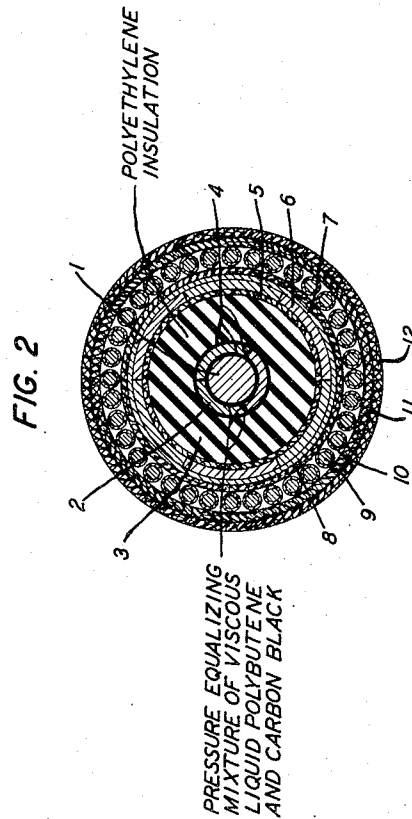
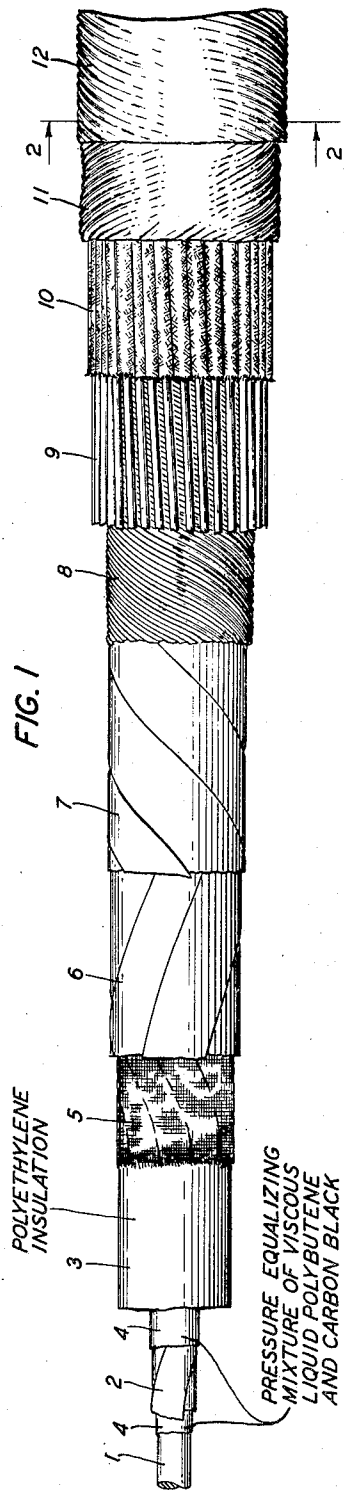


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INSULATED CONDUCTOR

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This invention relates to insulated electrical conductors.

More particularly it relates to improvements in insulated conductors in which a central conducting core is covered by a layer of a solid insulating material of high dielectric strength separated from the conducting core by a layer of a viscous, liquid insulating material which prevents the occurrence of voids between the core and the solid insulating layer.

One type of conductor in which such a structure is found is in submarine communication cable wherein the viscous liquid serves as a "pressure equalizer." In submarine cables, the conducting metal core is commonly surrounded by a helically wound metal tape which serves the purpose of maintaining a conducting path if, in use, the conducting core accidentally snaps. If the solid insulating layer is placed directly over such a wound tape, a considerable volume of air will remain in the voids around the windings.

When the submarine cable is placed under water, the pressure of the water tends to push this trapped air along the cable until a large quantity of air is localized in one spot, causing a bulge in, and ultimate failure of, the insulation. For this reason, a viscous insulating liquid is commonly interposed between the conductor and the solid insulation so as to fill all the voids and displace all the air. The insulating liquid, because of its viscosity, shows little tendency to be pushed along the cable by the pressure of the water surrounding the cable.

In an example of a submarine cable of this type, the primary electrical insulation for the central conducting core may be formed of a layer of a normally solid polymer of ethylene (polyethylene) of adequate thickness. The pressure equalizing liquid may be formed of a viscous, normally liquid butene polymer (polybutene), particularly a viscous, normally liquid polymer of isobutylene (polyisobutylene).

Since submarine cable for communication purposes is normally operated at a relatively low potential, no problem of dielectric strength of the insulation is encountered in ordinary use. However, in the manufacture of cable of this type, the most satisfactory method of testing the cable for faults in the insulation is by the application of a high voltage across the insulation. In order for this test to be usable, it is necessary for the cable insulation to have a sufficient dielectric strength to withstand the applied voltage gradient.

The polyethylene layer, having an average dielectric strength of over 5,000 volts per mil, would be well able to withstand the test potential if it were situated directly over the central conductor with only the air-gaps referred to

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above between the polyethylene and the conductor. When, however, the viscous, liquid polyisobutylene, which has an average dielectric strength of about 500 volts per mil, is interposed between the conductor and the polyethylene layer, the over-all potential which the insulation will withstand is very markedly reduced in spite of the fact that the same thickness of polyethylene is present and the total thickness of the insulation is somewhat increased. This reduction in the dielectric strength of the insulation may be sufficient to prevent the insulation from consistently withstanding the test potential.

According to the present invention, this loss of dielectric strength is avoided by intimately mixing with the viscous liquid a finely divided conductive or semiconductive solid which acts to reduce the dielectric strength of the liquid layer still further. The most suitable finely divided solid for this purpose is carbon black.

The finely divided solid, such as carbon black, need be added to the viscous liquid only in exceedingly small amounts, such as 0.1 per cent, in order to avoid a reduction of the dielectric strength of the composite insulation substantially below the high values to be expected due to the high dielectric strength of the solid insulation. The addition of such a small amount of carbon black to the viscous liquid materially lowers its individual dielectric strength but its resistivity remains at an exceedingly high value. The increased dielectric strength of the composite insulation appears to result directly from the lowered dielectric strength of the viscous liquid portion of the insulation.

In the accompanying drawing:

Fig. 1 is a front elevation of a submarine cable representing one embodiment of the present invention, with the successive layers cut away to show the structure; and

Fig. 2 shows a radial cross-section of the cable of Fig. 1.

In the cable shown in these figures, the signal conducting members are the conducting metal core 1 and the helical winding 2 of a plurality of metal tapes surrounding the central core. The electrical insulation, with which the present invention is concerned, is made up of a layer 3 of solid insulating material of high dielectric strength, such as polyethylene, and the pressure equalizer 4 formed of a viscous liquid insulating material, such as polyisobutylene containing carbon black, which forms a thin layer between the solid insulation 3 and the metal tape winding 2 and between this winding and the central conductor 1, and which also fills the interstices of the winding.

The remainder of the cable structure merely forms a protective covering for the underlying insulated conductor and, in the cable shown, is

made up of successive layers of impregnated fabric tape 5, helically wound metal tapes 6 and 7, tanned jute yarn servings 8, steel wires 9 each covered with impregnated cotton braid 10, and servings 11 and 12 of jute yarn saturated and coated with a waterproofing and protective compound.

In a cable of this type, the dielectric strength of the electrical insulation is as high as it would be if the solid insulating layer 3 were used alone without the pressure equalizer 4 since, as discussed above, the dielectric strength of the pressure equalizer is reduced to a harmless value by the addition of carbon black or other finely divided conductive solid. The reason for this effect is not completely known but it can be explained on the assumption that, when electrical stress is applied across and divided between the layer of high dielectric strength solid and the layer of lower dielectric strength liquid, the layer of lower dielectric strength breaks down and this breakdown may be propagated through the high dielectric strength solid layer. Whether the breakdown carries through the solid layer appears to be governed, to a large extent, by the energy dissipated in the breakdown of the liquid layer.

If this energy is sufficiently great, the breakdown is propagated through the high dielectric strength solid layer even though the electrical stress present would not ordinarily be sufficient to cause breakdown of this layer. The higher the dielectric strength of the liquid layer, the greater is the energy dissipated when this layer breaks down and the greater is the likelihood that the breakdown will be propagated through the solid layer. Therefore, by lowering the dielectric strength of the liquid layer sufficiently, and thereby lowering the dielectric breakdown energy, the breakdown of the solid layer can be avoided and the dielectric strength of the overall insulation can be restored.

As indicated above, carbon black is a suitable substance to be incorporated in the substance forming the liquid layer to reduce its dielectric strength. The carbon black is particularly effective for this purpose in the smaller particle sizes. Carbon blacks having average particle diameters of 100 millimicrons or less have been found particularly suitable.

As little as 0.1 per cent by weight of carbon black in the viscous liquid has been found effective. Ordinarily it is preferable to add somewhat larger amounts of the order of 0.5 per cent to 1 per cent. Larger amounts have no harmful effect and may be added, up to 5 per cent or 10 per cent for instance, if desired.

Carbon black in these amounts lowers the dielectric strength of the liquid effectively but is not sufficient to render it conductive. Thus a polyisobutylene of average molecular weight of about 10,000, as determined by the Staudinger method, and having a viscosity of 29,000 poises at 25° C. had an average dielectric strength of 500 volts per mil. This dielectric strength was lowered to 180 volts per mil when 0.1 per cent carbon black was added and to 110 volts per mil when 0.5 per cent carbon black was added. The resistivity of the polyisobutylene remained in excess of 10^{15} ohm-centimeters even with the addition of the carbon black.

Although carbon black has been found particularly effective, it is apparent that similar results can be obtained by incorporation in the viscous liquid of other finely divided solids which

possess a substantial conductivity and which, because of resulting distortion of the electric field, will lower the dielectric strength of the viscous liquid even though not used in amounts which will render the liquid appreciably conductive. The carbon black or other finely divided solid can be dispersed in the viscous liquid by any suitable means, as by milling.

The invention has been described particularly with reference to submarine cables having a solid insulation of polyethylene and a viscous liquid pressure equalizer of polyisobutylene. It is apparent that the invention is applicable to any insulated conductor structure having a layer of solid insulating material and an underlying layer of a liquid insulating material of lower dielectric strength than the solid material, where it is desired to increase the over-all dielectric strength of the insulation.

Since other modifications and equivalents will be apparent to those skilled in the art, the description above of the specific embodiments of the invention are intended to be illustrative of, but not necessarily to constitute a limitation upon, the scope of the invention.

What is claimed is:

1. An insulated conductor comprising a conducting core, a layer of normally solid insulating material surrounding said core and a layer of viscous, normally liquid insulating material of lower dielectric strength than said solid insulating material interposed between said layer of solid insulating material and said conducting core, said viscous, normally liquid insulating material having dispersed therethrough finely divided particles of carbon in an amount of at least 0.1 per cent of the weight of the viscous liquid insulating material but not in an amount sufficient to lower the resistivity of the viscous liquid insulating material appreciably below 10^{15} ohm-centimeters.

2. An insulated conductor comprising a conductive core, a layer of polyethylene surrounding said core and a layer of normally liquid polyisobutylene, containing carbon black dispersed therein, interposed between said polyethylene layer and said conductive core.

3. A submarine cable comprising a conductive core, a layer of polyethylene surrounding said core and a layer of normally liquid polyisobutylene, containing between 0.1 per cent and 10 per cent by weight of carbon black dispersed therein, interposed between said polyethylene layer and said conductive core.

4. A submarine cable comprising a metal core, a metal tape helically wound about said core, a layer of polyethylene surrounding said tape winding and a layer of viscous, normally liquid polyisobutylene interposed between said polyethylene layer and said tape winding and filling the interstices of said tape winding, said polyisobutylene having intimately dispersed therethrough between 0.1 per cent and 1 per cent by weight of carbon black having an average particle diameter not greater than 100 millimicrons.

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