June 22, 1943. I. W. A. KIRKWOOD ET AL 2,322,214

ELECTRICALLY INSULATING BODIES

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Fig. 1.

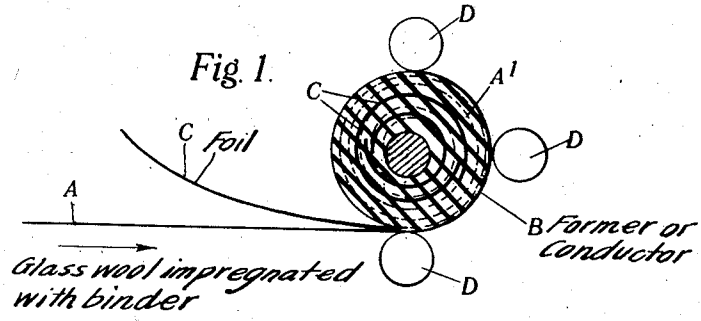

Fig. 2.

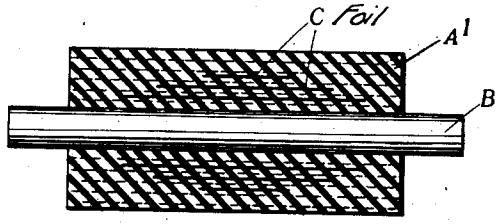

Fig. 3.

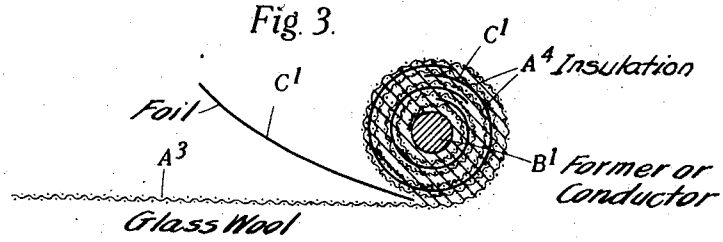

Fig. 4.

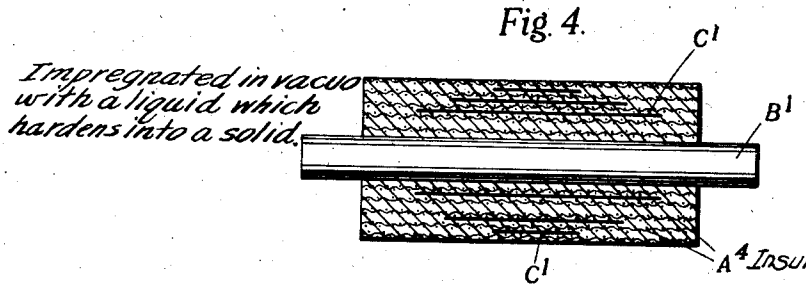

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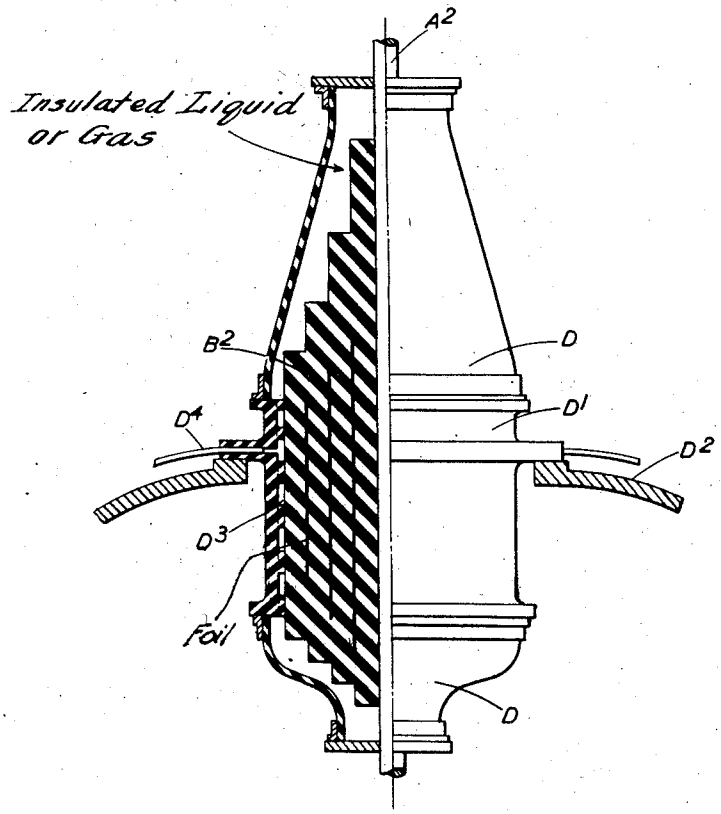
FIG. 5.



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ELECTRICALLY INSULATING BODIES

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20 Claims. (Cl. 174—143)

This invention relates to electrically insulating bodies, such for example as insulating bushings or sleeves.

Electrical insulators which consist of superimposed layers of a cellulosic base, such for example as paper or cloth, bonded with synthetic resins or other binders are open to the difficulty that they are liable to absorb moisture, since cellulosic materials, in general, are inherently hygroscopic. Even if the cellulosic insulator is impregnated with a synthetic resin the absorption of moisture by the fibres will not be wholly prevented and there will ultimately be a decrease in the dielectric strength, increase of power factor, and swelling of the insulator at the exposed ends of the fibrous layers.

An object of the invention is to overcome this difficulty by winding or wrapping fibres of a vitreous substance, for example glass-wool, preferably felted or in the form of a woven fabric, in a number of superimposed layers about a conductor, or about a former which may in certain cases be a conductor, and filling the interstices with an electrically insulating gas, or with an insulating medium which, during the filling process, is in a liquid, semi-liquid or dissolved state.

It is desirable that the non-crystalline substance employed be uniform in structure and free from incorporated foreign matter, that it will provide individual fibres of a satisfactory textile length, and that it will be wholly (or substantially wholly) non-hygroscopic.

In order to facilitate filling of the interstices between the fibres with the insulating medium the fibres may be bound together in open texture by a preliminary binder prior to filling of the interstices with the insulating medium.

According to a further object of the invention the interstices in the fibrous layers are filled with an insulating binder, such for example as a phenol-formaldehyde resin, a higher chlorinated naphthalene, or shellac applied in solution or, in certain cases where this is possible, in liquid or semi-liquid state. The insulating binder may be applied to the fibres prior to the winding or wrapping which is then effected under the application of pressure and/or heat so that the layers are impregnated with the binder which binds the layers into a solid mass. Alternatively, the fibres (preferably bound in open mesh by a preliminary binder as above described) are first wound or wrapped and the interstices are then filled with the insulating binder, as by dipping the wound or wrapped layers in the insulating binder while this is in a liquid or semi-liquid state.

According to yet a further object of the invention the interstices in the wound or wrapped layers are filled by impregnation, preferably in vacuo, with a polymerisable liquid, such for example as styrene, this liquid being then polymerised by heating, if necessary under pressure. Thus, for example, the liquid impregnant may be forced through the insulating mass from end to end so as to force out the air and fill the interstices with the impregnant.

With a view to imparting flexibility as may be desired a suitable plasticiser may, in any of the above methods, be incorporated in the insulating binder.

Instead of binding the fibres into a solid mass, the wound or wrapped layers may be arranged within a suitable casing containing an insulating liquid such as hydrocarbon oil, or a liquid chlorinated hydrocarbon such, for example, as chlorinated diphenyl, this insulating liquid remaining in the liquid state and filling the interstices in the wound or wrapped layers.

According to yet a further method the interstices in the wound or wrapped layers are filled with an insulating gas at or above atmospheric pressure which will have a dielectric strength within the interstices substantially greater than that of air at atmospheric pressure. For example, the interstices may be filled with dichlorodifluoro-methane, or other gaseous fluorinated chloro-paraffin, or nitrogen, an argon, the whole being enclosed in a gas-tight casing or jacket.

In the accompanying drawings,

Figure 1 illustrates one method of forming a condenser bushing according to the invention;

Figure 2 shows the finished bushing in longitudinal section;

Figure 3 illustrates another method according to the invention;

Figure 4 shows the finished bushing in longitudinal section, and

Figure 5 illustrates a modified form of finished bushing.

In Figure 1 the bushing is formed by applying to a cord or a strip of felted glass wool or woven glass cloth, for example a glass wool fabric, a binder constituted by phenol formaldehyde resin, polystyrene or polyvinyl acetal. The strip or cord A thus treated or "varnished" is dried and then wrapped in a number of superimposed layers A^1 about a former B, which may be a conductor, with the insertion of stress-grading foils C between the layers A^1 as they are wound. The layers A^1 with the foils C between them are subjected to heat and pressure by rolls D so that the

interstices in and between the layers A^1 are impregnated with the binder and the insulation is thus bound into a solid mass about the former or conductor B as shown in Figure 2.

In accordance with a second method, as shown in Figure 3, a cord or a strip of felted or woven glass wool A^3 is first wrapped round a conductor or former B^1 in a number of superimposed layers A^4, stress-grading elements C^1 being inserted between the layers A^4 as they are wound. The layers are then impregnated, preferably in vacuo, with a polymerisable liquid such for example as styrene or methyl metchacrylate, or solutions therein of the corresponding polymers. The liquid is then polymerised by the application of heat, if necessary under pressure to avoid formation of bubbles. The finished bushing is shown in Figure 4.

According to a modified method the cord or strip of woven or felted glass wool A (Figure 1) wound in a number of superimposed layers about a conductor or former with stress-grading foils C between them, is dipped or otherwise impregnated, preferably in vacuo, with a molten wax-like material, such for example as chlorinated naphthalene or ceresine, which on cooling will set to bind the fibres into a solid mass.

According to another modification a cord or strip of glass cloth, for example felted or woven glass wool has applied thereto shellac, a natural wax, a chlorinated naphthalene or a phenolic, urea, vinyl or acrylic resin, each in a suitable solvent which is then removed in known manner. The cord or fibrous strip thus treated is wound or wrapped in a number of superimposed layers about a conductor or former as described with reference to Figure 1, metal foils being inserted between adjacent layers as they are wound and subjected to simultaneous heat and pressure by the rolls D.

In order to impart flexibility as may be desired a suitable plasticiser, such for example as chlorinated diphenyl, amyl naphthalene, dibutyl phthalate, or tricresyl phosphate, may in each of the above methods be incorporated in the binder.

Instead of binding the fibres into a solid mass as previously described, the layers B^2 may, as shown in Figure 5, be wound or wrapped around the conductor A^2 (with interposed stress grading foils C^2) and then inserted in a casing D consisting of porcelain or other suitable material and provided with a flange D^1 for fixing it to apparatus casing D^2. The casing contains an insulating liquid such as hydrocarbon oil or a liquid chlorinated hydrocarbon such, for example, as chlorinated diphenyl, this insulating liquid remaining in the liquid state and filling the interstices in the wound or wrapped layers. Grooves D^3 may be provided in the interior wall of the flange D^1 to assist in the circulation of the insulating liquid, the interior of the casing being connected by a pipe D^4 to a supply of the liquid so as to permit "breathing" and to compensate for air leakage.

Alternatively the casing D of the bushing shown in Figure 5 may be filled with an insulating gas at or above atmospheric pressure, the gas filling the interstices of the wound or wrapped layers B^2 and having a dielectric strength within the interstices substantially greater than that of air at atmospheric pressure. For example, the casing D may be filled with dichloro-difluoro-methane or other gaseous fluorinated chloro-paraffine or nitrogen or argon.

Impregnation of the interstices between the fibres will be facilitated if the texture of the fibrous layers is as open as may be practicable. Though it is a matter of some difficulty to weave a fibre-glass textile of loose open mesh owing to warp-slip, this difficulty may be overcome by using, for example in any of the methods above described, a felted mat of glass fibres held together by a small quantity, say 1% to 2% by weight, of a preliminary binder such for example as phenol-formaldehyde resin or polystyrene, the binder content being just sufficient to hold the fibres against slip at their main points of mutual contact. This gives an open-textured material which will be readily permeated by the liquid impregnant. Alternatively a felted mat as described may be employed, for example with the first and fourth methods above described, in which the preliminary binder content is high, for example 40% to 60% by weight of the whole, so that, after winding or wrapping, impregnation of the felted mat by the binder can be effected by hot-pressing or hot-rolling the superimposed layers. If a thermoplastic binder is employed with this method careful control of the tension to which the material is subjected during winding or wrapping should be exercised in order to avoid undesirable stretching.

The felted mat, incorporating the binder, may be formed for example by agitating a suspension of short fibres of a glass-like substance in non-crystalline form (e. g. glass-wool) in a reaction mixture giving rise to a synthetic resin. For example, the fibres may be stirred into a heated mixture of phenol and aqueous formaldedyde in suitable proportions. When the condensation has proceeded to the point where the reactants have formed an A-stage phenolic resin (resole) the whole is poured out on to a smooth, endless conveyor belt, forming a thin film from which all surplus water is carefully evaporated, if desired under reduced pressure. The resulting film may then be wound into a bushing in the usual manner under the action of heat and pressure.

It will be understood that the electrical, mechanical, and other properties of the insulating body produced in accordance with the invention may be modified to suit requirements and conditions of use, by suitable selection not only of the vitreous non-crystalline material but also the filler or binder. Thus, a lead glass will usually give a lower power factor and a higher dielectric constant than a soda-lime glass, but both possess a surface which is somewhat susceptible to atmospheric moisture. The thickness of the layer of moisture which can be adsorbed on the surface of the fibres will depend upon their chemical composition, such thickness usually decreasing, for example, with decrease of the soda and increase of the boric oxide content of the fibres. It is in general preferred to employ the substantially alkali-free boro-silicate glass fibres already available in the industry, but a particularly desirable combination of materials, from the dielectric standpoint, comprises vitreous silica fibres impregnated or bound with a hydrocarbon such as polystyrene, or a polymerized ethylene plastic. When employing woven fibres the warp may differ chemically or otherwise from the weft, so as to produce intentional differences, in two mutually perpendicular directions, of various characteristics, such for example as elasticity. When the lowest possible power-factor is required, it is desirable that the fibres be as free as possible from the emulsions of oil, starch, and other materials with which

they are usually moistened during spinning into thread form. These materials usually contain emulsifying agents which, though present only in minute amount on the final weave, are polar compounds which could with advantage be removed, prior to the application of the binder or impregnant, for example by washing with water, trichlorethylene or other suitable solvents or vapours thereof, followed by intensive drying.

The vitreous substance employed in accordance with the invention has no inherent tendency to absorb moisture and, though it may tend to adsorb a surface layer of moisture from a humid atmosphere, this layer can readily be removed by heating prior to the fibres being "filled" or bound to form the bushing. For this purpose, by using an inorganic glass-like non-crystalline substance, a higher temperature can safely be employed than with cellulosic materials which will only withstand a comparatively low temperature. Further, whereas a cellulosic material, such as paper, coated with polystyrene, can be pressed into laminated sheets at temperatures of about 120° C. to 160° C., paper coated with polymerized N-vinyl carbazole would require a temperature of about 250° C. to 300° C. in order to render the binder sufficiently plastic to flow readily into the interstices. This would, however, damage the paper and render it brittle. By employing an inorganic vitreous substance instead of cellulosic material much higher manufacturing temperatures can safely be applied. Again, insulators composed of cellulosic materials bound with phenolic resins are readily "tracked," that is to say they produce a carbonized conducting track when brought into contact with an electric arc. This tendency can be reduced by substituting a urea for a phenolic resin, or glass for cellulosic material. It can be substantially eliminated in an insulating body according to the invention using glass fibres bound with a urea or other non-tracking plastic since an arc will merely cause fusion of the surface fibres.

The vitreous material in the form of a tape or cord may be wound helically about the former or conductor. For example, the invention may be applied for the production of a long insulated conductor by helically winding about the conductor a woven strip or a cord of glass-wool, to which a phenol-formaldehyde resin has been applied according to the first method described. The wound helical layers are then subjected to heat and pressure so that the interstices therein are filled with the phenol-formaldehyde binder. Alternatively the tape or cord may first be helically wound about the conductor and the layers impregnated with liquid styrene or methyl methacrylate which is then polymerised, according to the second method described. The tape or cord may also be employed for the manufacture of insulated articles, such for example as current transformers, having a complicated shape.

It will be understood that the application of the insulating filler or binder may be effected either before or after winding or wrapping of the successive layers of the vitreous substance. For example, the vitreous substance may be varnished with a thermo-setting varnish before winding on the conductor or former, or the layers may be wound before the interstices are filled, say by a monomer which is subsequently polymerized, or a syrupy solution of a polymer in a monomer may be applied to the glass-like substance before winding the layers on the conductor or former and then polymerising.

In any of the methods above described the filler or binder may be applied as an emulsion or suspension of globules or particles of the filling or binding medium in an immiscible liquid.

The superimposed layers may be formed from a textile fabric woven from spun fibres or threads of the glass-like substance in non-crystalline form. These layers may also be formed by winding thin fibres, sheets, irregular layers similar to felt, or extruded woven or braided cord, made of the said glass-like substance.

What we claim as our invention and desire to secure by Letters Patent is:

1. The method of forming an electric condenser bushing, comprising wrapping fibres of a vitreous substance previously woven into the form of a fabric in super imposed layers about a former, inserting separate condenser foils between successive layers as they are wound, and filling the interstices in the layers with an insulating medium whose dielectric strength within the interstices exceeds that of air at atmospheric pressure.

2. The method of forming an electric condenser bushing about a conductor, comprising winding fibres of glass-wool previously woven into the form of a fabric in superimposed layers about the conductor, successively inserting separate stress-grading layers between adjacent fibrous layers as they are wound, and filling the interstices in the layers with an insulating medium whose dielectric strength within the interstices exceeds that of air at atmospheric pressure.

3. In the method as claimed in claim 1, the additional step of binding the fibres together in open texture by a preliminary binder prior to filling of the interstices with the insulating medium.

4. The method of forming an electric condenser bushing, comprising wrapping fibres of a vitreous substance in superimposed layers about a former, successively inserting separate stress-grading foils between adjacent layers during the winding, and filling the interstices in the layers with a solid insulating binder which, during the filling process, is in a fluid state.

5. The method of forming an electric condenser bushing, comprising applying an electrically insulating binder to fibres of a vitreous substance, winding the fibres in superimposed layers about a former, inserting at least one stress-grading foil between successive layers during the winding, and subjecting the layers so formed to heat to cause the interstices in the layers to be filled by the binder.

6. In the method as claimed in claim 5, the additional step of weaving the fibres to which the binder is applied, prior to the winding in the form of a fabric.

7. The method of forming an electric condenser bushing, comprising arranging fibres of a vitreous substance in superimposed layers, disposing at least one stress-grading foil between adjacent layers, filling the interstices in the layers with a polymerizable liquid filler, and subjecting the filled layers to heat which polymerises the filler.

8. The method of forming an electric condenser bushing, comprising weaving fibres of glass-wool into the form of a fabric winding the fabric in superimposed layers about a former, inserting separate stress-grading conducting layers between adjacent fabric layers during the

winding, filling interstices in the layers with a polymerisable liquid filler, and subjecting the filled layers to heat which polymerises the filler.

9. The method of forming an electric condenser bushing about a conductor, comprising first treating a strip of woven glass-wool fibres with a binder including a plasticiser, wrapping the strip in a number of superimposed layers about the conductor, inserting stress-grading foils between adjacent layers during the winding, subjecting each layer as it is wound to heat and pressure whereby the binder is caused to fill the interstices in the layers thus binding the whole into a solid mass about the conductor.

10. The method of forming an electric condenser bushing about a conductor, comprising wrapping a strip of felted or woven glass-wool fibres in a number of superimposed layers about the conductor, inserting at least one conducting layer between adjacent felted layers during the winding, impregnating the layers with a polymerisable liquid filler, subjecting the whole to heat and pressure, polymerizing the liquid filler and thus binding the layers into a solid mass about the conductor.

11. The method of forming an electric condenser bushing, comprising applying an electrically insulating resinous binder to glass-wool fibres, winding the fibres in superimposed layers about a former, inserting separate stress-grading foils between adjacent layers during the winding, and subjecting the layers so formed to heat which causes the interstices in the layers to be filled by the binder.

12. The method as claimed in claim 11, in which the binder comprises phenol-formaldehyde resin.

13. The method as claimed in claim 11, in which the binder comprises an unsaturated aromatic hydrocarbon of the vinyl type.

14. The method as claimed in claim 11, in which the binder comprises polyvinyl acetal.

15. The method as claimed in claim 9, in which the plasticiser comprises chlorinated diphenyl.

16. The method as claimed in claim 9, in which the plasticiser comprises amyl naphthalene.

17. The method of forming an electric condenser bushing comprising preparing a suspension of short glass-wool fibres in a reaction mixture giving rise to a synthetic resin, agitating the same, pouring the suspension on to a flat belt thereby forming a film-like strip, winding said strip in superimposed layers on a former and subjecting the whole to heat.

18. The method of forming an electric condenser bushing, which comprises creating a suspension of short glass-wool fibres in a reaction mixture comprising phenol and aqueous formaldehyde and giving rise to a synthetic resin, agitating until condensation has cuased the reactants to form an A-stage phenolic resin, pouring the whole on to a flat belt thereby forming a film-like strip, winding said strip in superimposed layers, inserting at least one stress-grading conducting layer between adjacent film layers during the winding, and subjecting the wound layers to heat which causes the interstices in the layers to be filled by the synthetic resinous binder.

19. The method of forming an electric condenser bushing, which comprises winding fibres of a vitreous substance in superimposed layers, inserting at least one stress-grading foil between successive layers during the winding, filling the interstices in the layers with an insulating binder in the form of an emulsion and subsequentiy solidifying said emulsion.

20. The method of forming an electric condenser bushing, which comprises wrapping fibres of a vitreous substance in superimposed layers, inserting at least one stress-grading foil between successive layers during the winding, filling the interstices in the layers with an insulating binder in the form of a suspension and subsequently solidifying said suspension.

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