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COATING FOR EQUALIZING THE POTENTIAL GRADIENT ALONG THE SURFACE OF AN ELECTRIC INSULATION

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Fig.1

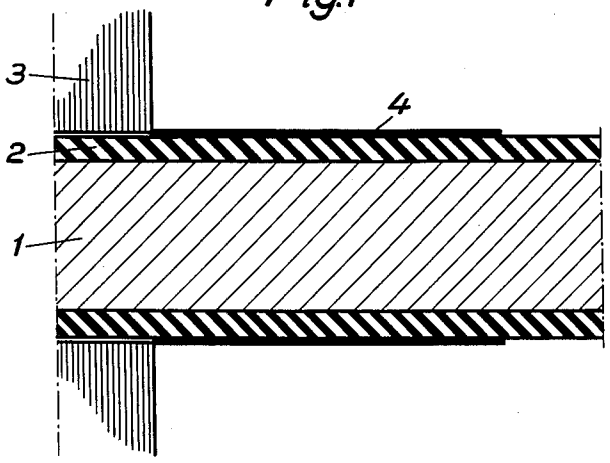
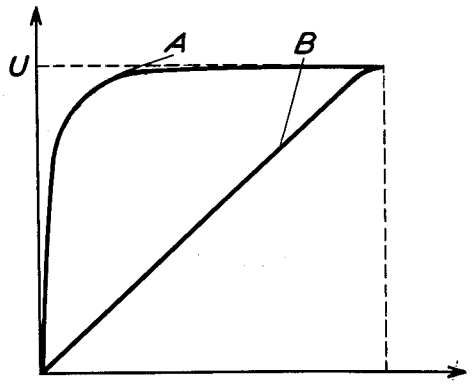


Fig.2



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COATING FOR EQUALIZING THE POTENTIAL GRADIENT ALONG THE SURFACE OF AN ELECTRIC INSULATION

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The present invention is related to a coating for equalizing the potential gradient along the surface of an electrical insulation, particularly on the surface of insulated conductors, such as the end coils in electric machines or high tension inlets.

This application is a continuation-in-part of our Serial No. 723,807, filed March 25, 1958, now abandoned.

When the electrostatic potential gradient along the surface of an electrical insulation surrounded by air or any other gas, exceeds a certain value, a corona effect, i.e. gas discharges, arises which breaks down the surface of the electrical insulation and destroys the insulation material which results in a puncture of the insulation. This phenomenon is especially troublesome in high tension electric machines with slotted armatures, in which a very large potential gradient arises between the iron-core and the coil ends projecting from the core and gives rise to corona. The same problem also exists in high tension bushing insulators.

In order to equalize the potential gradient appearing on the surface of insulated conductors in electric machines and apparatus and thereby to prevent corona from appearing, the surface of the insulation has hitherto generally been provided with a conducting coating having a suitable resistivity between the values of resistivity for a good insulator and a metallic conductor. The coatings previously used, generally consisted of a suitable binder in which, for instance, graphite, charcoal, anthracite or soot were intermixed. It has become evident, however, that these coatings are, in general, unable to equalize the potential gradient sufficiently to prevent corona from appearing. The reason for this is most easily explained in connection with the accompanying drawing in which FIGURE 1 is a schematic sectional view of a winding projecting from the iron-core in an electric machine. The conductor **1** is as usual, environed by an insulation **2** and projects from the iron-core **3** of the machine. If no special precautions are taken, the surface of the insulation on the coil end assumes substantially the same potential as the conductor, due to which, a very large potential gradient arises between the grounded iron-core and the surface of the insulation of the coil end, which causes a very heavy corona. In order to prevent this, it is, as already mentioned, usual to provide that part of the coil end which is situated in the proximity of the iron-core with a conducting surface coating **4** of any of the above mentioned types. It can easily be seen that from every point on the conductor **1**, situated inside the corona preventing coating **4**, a leakage current flows to the coating **4** and then to the grounded iron-core **3**. The intensity of the current through the coating **4** consequently increases progressively from the outer end of the coating towards the iron-core and as all coatings hitherto suggested or used, have a resistivity which is substantially independent of the current and the voltage, a much larger potential gradient arises near to the iron-core than at the outer end of the corona preventing coating. In FIGURE 2 of the drawing, curve A indicates how the potential of a coating of the type used hitherto, varies, as a function of the distance from the end surface of the iron-core. The potential of the conductor **1** is indicated by U in FIGURE 2. From this figure it is

evident that the coatings previously used could equalize the potential gradient only to a very small degree and that a large potential gradient remained in the neighbourhood of the iron-core with the danger of corona. Even if this potential gradient does not exceed the permitted limit value at normal service voltage of the machine, it is evident that even a very small increase in the voltage is sufficient to cause the potential gradient to become so large that corona appears. Consequently, it has hitherto been very difficult to procure a corona preventing coating which is effective at service voltage, as well as at test voltage. Certainly the potential gradient close to the iron-core can be lessened by decreasing the resistivity of the coating in which case however, the outer end of the coating will assume a potential which is lower than the potential of the conductor, because of which a large potential gradient and danger of corona arises at this point instead.

From the above it is obvious that the corona preventing coatings used hitherto, are only effective within a comparatively narrow voltage range and that their efficiency is strongly dependent on the resistivity i.e. the composition, and the thickness of the coating.

The object of the present invention is a potential gradient equalizing coating which, within a wide voltage range creates a satisfactory equalization of the potential gradient and the function of which is less sensitive to variations in the composition and the thickness of the coating. According to the invention this is achieved by a coating containing a conducting component which gives the coating a pronounced voltage dependent resistivity. In this way the coating gets a strongly non-linear current voltage characteristic, so that the voltage across a certain part of the coating, within a wide voltage range becomes substantially constant and independent of the current intensity in that part of the coating. In FIGURE 1 the high current intensity in the coating **4**, near to the iron-core **3**, will consequently not give cause to any larger voltage drop than the low current intensity in the outer part of the coating, because of which the distribution of the potential along the coating becomes substantially linear, as indicated by curve B in FIGURE 2. As the resistivity of the coating at every point automatically assumes the most suitable value, independent of the potential of the conductor, i.e. the machine voltage, the coating according to the invention will automatically provide for a satisfactory equalization of the potential gradient even if the conductor tension varies within wide limits.

The coating according to the invention consists suitably of a substance having a pronounced voltage dependent resistivity, which is intermixed in dispersed state in a solid resinous binder. When applying the coating on the surface the potential gradient of which has to be equalized, a suspension of the mentioned susbtance in a thermosetting or air-drying varnish is suitably used, whereby the varnish contains the binder in uncured state. After the application of the varnish on the surface, solvents occurring, if any, are removed and the binder cured.

As a substance with pronuonced voltage dependent resistivity silicon carbide in the form of small particles can be used provided that the concentration and the particle size of the substance is such that at an applied voltage the voltage between contiguous silicon carbide crystals is 0.5 v. A coating in which this voltage is less than 0.5 v. will not have a pronounced voltage dependent resistivity and therefore is outside the scope of the invention. If the voltage per particle contact is at least 0.5 v. the known law of voltage (U) dependence of current (I): $I=C.U^{a}$ where C is a constant characteristic for the material, is valid. For the coating according to the invention, the power, a has a value of 2–7.

We have found that good results are obtained if the

varnish contains such an amount of silicon carbide that after applying the varnish on the surface of the insulation and transferring it to the final solid state the content of silicon carbide in the coating is 10 to 65, preferably 15 to 35 percent by volume of the coating. It has been proved that the most suitable particle size of the silicon carbide is in the range particle size 100 to particle size 400. These particle sizes and other particle sizes specified in the specification are according to U.S. Standard Sieve specifications.

Though good results can be obtained by using low-resistivity silicon carbide of the types usually used for electrical purposes, e.g. in lightning arresters and varistors, it has often been found impossible to avoid discharges within coatings with such silicon carbides. As a consequence of such discharges these coatings will not have the same durability as coatings within which no discharges arise. It has been proved that discharges within the coatings are totally eliminated by using high-resistivity silicon carbide types and therefore especially good results are obtained with such silicon carbide-types. These last mentioned silicon carbide types are electronic conductors of the n-type with volume resistivities in the range from a few ohm-cm. to several millions ohm-cm. Coatings with extremely good quality have been obtained with high-resistivity silicon carbide when the content of carbide in the finished coating is 20–30 percent by volume of the coating. An explanation of the higher quality of the coatings containing high-resistivity silicon carbide is that by using this type of silicon carbide the concentration of the conducting material can be made considerably higher than by using low-resistivity silicon carbide and therefore it is possible to avoid spots with insufficient amounts of silicon carbide particles and so to avoid spots where discharges arise.

The resinous binder in the varnish used for giving the surface of the electric insulation a coating for equalizing the potential gradient, has the property of shrinking when it is transferred to its final state on the insulation. Due to the shrinkage, the intermixed conducting particles are pressed against one another so that conducting contacts arise between them.

As the critical property of the resinous binder is not its chemical composition but its property of shrinking during the attaching of the coating onto the surface of the electric insulation, the invention is not limited to binders belonging to any particular chemical group of resinous materials. Provided that the binder shrinks between 0.5 to 5 percent when it is transferred from fluid to the final solid state the binder may be selected from any chemical group of resinous materials. With respect to the requirement that the coating shall be easy to apply on the insulation and that the coating shall have good mechanical and thermal properties, there will be mentioned some groups of resinous materials from which special individual ones with the desired shrinkage may be selected. Such groups of resinous materials are e.g. oil-modified alkyd resins and epoxy resins.

The oil-modified alkyd resins may be prepared by reacting, with heat treatment, polybasic acids, polyhydric alcohols and drying oil or drying oil acids. Among the various polyhydric alcohols which can be used in the manufacture of the alkyds, there may be mentioned ethylene glycol, propylene glycol, diethylene glycol, glycerol, pentaerythritol and various mixtures of these polyhydric alcohols. Polycarboxylic acids which can be used for the preparation of the alkyds include, e.g. succinic adipic, sebacic maleic, fumaric malic, phthalic and terephthalic acid. The anhydride can be used instead of the acid, and in many instances this is preferable. Suitable drying oils serving as modifying agents include, among others, linseed oil, soya oil, Chinawood oil. Also the acids derived from the fatty oils may be used. The different ingredients are reacted in ways well-known to those skilled in the art, and dissolved in suitable solvents, to give air drying or baking coating compositions.

The epoxy resins can be manufactured in a well-known way by reacting a phenol having at least two phenolic hydroxy groups and an epihalogenohydrin, e.g. epichlorohydrin. The reaction product contains at least two ethylene oxide groups and can be converted to the substantially thermoset stage by employing, e.g. a polybasic acid or anhydride such as phthalic acid or anhydride, or an amine as a curing agent. Besides these mentioned unmodified resins, also modified epoxy resins may be used. It is well-known to those skilled in the art that epoxy resins can be modified in a number of ways. A well-known group of such modified epoxy resins comprises the combination products of epoxy resins and oil-modified acidic polyester resins. These last-mentioned polyester resins may be prepared from the same ingredients as those mentioned earlier for alkyd resins. In order that the polyester resin may be able to react with the epoxy resins it is necessary that they contain excess carboxyl groups, which when heating the epoxy resins together with acidic polyester resins will react with the reactive groups of the epoxy resins. If suitable drying oils or fatty acids of drying oils are incorporated in the acidic polyester resins, the reaction products of the epoxy resins and the polyester resins can be given air-drying properties.

The coating compositions can be made up as desired and in known manner with metallic driers, plasticizers, thinners and other such common auxiliary components. The binders can also, as necessary and desirable, contain other film-forming materials such as for example nitrocellulose, phenolic resins and polyvinyl acetate.

Suitable binders may also be taken, e.g. from the polyurethane resin group, i.e. resins manufactured from polyisocyanates and polyhydric alcohols, and from the silicon resin group.

Besides silicon carbide particles the varnishes may, to a limited extent, contain other solid particles. Such solid particles may be of the types usually used as pigments in varnishes, such as for example zinc chromate and iron oxide.

The invention will be further illustrated by the following examples, but it will be understood that the invention is not limited thereto. The binders of the varnishes in all examples have a volume shrinkage of 0.5–5 percent when transferred from uncured fluid state to cured solid state. In the examples the parts given are by weight.

Example 1

A fluid solventless varnish consisting of 35 parts low resistivity, 220 particle size silicon carbide, 59.1 parts of a fluid, solventless epoxy resin, and 5.9 parts a curing agent consisting of an aliphatic polyamine, is applied on the coil ends of a machine intended for a line voltage of 13.8 kv. The length of the coating, which is designated 4 in FIGURE 1, is 8 cm. and the thickness of the coating not exceeding 0.5 mm. After staying for about 40 hours at room temperature, the applied varnish is transferred to a solid, cured coating having a pronounced voltage dependent resistivity. The content of silicon carbide in the cured coating is about 17 percent by volume of the coating.

Example 2

A varnish of the same kind as that in Example 1 but with 120 particle size silicon carbide is applied on the coil ends of a machine intended for a line voltage of 16 kv. The length of the coating is made 10 cm. and the thickness about 0.3 mm.

Example 3

A varnish consisting of 30 parts low-resistivity silicon carbide with a particle size corresponding to grit 120, 63.6 parts of a fluid solventless epoxy resin and 6.4 parts of a curing agent consisting of an aliphatic polyamine is applied on the coil ends of a machine intended for a line

voltage of 13.8 kv. The coated length is 8 cm. and the thickness of the coating about 0.3 mm. The varnish is cured at 60° C. for 6 hours. The content of the silicon carbide in the solid coating is about 14 percent, by volume of the coating.

Example 4

A varnish consisting of 48 parts high-resistivity, 120 particle size silicon carbide, 47.2 parts of a fluid solventless epoxy resin and 4.8 parts of a curing agent consisting of an aliphatic polyamine is applied on the coil ends of a machine intended for a line voltage of 13.8 kv. The length of the coating is 8 cm. and the thickness about 0.3 mm. The varnish is cured at room temperature for about 40 hours. The content of silicon carbide in the solid cured coating is about 26 percent by volume of the coating.

Example 5

A varnish consisting of 30 parts low-resistivity, 120 particle size silicon carbide, 65.4 parts of a fluid epoxy resin, which contains about 18 percent by weight of low boiling solvents, and 4.6 parts of a curing agent consisting of an aliphatic polyamine, is applied on the coil ends of a machine intended for a line voltage of 16 kv. The coated length is 10 cm. and the thickness of the coating not exceeding 0.5 mm. After staying for about 40 hours at room temperature the applied varnish is transferred to a solid cured coating having a pronounced voltage dependent resistivity. The content of silicon carbide in the cured coating is about 16 percent by volume of the coating.

Example 6

A varnish consisting of 35 parts high-resistivity, 280 particle size silicon carbide, 3.5 parts highly disperse silicon oxide, and 61.5 parts linseed oil modified alkyd varnish, is applied on the coil ends of a machine intended for a line voltage of 16 kv. Of the 61.5 parts of the varnish, 31.4 parts are alkyd binder, 4.0 parts zinc chromate, 8.0 parts iron oxide and 17.6 parts solvent, being xylol. The coated length is 10 cm. and the thickness of the coating not exceeding 0.5 mm. The varnish is cured at room temperature over night. The content of silicon carbide in the cured coating is about 24 percent by volume of the coating.

Instead of applying the coating as a varnish directly onto the insulated surface to be protected, the coating substance may first be applied on a tape which is then wound round the insulated conductor, after which the curing of the binder is performed. This method makes it much easier to control the thickness of the finished coating.

It is further evident that the invention is not only applicable to the coil ends in electric machines and to high tension bushing insulators, but it can be advantageously used in many other instances for electric apparatus and machines where it is necessary to equalize the potential gradient on the surface of an insulation.

What is claimed is:

1. A high voltage means comprising an electrical conductor, an electrical insulation applied around said conductor and in contact with said conductor, a coating of a material having a substantial voltage dependent resistivity within the actual voltage range of the conductor applied on the surface of said insulation and in contact with the surface of said insulation, and a body of conducting material situated at the surface of said insulation and in contact with said coating, said body having a potential considerably different from that of the conductor.

2. A high voltage means comprising an electrical conductor, an electrical insulation applied around said conductor and in contact with said conductor, a coating of a material having a substantial voltage dependent resistivity within the actual voltage range of the conductor applied

to the surface of said insulation and in contact with the surface of said insulation, said coating comprising silicon carbide particles intermixed with a solid resinous binder and being derived from a composition comprising said silicon particles and said resinous binder in a fluid state, said fluid resinous binder having the property of shrinking when transformed into said solid resinous binder, and a body of conducting material situated at the surface of said insulation and in contact with said coating, said body having a potential considerably different from that of the conductor.

3. A high voltage means as claimed in claim 2, said silicon carbide particles having a volume resistivity in the range of a few ohm-cm. to several million ohm-cm.

4. A high voltage means comprising an electrical conductor, an electrical insulation applied around said conductor and in contact with said conductor, a coating of a material having a substantial voltage dependent resistivity within the actual voltage range of the conductor applied to the surface of said insulation and in contact with the surface of said insulation, said coating comprising silicon carbide particles having a volume resistivity in the range of a few ohm-cm. to several million ohm-cm., intermixed with a solid resinous binder, the content of said silicon carbide particles being 15–35 percent by volume of said coating, said coating being derived from a composition comprising said silicon carbide particles and said resinous binder in a fluid state, said fluid resinous binder having the property of shrinking 0.5–5 percent by volume when transformed to said solid resinous binder, and a body of conducting material situated at the surface of said insulation and in contact with said coating, said body having a potential considerably different from that of the conductor.

5. A high voltage means comprising an electrical conductor, an electrical insulation applied around said conductor and in contact with said conductor, a coating of a material having a substantial voltage dependent resistivity within the actual voltage range of the conductor applied to the surface of said insulation, said coating comprising silicon carbide particles having a volume resistivity in the range of a few ohm-cm. to several million ohm-cm. and a particle size in the range of particle size 100 to particle size 400 intermixed with a solid resinous binder the content of said silicon carbide particles being 15–35 percent by volume of said coating, said coating being derived from a composition comprising said silicon carbide particles and said resinous binder in a fluid state, said fluid resinous binder having the property of shrinking 0.5–5 percent by volume when transformed into said solid resinous binder, and a body of conducting material situated at the surface of said insulation and in contact with said coating, said body having a potential considerably different from that of the conductor.

6. A high voltage means comprising an electrical conductor, an electrical insulation applied around said conductor and in contact with said conductor, a coating of a material having a substantial voltage dependent resistivity within the actual voltage range of the conductor applied to the surface of said insulation and in contact with the surface of said insulation, said coating comprising silicon carbide particles intermixed with a solid resinous binder, the content of said silicon carbide particles being 10–65 percent by volume of said coating, said coating being derived from a composition comprising said silicon carbide particles and said resinous binder in a fluid state, said fluid resinous binder having the property of shrinking 0.5–5 percent by volume when transformed to said solid resinous binder, and a body of conducting material situated at the surface of said insulation and in contact with said coating, said body having a potential considerably different from that of the conductor.

7. A high voltage means comprising an electrical conductor, an electrical insulation applied around said conductor and in contact with said conductor, a coating of

a material having a substantial voltage dependent resistivity within the actual voltage range of the conductor applied to the surface of said insulation, said coating comprising silicon carbide particles having a particle size in the range of particle size 100 to particle size 400 intermixed with a solid resinous binder, the content of said silicon carbide particles being 10–65 percent by volume of said coating, said coating being derived from a composition comprising said silicon carbide particles and said resinous binder in a fluid state, said fluid resinous binder having the property of shrinking 0.5–5 percent by volume when transformed into said solid resinous binder, and a body of conducting material situated at the surface of said insulation and in contact with said coating, said body having a potential considerably different from that of the conductor.

References Cited in the file of this patent

UNITED STATES PATENTS

1,626,931	Grondahl	May 3, 1927
2,199,803	Light	May 7, 1940
2,276,656	Johnson	Mar. 17, 1942
2,276,732	Ludwig et al.	Mar. 17, 1942
2,376,815	Roman	May 22, 1945
2,593,507	Wainer	Apr. 22, 1952
2,795,680	Peck	June 11, 1957
2,796,505	Bocciarelli	June 18, 1957
2,825,702	Silversher	Mar. 4, 1958
2,916,460	Vander Der Beck	Dec. 8, 1959

OTHER REFERENCES

Fetterley: "Electrical Conduction in Silicon Carbide," J. Electrochemical Society, vol. 104, No. 5, pp. 322–327.