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"Protective sleeve for electrical
cable termination or splice"

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This invention relates to recoverable sleeves for use in protecting terminations and joints for electrical cables.

When a continuously shielded high voltage cable is terminated or spliced, the shield is removed for such a distance from the termination or splice that electrical breakdown along the surface of the insulation from the exposed conductor to the shield cannot occur. The removal of the shield causes discontinuity of the electrical field so that there is severe electrical stress at the end of the shield. In order to relieve this stress and so prevent failure of the cable insulation in service, a number of methods have been proposed to provide stress control by resistive or capacitative effects, for example as described in U.S. Patent No. 3,396,231, and British Patent No. 1,434,719, the disclosures of which are incorporated herein by reference.

According to the present invention there is provided a protective sleeve for a cable termination or splice which comprises a dimensionally recoverable extruded tubular article having an innermost stress grading resistive layer, an insulating inner layer and a conductive outer layer, wherein the insulating layer has a substantially uniform wall thickness along its entire length. In use, the sleeve is desirably applied over

(18) a shielded electrical cable termination or a shielded joint between two shielded electrical cables, the or each cable being a shielded electrical cable comprising a conductor, a dielectric layer which surrounds the
5 conductor and which has been cut back to expose a length of the conductor, and an electrically conductive shield which surrounds the dielectric layer and which has been cut back to expose a length of the dielectric layer, so that it overlaps the or each cable shield,
10 and recovered, advantageously by heating the sleeve.

Preferably the conductive outer layer is electrically connected to the or each cable shield at or beyond the end of the sleeve.

The insulating inner layer is preferably formed from a material with appropriate electrical properties including discharge resistance, permittivity, and high breakdown strength and may comprise for example a polymeric matrix having dispersed therein if necessary a filler to give enhanced electrical properties.

Polymeric material suitable for use as the polymeric matrix may include resins comprising, for example, polyolefins and olefin copolymers such as polyethylene, polypropylene, ethylene/propylene copolymers, and polybutylenes; substituted polyolefins, particularly halogen-substituted polyolefins such as polyvinyl chloride, polyvinylidene chloride, polyvinylidene fluoride, Teflon* 100 (a polytetrafluoroethylene manufactured by DuPont), Teflon FEP (a copolymer of tetrafluoroethylene and hexafluoro-propylene manufactured by DuPont) Teflon PFA (a copolymer of tetrafluoroethylene and perfluoroalkoxy moieties manufactured by DuPont), Tefzel* (a terpolymer of ethylene, tetrafluoroethylene and a fluorinated monomer manufactured by DuPont), and Halar* (a copolymer of ethylene and chlorotrifluoroethylene manufactured by Allied Chemicals); polyesters, particularly segmented copolyester polymers such as Hytrel* (segmented polyether ester copolymer derived from terephthalic acid, polytetramethylene ether glycol and 1,4-butanediol manufactured by DuPont); and polyurethanes.

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Other suitable polymeric materials for use as the polymeric matrix include elastomers comprising, for example, copolymers of dienes with olefinically unsaturated monomers such as ethylene/propylene/non-conjugated diene terpolymers, styrene/butadiene polymers, butyl rubbers and copolymers of dienes with unsaturated polar monomers such as acrylonitrile, methyl methacrylate, ethyl acrylate, vinyl pyridine and methyl vinyl ketone; halogen-containing elastomers such as chloroprene polymers and copolymers, for example chloroprene, chlorinated polyethylene, chlorosulphonated polyethylene and Viton* (a copolymer of vinylidene fluoride and hexafluoropropylene manufacture by DuPont); copolymers of olefins with olefinically unsaturated esters such as elastomeric ethylene/vinyl acetate polymers, ethylene/acrylic acid ester copolymers such as ethylene/ethyl acrylate and methacrylate copolymers and particularly ethylene/acrylic rubbers such as Vamac* (a terpolymer of ethylene, methyl acrylate and a curesite monomer manufactured by Du Pont); acrylic rubbers such as polyethyl acrylate, polybutyl acrylate, butyl acrylate/ethyl acrylate copolymers, and butyl acrylate/glycidyl methacrylate copolymers, silicone elastomers such as polydiorganosiloxanes, dimethylsiloxanes, methylvinylsiloxanes and methylphenylsiloxanes, fluorosilicones for example those derived from 3,3,3-trifluoropropyl siloxane and carborane siloxanes; elastomers polyurethanes; and polyethers such as epichlorhydrin rubbers.

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Blends of the above mentioned elastomers and resins may also be used. Particularly good results have been obtained using polyolefins, olefin copolymers and blends of olefin polymers.

The insulating inner layer is desirably, though not essentially, formed from a substantially track resistant, and preferably non-tracking material. By "non-tracking" there is meant a material which is resistant to the formation of dendritic, carbonaceous, electrically conducting deposits on its surface under the influence of high electrical voltages. Suitable discharge and track resistant material comprising anti-tracking fillers are described in British Patent Nos. 1,041,503; 1,240,403, 1,303,432 and 1,337,951 the disclosures of which are incorporated herein by reference.

Preferably the insulating inner layer has a dielectric constant of from 2 to 6 and a volume resistivity of at least 10^{10} , preferably at least 10^{12} ohm cm.

The conductive outer layer may comprise a woven or stranded metal braid but is preferably a layer of a polymeric matrix having a conductive filler dispersed therein in which case the enclosure may further comprise a woven or stranded metal braid positioned about the conductive outer layer. The polymeric matrix may comprise any of the polymeric materials listed previously, or a mixture of such materials, and the

conductive filler may comprise metal particles or a
conductive carbon black. Suitable carbon blacks may be
chosen from among those currently commercially available,
for example, types HAF, SRF, EPC, FEF and ECF. Parti-
5 cularly good results have been achieved using an elec-
trically conductive polymeric composition as described
in British Patent No. 1,294,665, the disclosure of which
is incorporated herein by reference. The conductive
outer layer preferably comprises from 10 to 70 more
10 particularly 10 to 20 e.g., 15 to 17, parts by weight
of the conductive filler, based on the total weight
of the polymeric matrix and the filler.

The conductive outer layer preferably has a resistance
of less than 5×10^4 ohm cm, and most preferably less
15 than 100 ohm cm.

The enclosures of the present invention may be formed
by urging the protective sleeve into conforming engage-
ment with the cable joint or termination to be protected.
By conforming engagement is meant the property of a
20 material to follow closely the contours of an underlying
substrate. Such conforming engagement may be obtained
by the use of a sleeve that comprises elastomeric or heat
recoverable materials, or both. In order to eliminate
the possibility of undesirable voids between the sleeve
25 and the surface of the termination or joint, the surface
thereof and/or the inner surface of the tube may be
coated with an appropriate

void filler such as a grease or heat activated adhesive, sealant or mastic.

In one embodiment an elastomeric tubular article may be "held-out" in a stretched state by an inner or
5 outer hold-out member which can be removed or displaced, the elastic stresses released thereby urging the tubular article to recover into conforming engagement with the electrical apparatus. In a further embodiment the tubular article may be bonded
10 to the hold-out member and the bond weakened, for example by solvent or mechanical treatment, to permit recovery.

Preferably, however, the sleeve is a heat-recoverable article. Usually these articles

recover, on heating, towards an original shape from which they have previously been deformed, but the term "heat-recoverable" as used herein also includes an article, which on heating, adopts a new configuration, even if it has not previously been deformed. In their most common form, such articles comprise a polymeric material exhibiting the property of elastic or plastic memory as described for example, in US Patent 2,027,962, 3,086,242 and 3,957,372. In other articles, as described, for example in British Patents 1,434,719 and 1,440,524, an elastomeric member is held in a stretched state by a second member, which upon heating, weakens and thus allows the elastomeric member to recover. The disclosures of these specifications are incorporated herein by reference. The insulating inner layer and the conductive outer layer may each be independently heat recoverable, or one or both of the layers may be elastomeric, provided that the sleeve as a whole is heat recoverable.

In contradistinction to the tubular articles which have hitherto been proposed for the protection of cable terminations and splices, the enclosure of the present invention can if desired be formed so as to have a substantially uniform cross-section along its entire length, at least in the stable or freely recovered state, thus enabling the enclosure to be produced by relatively inexpensive extrusion methods. This is a considerable

advantage over prior art designs which frequently require sophisticated moulding operations. However, the preferred method of production is by multiple extrusion of the layers, followed if necessary by treatment to render the extruded product recoverable. This treatment may involve, for example, cross-linking by ionising radiation or by chemical cross-linking agents, followed by expansion, for example, using differential gas pressure or a mandrel.

10 The stress grading innermost resistive layer and the conductive outer layer are required to be in electrical contact at least after the enclosure is conformingly engaged with the electrical cable termination or joint, and this may be achieved by an appropriate configuration of the ends of the enclosure or by the provision of means for making electrical contact between the layers. Electrical contact between the stress grading innermost layer and the conductive outer layer may be direct or indirect.

20 Earth continuity is provided across the cable termination or joint by connecting the conducting outer layer of the enclosure to the shield or shields. In order to connect the outer conducting layer to the shield or shields indirect electrical contact may be provided by conductive members which fit on the ends of the sleeve. Such members can, for example, be metal straps, or moulded parts formed from conductive polymeric materials, which may, if desired, be heat-recoverable.

Electrical contact may instead be provided by wrapping a metal braid helically around the conductive outer layer and connecting the end or ends to the shield(s) for example by soldering.

- 5 The moulded parts may, for example, be annular members having grooved faces adapted to fit over the ends of the enclosure, and may advantageously be provided with an internal coating of a sealant, for example a mastic or hot melt adhesive, to give environmental protection
- 10 to the ends of the enclosure. Naturally where the moulded part is employed to provide electrical contact, then any internal coating of sealant is electrically conductive.

- In some circumstances, as previously mentioned, it may
- 15 be found advantageous to provide the space adjacent to the exposed electrical conductor, for example the region surrounding the crimped central conductors of a cable joint, and/or the space adjacent to the end of the shield, with a void-filling material in order to
 - 20 minimize the possibility of breakdown due to ionization of air in any voids. Such a material may be a grease, for example a silicone grease, a mastic or a hot melt adhesive. The void filling material may have electrically insulating, conductive or semi-conductive properties
 - 25 although, where it has semi-conductive properties, it does not in general exhibit a significant stress grading effect since it is generally applied in

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localized areas. A particularly suitable void-filling material is described and claimed in German Offenlegungsschrift No. 2,748,371 the disclosure

of which is incorporated herein by reference.

The invention may find application in the termination and splicing of high voltage cables operating at voltages up to 15 kV, and even higher e.g. up to 40 kV, or 72 kV in some cases. The stress grading material may have electrical impedance characteristics which are wholly resistive or partly capacitative. Preferably the stress grading inner layer is semi-conductive and comprises a polymeric matrix having dispersed therein a conductive filler, and especially carbon black. Suitable polymeric materials and carbon blacks for use in the polymeric matrix include those listed previously. The amount of carbon black in the stress grading materials will depend to some extent on the type of black used and the polymer matrix, but preferably the material comprises from 5 to 150 parts by weight of carbon black, per 100 parts by weight of resin.

Alternatively there may be used as the stress grading innermost layer a composition having non-linear electrical resistive characteristics, for example as described in British Patents Nos. 1,470,501, 1,470,502, 1,470,503 and 1,470,504, the disclosures of which are incorporated herein by reference. In place of the polymeric materials listed previously, the stress grading innermost layer may comprise a fluid coating such as a mastic, for example as described in British Patent No. 1,526,397.

The stress grading innermost layer preferably has a specific impedance in the range 10^7 to 10^{10} ohm cm, for example close to 10^9 ohm cm, measured at a frequency of 50 Hz. The stress grading layer used in the closure advantageously has a D. C. resistivity in the range of 10^{10} to 10^{11} ohm cm.

Since the resistive stress grading layer extends from the exposed conductor to the or each shield when the protective sleeve is installed the stress grading layer extends along substantially the entire length of the sleeve. Also, it has been found that it is possible thereby to dispense with other forms of stress grading such as stress grading cones, allowing the entire sleeve to be formed by relatively inexpensive extrusion methods.

The relative thickness of the insulating inner layer and the conductive layer ~~layer~~ will be dictated to some extent by the required electrical properties of the enclosure, but in general the insulating layer will have a thickness of from 2 to 15 mm, preferably from 3 to 10 mm, and the conductive layer will have a thickness of from 0.5 to 5 mm, preferably from 1 to 3 mm.

Preferably, the sleeve overlaps the cable shield by an amount at least equal to the thickness of the insulating layer. Preferably, the overlap is from 2.5 to 6 times the thickness of the insulating layer. In the majority of cases, no significant further improvement is

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obtained by using an overlap in excess of 3 times the thickness of the layer.

The thickness of the innermost stress grading layer will be dictated to some extent by the required
5 electrical properties of the enclosure, but in general the innermost layer will have a thickness of from 0.5 to 4.0 mm.

Preferably the stress grading layer extends for at least 75% of the length of the sleeve. In certain embodiments the
10 stress grading layer extends for the full length of the sleeve. Desirably at least that portion of the sleeve comprising the stress grading layer should be of substantially uniform cross-section along its length in the stable or freely recovered state, that
15 is to say, the ratio of the thickness of the layers is substantially constant along the length of the stress grading layer and the general configuration of the cross-section is substantially unchanged. In most cases the stress grading layer will be centrally dis-
20 posed along the length of the enclosure.

The invention is illustrated by the following example. Reference is made to the accompanying drawings in which the sole Figure is a sectional elevation of a sleeve according to the invention in position on a cable.

EXAMPLE

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A heat-recoverable coextruded tubular 5 - 8 kv joint enclosure as shown in the Figure comprised a radially outermost layer 51 comprising conductive high carbon loaded polyethylene, a radially intermediate layer 52 comprising insulated modified polyethylene and a radially innermost layer 53 comprising a stress-grading layer. The tube was rendered heat shrinkable by electron beam radiation cross-linking and expansion under heat to an expansion ratio of 3.5:1. In the fully recovered condition, the wall thicknesses for the various layers were 1 mm for the conductive outer layer, 5 mm for the insulating intermediate layer and 1 mm for the inner stress-grading layer. The conductive layer had a specific resistance of 1000 ohm cm, the insulating layer had a volume resistivity of 5×10^{13} ohm cm and the stress-grading layer a specific resistance of 10^{11} ohm cm.

A 5 - 8 kv in-line cable joint was prepared by crimping the central conductors of a cable and cutting back the cable screen 55 on each side of the crimp for a distance of 6 cm. The expanded jointing enclosure was positioned over the joint and shrunk down by heating such that the recovered tubing conformed closely to the contours of the joint and was in contact with the central conductors and the shields on either side of the crimp with a $2\frac{1}{2}$ cm overlap onto each shield. The outer layer 51 of the enclosure was then electrically

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connected to the cable screen 55 at each end of the enclosure by means of wires 56 in order to provide earth continuity across the joint.

The reader's attention is directed to our copending
5 Applications Nos. 79.31976 (Serial No. 2,036,460) and
82.32824 (Serial No.) which describe and claim
subject-matter related to that of the present application.



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Claims

1. A protective sleeve suitable for application over a cable termination or splice, which comprises a dimensionally recoverable extruded tubular article
5 having an innermost stress grading resistive layer, an insulating inner layer and a conductive outer layer, wherein the insulating layer has a substantially uniform wall thickness along its entire length.
2. A sleeve as claimed in claim 1, which is
10 heat-recoverable.
3. A sleeve as claimed in claim 1 or claim 2, which has been produced by co-extrusion of the specified layers.
4. A method of protecting a cable termination
15 or splice which comprises recovering a sleeve as claimed in any one of claims 1 to 3 over the splice.
5. A protected cable termination or splice made by the method of claim 4.
6. A sleeve as claimed in claim 1, substantially
20 as described in the example herein.
7. A sleeve as claimed in claim 1, substantially as described with reference to and as illustrated by the drawing.

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