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(54) **Method and arrangement for reactor manufacturing, and a reactor**

(57) A reactor (1) is manufactured such that in a first step resin-dipped fibrous reinforcement material, such as roving thread (11), is wound to form a cylinder. On top of the obtained insulation layer there is wound an insulated conductor (5) to form a conductor layer (8). On the conductor layer (8) there is wound an intermediate layer (9) of resin-dipped fibrous reinforcement material. On the intermediate layer (9) there is wound a new insulated conductor layer (5). On top of the outermost conductor layer (5) there is wound an outer layer (7) of resin-dipped fibrous reinforcement material.

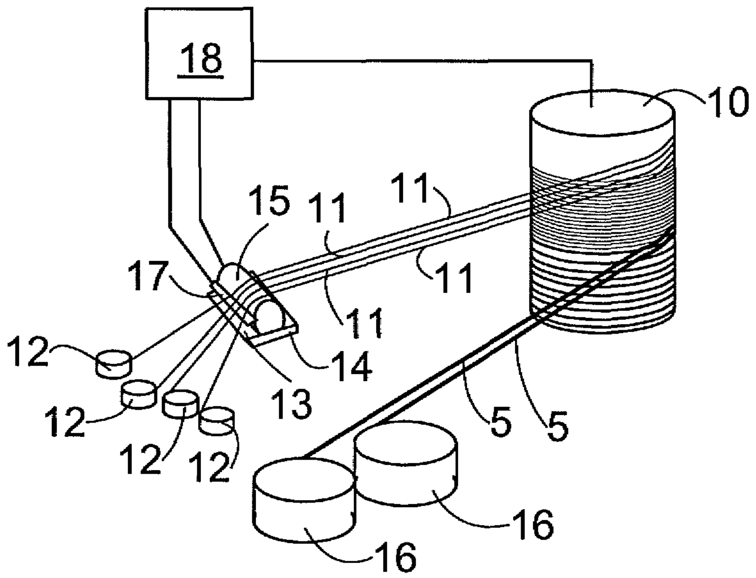

FIG. 3

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Description

BACKGROUND OF THE INVENTION

[0001] The invention relates to a method for manufacturing a reactor, the method producing at least one coil having conductor layers and inside them an inner sheath of fibrous reinforcement material and resin, and outside an outer sheath of fibrous reinforcement material and resin.

[0002] The invention also relates to an arrangement for manufacturing a reactor, the arrangement comprising means for winding an insulated conductor to form a conductor layer so as to provide a coil.

[0003] The invention further relates to a reactor comprising at least one coil with conductor layers and inside them an inner sheath and outside an outer sheath.

[0004] Dry-insulated air-core reactors are used in a wide variety of applications. The reactors may be used, for instance, as damping choke coils in connection with compensating capacitor units, as filtering reactors to filter harmonics in electrical power networks, and as parallel reactors to compensate for capacitive reactive power of transmission lines. Further, the reactors may be employed in various filtration uses as current limiters. In addition, the reactors cover many other applications.

[0005] FI publication 70755 discloses a reactor whose coil consists of conductor bundles. Around the coil there is arranged permeable insulation material, which may be fibreglass fabric, for instance. Resin is impregnated on the insulation material. Corresponding reactors are also disclosed in publications EP 0084412 and FI 91570. To form coils from conductor bundles makes it difficult to dimension the coil accurately. For example, a slight change in capacity is difficult to implement in the reactor, because addition of conductor layers is performed one conductor bundle at a time. It is particularly difficult to get resin thoroughly impregnated around the reactor and between the conductors. Thus, it is relatively difficult to manufacture a reactor and it is a demanding task to make the reactor sufficiently rigid in its mechanical structure.

BRIEF DESCRIPTION OF THE INVENTION

[0006] The object of the present invention is to provide a novel solution for the manufacture of a reactor as well as a novel reactor.

[0007] The method of the invention is characterized by dipping fibrous reinforcement material in resin and winding the resin-dipped fibrous reinforcement material to form an inner sheath, winding a conductor layer of an insulated conductor or conductors outside the inner sheath, dipping fibrous reinforcement material in resin and winding the resin-dipped fibrous reinforcement material to form an intermediate layer on the conductor layer, winding a subsequent conductor layer of an insulated conductor or conductors outside the intermediate layer, whereby there will be provided at least two conductor layers and between each conductor layer there is formed an intermediate layer, and dipping fibrous reinforcement material in resin and winding the resin-dipped fibrous reinforcement material on top of the outermost conductor layer to form an outer sheath.

[0008] The arrangement of the invention is further characterized by comprising means for dipping fibrous reinforcement material in resin and applying the resin-dipped fibrous reinforcement material to form the coil's inner sheath, outer sheath and intermediate layers between the conductor layers.

[0009] Further still, the reactor of the invention is characterized in that the inner sheath and the outer sheath are obtained by winding the resin-dipped fibrous reinforcement material and that between the conductor layers there are intermediate layers which are obtained by winding the resin-dipped fibrous reinforcement material.

[0010] In the presented solution the reactor is produced such that in a first step resin-dipped fibrous reinforcement material, preferably thread, for instance roving thread, is wound to form a cylinder. On the obtained insulation layer there is wound an insulated conductor to form a conductor layer. On the conductor layer there is again wound an intermediate layer of resin-dipped fibrous reinforcement material, for instance roving thread. On the intermediate layer there is again wound a layer of insulated conductor. There are wound at least two layers of insulated conductors, but there may be even more conductor layers. Between each conductor layer there is wound an intermediate layer of resin-dipped fibrous reinforcement material, for instance roving thread. On top of the outermost conductor layer there is wound an outer layer of resin-dipped fibrous reinforcement material, for instance roving thread. In the above-described manner it is possible to apply resin evenly throughout the reactor. Resin insulation will be well applied also between the conductors, in particular the conductor layers. On the whole, the structure of the reactor becomes very solid. The implementation of the solution may also be relatively easily automated, which allows considerable savings in manufacturing costs. Moreover, the solution can be implemented at normal atmospheric pressure, i.e. without pressurization or partial vacuum, and despite that resin is very well introduced between the conductors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] In the following the invention will be described in greater detail in the attached drawings, in which

- Figure 1 is a schematic top view of a reactor;
- Figure 2 is a schematic sectional side view of one coil in the reactor; and
- Figure 3 is a schematic view of the solution for manufacturing the reactor.

DETAILED DESCRIPTION OF SOME EMBODIMENTS OF THE INVENTION

[0012] Figure 1 shows a reactor 1. The reactor 1 is a dry-insulated air-core reactor. The reactor 1 may be used, for instance, as a damping choke coil in connection with parallel compensating capacitor batteries or as a filtering reactor to filter harmonics from the electric power distribution network. Further, the reactor may be used, for instance, as a parallel reactive coil to compensate for capacitive reactive power in long, lightly loaded transmission lines. The reactor 1 may also be used as a current limiting reactor to limit short-circuit current, for instance, in connection with the electric power distribution network, or the reactor 1 may find its application in other suitable uses.

[0013] The reactor 1 comprises at least one cylindrical coil 2, but it may also comprise a plurality of nested, concentric cylindrical coils 2. In the case of Figure 1 the reactor 1 comprises three nested, concentric cylindrical coils 2. The coils 2 are separated from one another by means of supports 3 made of insulation material. Thus, between the coils 2 there is an air gap, whereby it is possible to ensure the cooling of the reactor 1. The coils 1 are connected with end bars 4 in a manner known per se. Typically the coils 2 are coupled in parallel.

[0014] Each coil 2 consists of conductors coated with insulation in accordance with Figure 2. The conductors 5 may be of aluminium or copper, for instance. The insulation covering the conductor may be made of polyethylene terephthalate (PET) membrane, paper, enamel, aramide paper, polytetrafluoroethylene (PTFE) or another suitable, relatively thin insulation material. The inner part of the coil 2 constitutes an inner sheath 6 and the outermost part of the coil 2 is an outer sheath 7. The conductors 5 form conductor layers 8. Between the conductor layers 8 there are intermediate layers 9.

[0015] The inner sheath is obtained by winding resin-dipped roving thread around a cylindrical form. Thereafter on the outside of the inner sheath there is wound a conductor 5 to form a conductor layer 8. On the conductor layer 8 there is wound an intermediate layer 9, which is also made of resin-dipped roving thread. Thereafter there is wound a subsequent conductor layer 8 and thereon a subsequent intermediate layer 9. On the second intermediate layer 9 there is wound a third conductor layer 8 and so on. Outside the fifth conductor layer, which in this case constitutes the outermost conductor layer, there is produced an outer sheath 7. The outer sheath 7 is also made of resin-dipped roving thread. Typically one coil comprises 1 to 20 conductor layers 8.

[0016] Figure 3 shows schematically an arrangement for manufacturing a reactor. The arrangement comprises a cylindrical form 10. The form 10 is rotated about its axis, whereby the roving threads 11 are wound around the form. The roving threads 11 are unwound from roving thread reels 12. The attached figures show only four roving thread reels 12, but advantageously the number of roving threads 11 simultaneously wound around the form 10 may be, for instance, 10 to 50 threads. The weight of the roving thread per unit of length, i.e. thread number is about 400 to 2,400 tex., for instance. By using 40 roving threads 11, for instance, it is possible to spread the roving threads over the form 10 as a strip that is several centimetres wide. Prior to winding onto the form 10 the roving threads 11 are dipped in resin 13. The resin may be epoxy resin or polyester resin, for instance.

[0017] The dipping of the roving threads may be carried out such, for instance, that the resin 13 is arranged in a container 14. On top of the container 14 there is arranged a cylinder 15, the lower part of which comes into contact with the resin 13 and as the cylinder 15 rotates it wets the roving threads 11 passing over it. The roving thread 11 dipped in resin 13 is wound around the form 10 in a plurality of layers. Thus is obtained an inner sheath 6. The thickness of the inner sheath may vary within the range of 1 to 10 mm, for instance.

[0018] After accomplishing the inner sheath 6 a first conductor layer 8 is wound thereon. The conductor layer 8 is made of an insulation-coated conductor 5 unwinding from a conductor reel 16. Figure 3 shows two conductors 5 to be wound simultaneously side by side in the axial direction. There may be 1 to 40 axially parallel conductors 5. The diameter of the conductor 5 may be 1 to 5 mm, for instance, when a round conductor 5 is used. If so desired, the conductor 5 may also be square or rectangular in shape. In Figure 3 the roving threads 11 and the conductor 5 are shown as wound simultaneously, but in practice their winding is not performed simultaneously, but the inner sheath 6 is prepared first, the roving threads 11 are cut and thereafter the conductor 5 is wound and so on.

[0019] After accomplishing the conductor layer 8 the conductor 5 is cut. Thereafter an intermediate layer 9 is wound on the conductor layer 8 with dipped 13 roving threads 11. On the intermediate layer 9 there is again wound a subsequent conductor layer 8, on which a new intermediate layer 9 and so on. The thickness of the intermediate layer 9 is about 0.1 to 0.2 mm, for instance. The thickness of the intermediate layer 9, i.e. the distance between the conductors 5 of two different conductor layers 8 is advantageously as small as possible. Thus, the intermediate layer 9 may be so thin that it need not be considered in dimensioning calculation of the reactor. On the other hand, there may also be thicker areas in the intermediate layer 9, which fill the holes resulting from cross sectional shapes of the conductors 5. Advantageously the amount of resin is such that substantially no air gaps exist between the conductor layers 8. The different conductor layers 8 are coupled electrically to one another in a desired manner, either in series or in parallel.

[0020] Outside the outermost conductor layer 8 there is wound an outer sheath 7 made of resin-dipped 13 roving threads 11. The thickness of the outer sheath 7 is about 1 to 10 mm. The intermediate layer 9 is provided with more resin 13 than the inner sheath 6 and the outer sheath 7. This means that when the intermediate layer 9 is being produced the roving threads 11 are dipped wetter, i.e. more resin 13 is soaked in. When the intermediate layers 9 are provided with more resin 13 than the inner sheath 6 and the outer sheath 7, it is possible to ensure that resin will be applied between each conductor layer 8. This makes sure that the structure of the reactor is very rigid.

[0021] The amount of resin 13 may be controlled by means of a scraper 17, for instance. The scraper 17 is arranged in the vicinity of the cylinder 15. By adjusting the distance of the scraper from the cylinder with a control device 18 the amount of resin 13 to be applied to the roving threads 11 is controlled. When the scraper is further away from the cylinder 15 there is more resin on the cylinder to adhere to the roving threads 11. When the scraper 17 is arranged close to the cylinder 15 there is less resin on the cylinder 15 to adhere to the roving threads 11. The rotation speeds of the form 10 and the cylinder 15 also have an effect on the amount of resin. The rotation of the form 10 and the cylinder 15 are controlled with the control device 18. The cylinder 15 may also rotate freely driven by the roving threads 11.

[0022] For the sake of clarity Figure 3 does not show the arrangement's support structures or the like devices, such as rotating devices and, for instance, robotic arms by which the roving threads 11 and the conductors 5 are set into place when the winding starts. At the beginning of the winding the roving threads 11 and the conductors 5 may also be set into place manually. The resin 13 may be warmed prior to winding to lower the viscosity of resin.

[0023] After accomplishing the innermost coil 2 the supports 3 made of insulating material are arranged outside said coil and thereafter the inner sheath of the subsequent coil is wound on these supports 3 and on top of the inner sheath 6 a new conductor layer 8, whereafter an intermediate layer 9 and so on.

[0024] If so desired, it is also possible to produce the outer coils 2 on the form 10. In that case the reactor 1 is produced such that the readymade coils 2 are set in superposition and the supports 3 made of insulating material are arranged between them.

[0025] In addition to the roving threads 11, fibres in the axial direction of the coil 2 are also arranged in the inner sheath 6 and the outer sheath 7. This enhances the structural strength of the coil 2. When the coil is accomplished, the resin hardens. The hardening of resin may take place at room temperature, whereby the hardening typically takes about a couple of hours. If desired, the hardening may be accelerated by warming the resin in the coil. After the hardening the form 10 may be removed. If the form 10 is made of suitable material, it is also possible to leave it inside the innermost coil 2. Advantageously the conductor layers 8 are produced of one or more axially parallel conductors 5 by winding. Thus the mechanical solution of the arrangement is simple. Further, in connection with the reactor dimensioning it will be easy to change the reactor properties, when necessary, because it is possible to add just one wire turn, if necessary, and not a bundle of ten threads, for instance. One conductor layer 8 is produced by winding for instance 1 to 40 conductors simultaneously. It is further possible to arrange conductors into bundles of several conductors both in the axial and the radial directions, but in that case it will be slightly more difficult to get resin between each conductor to ensure the rigidity of the structure.

[0026] The diameter of the reactor 1 may vary from 30 cm to 4 m, and correspondingly the height of the reactor may vary from 30 cm to 4 m. Typically the weight of the reactor 1 then varies from 5 kg to 15,000 kg. The reactor 1 need not necessarily be an air-core reactor, but the presented solution may also be applied to the manufacture of an iron-core reactor. Most preferably the fibrous reinforcement material is a roving thread. Instead of the roving thread, i.e. untwisted or slightly twisted fibreglass bundle, it is possible to use any suitable fibreglass reinforcement for the manufacture of the reactor. Further, the most preferable roving thread to be used is the one that is fully untwisted, i.e. directly reeled. Thus, when an intermediate layer 9 is produced, for instance, the fibreglass bundle spreads evenly and neatly, and consequently the intermediate layer becomes relatively thin. Still further, the fibrous reinforcement material may be Kevlar or polyester, for instance. However, it is substantial that a wet blend of fibrous reinforcement material and resin is employed in the manufacturing.

[0027] In some cases features presented in this document may be used as such, irrespective of other features. On the other hand, features presented in this document may be combined, when necessary, to provide various combinations.

[0028] The drawings and the relating specification are only intended to illustrate the inventive idea. The details of the invention may vary within the scope of the claims.

Claims

1. A method for manufacturing a reactor, the method producing at least one coil (2) having conductor layers (8) and inside them an inner sheath (6) of fibrous reinforcement material and resin, and outside an outer sheath (7) of fibrous reinforcement material and resin, **characterized by**

   dipping fibrous reinforcement material in resin (13) and winding the resin-dipped (13) fibrous reinforcement material to form an inner sheath (6),

   winding a conductor layer (8) of an insulated conductor (5) or conductors (5) outside the inner sheath (6),

   dipping fibrous reinforcement material in resin (13) and winding the resin-dipped (13) fibrous reinforcement material to form an intermediate layer (9) on the conductor layer (8),

   winding a subsequent conductor layer (8) of an insulated conductor (5) or conductors (5) outside the

intermediate layer (9), whereby there will be provided at least two conductor layers (8) and between each conductor layer (8) there is formed an intermediate layer (9), and
dipping fibrous reinforcement material in resin (13) and winding the resin-dipped (13) fibrous reinforcement material on top of the outermost conductor layer (8) to form an outer sheath (7).

2. The method of claim 1, **characterized in that** the fibrous reinforcement material is fibreglass.

3. The method of claim 2, **characterized in that** the fibreglass is roving thread (11).

4. The method of claim 3, **characterized in that** the roving thread (11) is directly reeled roving thread.

5. The method of any one of the preceding claims, **characterized in that** the conductor layer (8) is produced by winding a single conductor (5) or only axially parallel conductors (5).

6. The method of any one of the preceding claims, **characterized by** arranging more resin in the intermediate layer (9) with respect to the length of the fibrous reinforcement material than in the inner sheath (6) and the outer sheath (7).

7. The method of any one of the preceding claims, **characterized by** arranging fibrous reinforcement material also in the axial direction in the inner sheath (6) and the outer sheath (7).

8. An arrangement for manufacturing a reactor, the arrangement comprising means for winding an insulated conductor (5) to form a conductor layer (8) so as to provide a coil (2), **characterized in that** the arrangement comprises means for dipping fibrous reinforcement material in resin (13) and for applying the resin-dipped (13) fibrous reinforcement material to form the coil's (2) inner sheath (6), outer sheath (7) and the intermediate layers (9) between the conductor layers (8).

9. The arrangement of claim 8, **characterized in that** the fibrous reinforcement material is fibreglass.

10. The arrangement of claim 9, **characterized in that** the fibreglass is roving thread (11).

11. The arrangement of claim 10, **characterized in that** the roving thread (11) is directly reeled roving thread.

12. The arrangement of any one of claims 8 to 11, **characterized in that** the conductor layer (8) is arranged for being produced of a single conductor (5) or only axially parallel conductors (5).

13. The arrangement of any one of claims 8 to 12, **characterized in that** the arrangement comprises a control means for controlling the amount of resin (13) to be applied in the fibrous reinforcement material such that the control device is arranged to apply more resin in the fibrous reinforcement material of the intermediate layer (9) with respect to its length than that of the inner sheath (6) and the outer sheath (7).

14. The arrangement of any one of claims 8 to 13, **characterized in that** the arrangement comprises means for arranging the fibrous reinforcement material in the axial direction in the inner sheath (6) and the outer sheath (7).

15. A reactor comprising at least one coil (2) with conductor layers (8) and inside them an inner sheath (6) and outside an outer sheath (7),
characterized in that
the inner sheath (6) and the outer sheath (7) are obtained by winding a resin-dipped (13) fibrous reinforcement material and that between the conductor layers (8) there are intermediate layers (9) which are obtained by winding the resin-dipped (13) fibrous reinforcement material.

16. The reactor of claim 15, **characterized in that** the fibrous reinforcement material is fibreglass.

17. The reactor of claim 16, **characterized in that** the fibreglass is roving thread (11).

18. The reactor of claim 17, **characterized in that** the roving thread (11) is directly reeled roving thread.

19. The reactor of any one of claims 15 to 18, **characterized in that** the conductor layer (8) is produced of single conductors (5) or simultaneously wound only axially parallel conductors (5).

20. The reactor of any one of claims 15 to 19, **characterized in that** the intermediate layers (9) comprise more resin in relation to the fibrous reinforcement material than the inner sheath (6) and the outer sheath (7).

21. The reactor of any one of claims 15 to 20, **characterized in that** the reactor (1) is an air-core reactor.

22. The reactor of any one of claims 15 to 21, **charac-**

terized
in that the inner sheath (6) and the outer sheath (7) comprise fibrous reinforcement material in the axial direction.

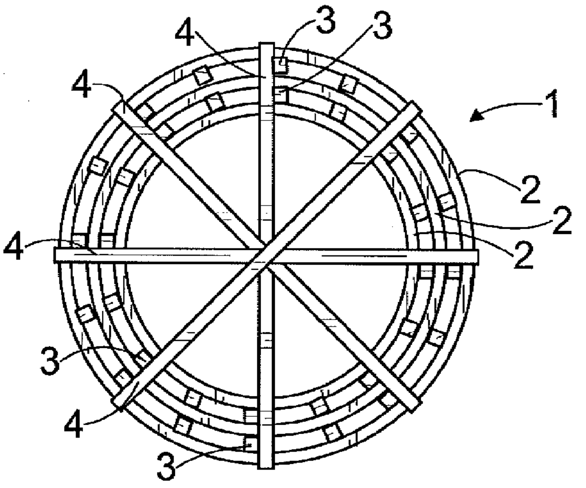

FIG. 1

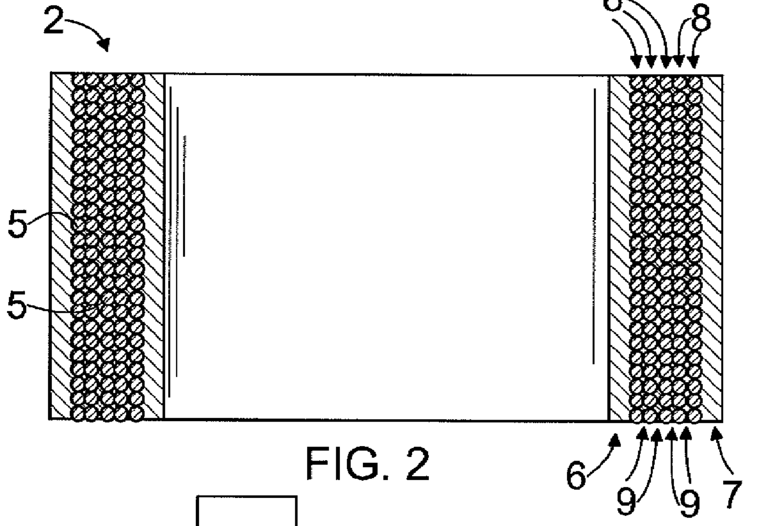

FIG. 2

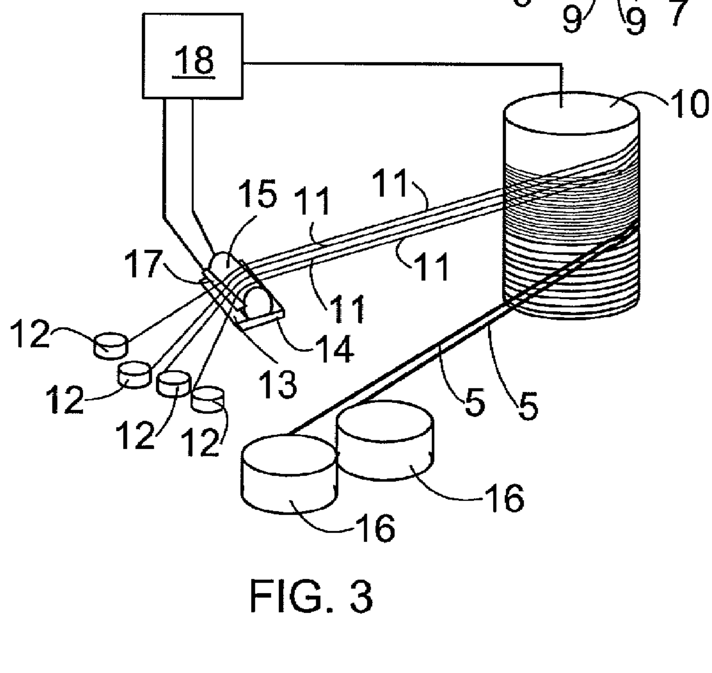

FIG. 3

REFERENCES CITED IN THE DESCRIPTION

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