adjacent turns of the coil by the setting of the casting resin.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. The method of producing a conducting coil having its turns embedded in a substantially solid homogeneous matrix composed of a dispersion of insulating particles in a solidified resinous mass which comprises coating a bare conductor with a fluid resinous material having solid particles of insulation dispersed therein, solidifying the fluid resinous material of the coating to a degree sufficient to maintain said particles on the conductor yet insufficient to maintain a separation between the wound turns of the conductor, then winding the conductor into a coil, the solid particles separating adjacent turns, then coalescing the resinous material of the coatings of adjacent turns of the conductor, and solidifying the coating completely.

2. The method of producing a conducting coil which comprises coating a bare conductor with a fluid thermosetting resin having finely divided solid insulating particles dispersed therein, solidifying the resin of the coating to a degree sufficient to maintain said particles on the conductor yet insufficient to maintain a separation between turns of the wound conductor, then winding the conductor into a coil, maintaining a separation between the adjacent turns of the wound conductor by the solid particles in the coating, then coalescing the resinous material of the coating of adjacent turns of the conductor, and solidifying the coalesced coatings.

3. The method of producing a conducting coil which comprises coating a bare conductor with a mixture of a high butadiene-styrene co-polymer and finely divided solid particles of insulating material, both dispersed in acrylonitrile, solidifying the coating to a degree sufficient to maintain said particles on the conductor yet insufficient to maintain a separation between wound turns of the conductor by applying heat thereto, then winding the conductor into a coil, the solid particles separating adjacent turns, then coalescing the co-polymer of the coatings of adjacent turns, and completely solidifying the coating.

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