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Mashikian

[11] **3,876,820**

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[54] **PRESSURIZED FLUID INSULATION FOR HIGH VOLTAGE CABLE**

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[73] Assignee: **The Detroit Edison Company,** Detroit, Mich.

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[52] **U.S. Cl.** ..... **174/19;** 174/73 R; 339/117 P; 174/21 R

[51] **Int. Cl.** **H02q 15/22**

[58] **Field of Search** ..... 339/117 R, 117 P, 118 R, 339/136 R, 137, 149 R, 150 R, 150 C, 151 R, 151 C, 200 R, 201, 206 R, 210 R, 213 R, 213 T, 217 R, 217 PS; 174/19, 21 R, 21 C, 73 R

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[57] **ABSTRACT**

An electrical connection for high votlage insulated cable, either to a cable termination or to a second cable is provided with a hollow tubular sleeve of resilient elastomeric insulating material which surrounds the insulated end portion of one or more cables. The sleeve is surrounded by a rigid shell or casing and contains an insulating fluid under elevated pressure provided to cause the inner surface of the sleeve to engage under elevated pressure in surface-to-surface contact with the exterior surface of the end portion of the insulation provided at the end or ends of the cable or cables.

33 Claims, 10 Drawing Figures

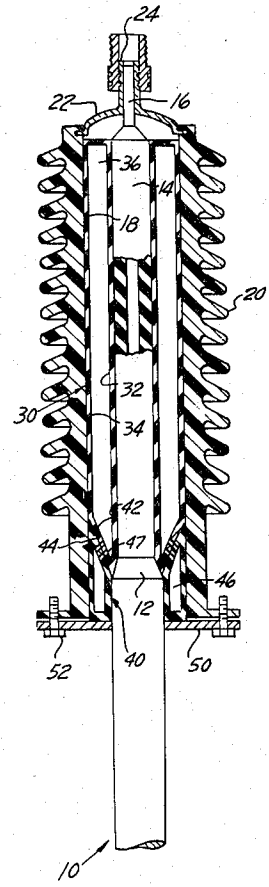


FIG. 1

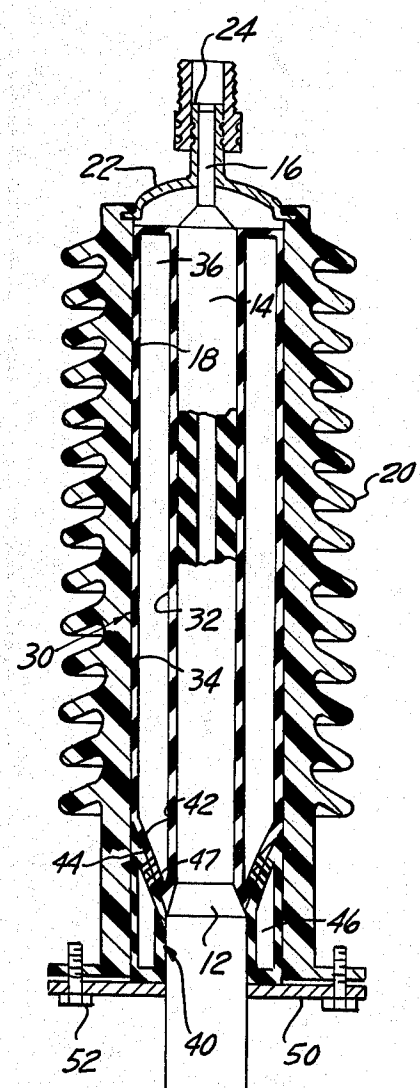
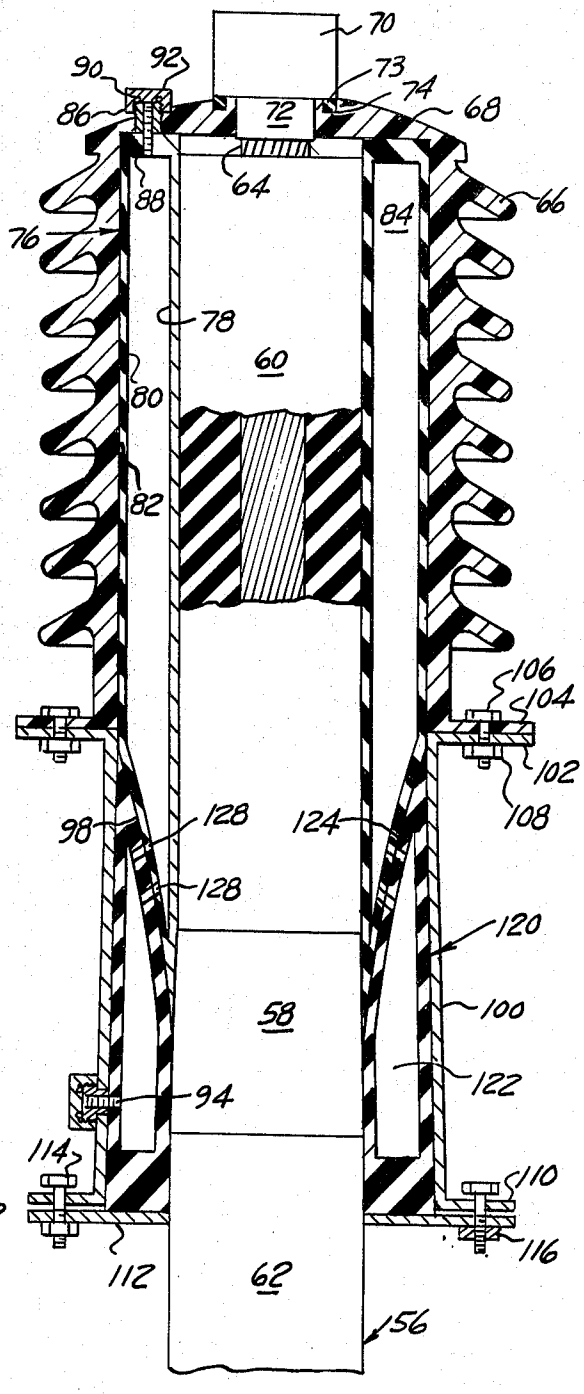


FIG. 2



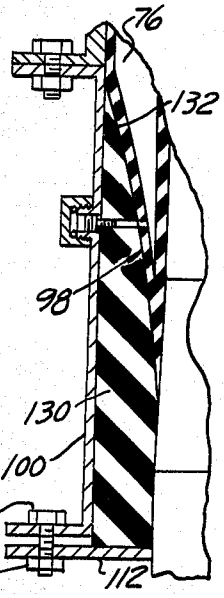


FIG. 3

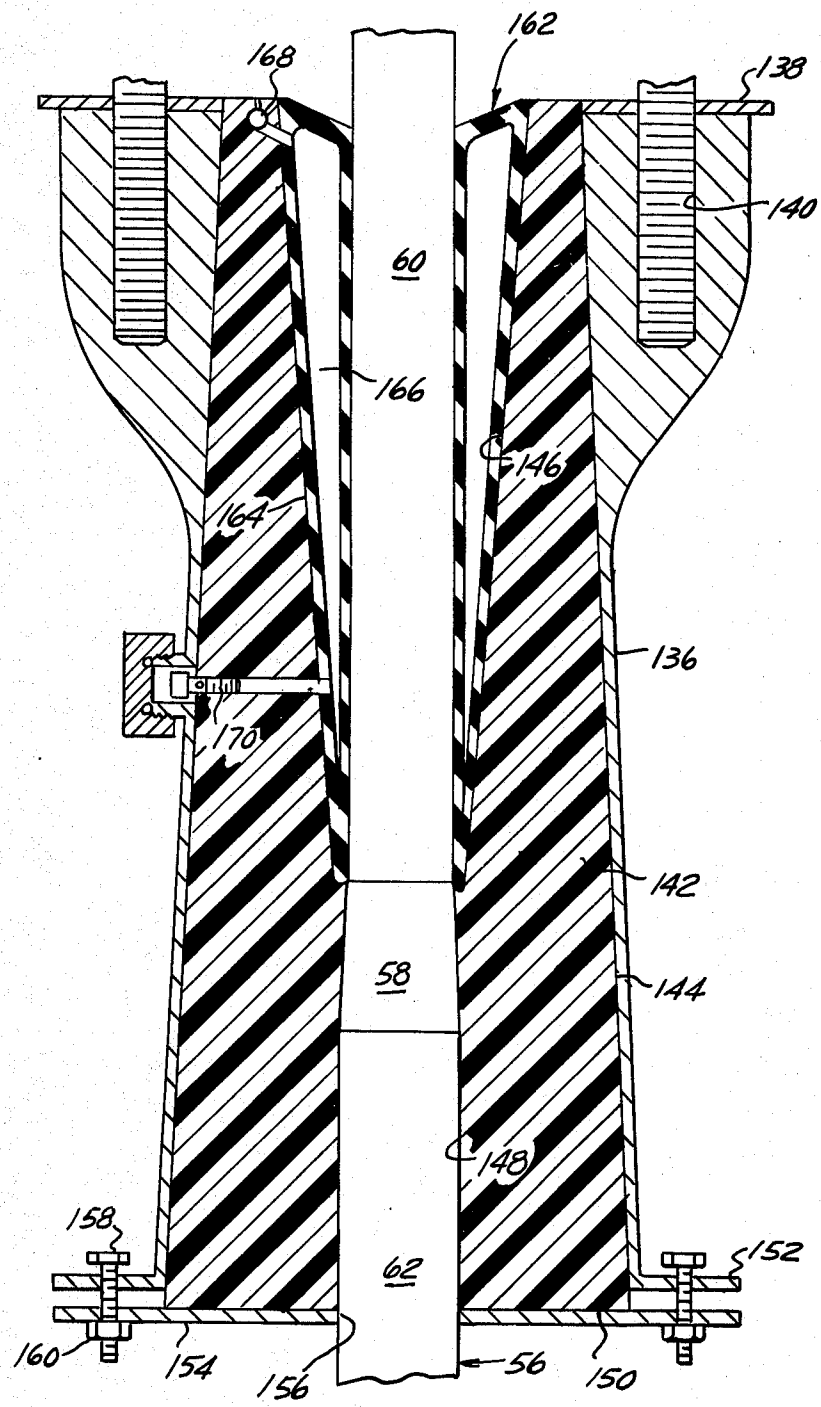

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FIG. 4

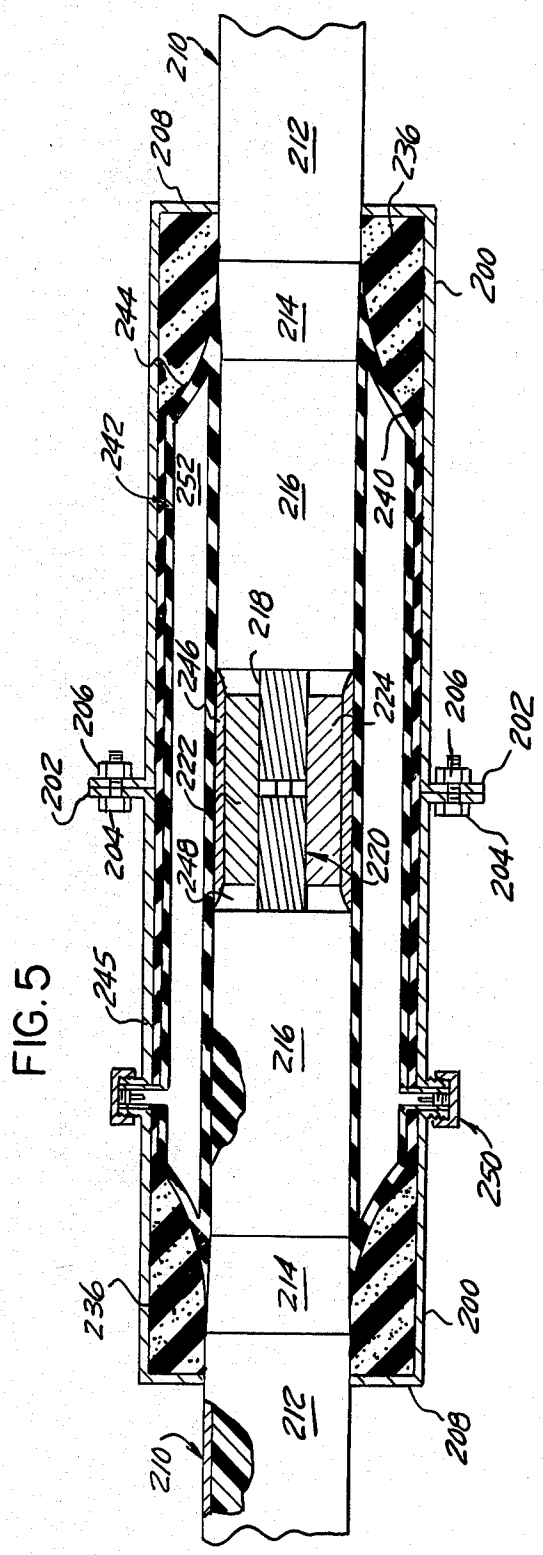


FIG. 5

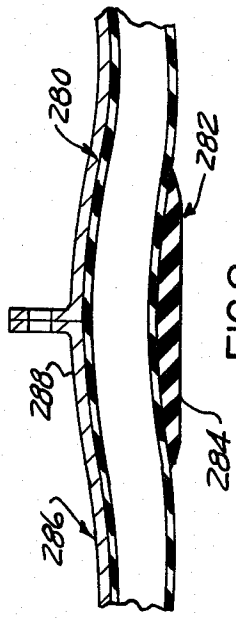


FIG. 8

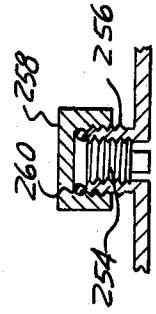


FIG. 9

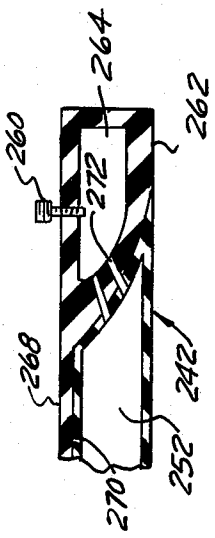


FIG. 7

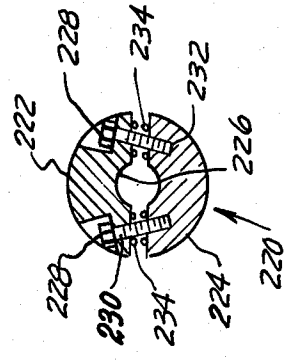
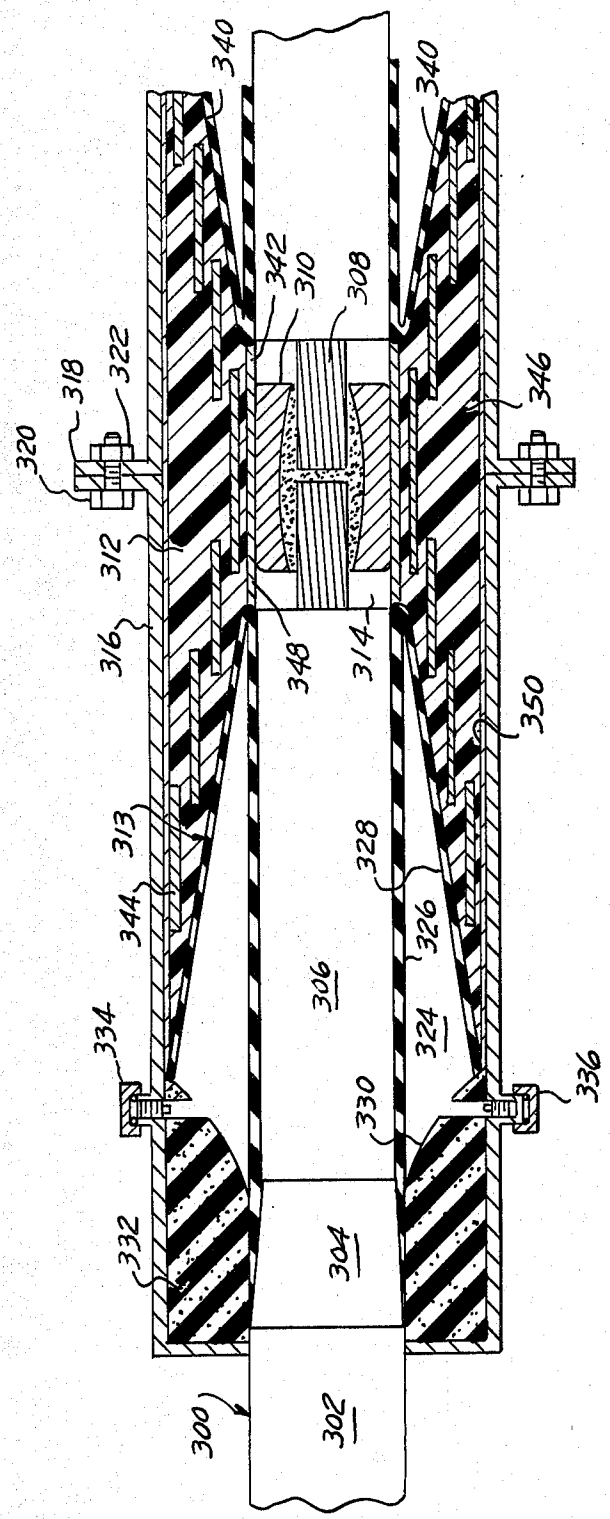


FIG. 6

FIG. 10


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PRESSURIZED FLUID INSULATION FOR HIGH VOLTAGE CABLE

BRIEF SUMMARY OF THE INVENTION

In providing a connection to the end of a high voltage insulated conductor, either to a terminal fitting or to the end portion of the conductor of a second cable, a problem has been presented in obtaining a proper surface-to-surface contact between an insulating sleeve provided to surround the end portion of insulating material adjacent the end of the cable or cables, and the outer surface of the insulation adjacent the end of the cable.

Where the insulating material is in the form of a resilient elastomeric filler, it has been difficult to provide adequate compression when the cable expands and contracts as a result of its daily and seasonal load cycle. Another disadvantage of this kind of cable termination (or connection) lies in the difficulty experienced in installing it. The difficulties in employing a fluid (liquid or gas) insulating material with or in place of the elastomeric material, with accompanying problems of sealing against leakage, are obvious.

In accordance with the present invention the insulating material is in the form of a sleeve which surrounds the end portion of the cable and is formed of a resilient elastomeric insulating material such for example as butyl or silicone rubber, or polyurethane, and is so shaped as to be hollow, or in other words, to be provided with an annular interior cavity. In use, this sleeve is received in a rigid shell which in accordance with the particular type of connection employed, may either be a metallic shell or it may be a rigid insulator body. The hollow interior of the sleeve is charged with an insulating fluid, either gas or liquid, at an elevated pressure sufficient to provide for inward displacement of the inner wall of the sleeve into a firm continuous surface-to-surface pressure contact with the outer surface of the end portion of the insulation adjacent the bared end of the conductor of the cable. Silicone or polybutene oil are examples of suitable insulating liquids, and sulfur hexafluoride, nitrogen and freon are examples of suitable insulating gases.

In general terms, the invention may be applied to a cable termination in which the bared end of the conductor may be suitably connected to an exterior fitting. Alternatively, the construction may be in the nature of a connection or joint between the ends of two sections of high voltage cable, in which case the ends of the conductors of the cables are bared and electrically connected together by conventional means, after which the connection between the conductors as well as the end portions of the insulation surrounding the conductors adjacent the ends of the cables, is surrounded by the hollow tubular insulating sleeve, the hollow interior chamber of which is charged with insulating fluid under elevated pressure.

Generally, an electrical stress relief element is provided in contact with one end of the hollow tubular sleeve. For this purpose the end of the hollow tubular sleeve remote from the bared conductor end of the cable is tapered to provide an outer generally conical surface. The stress relief sleeve is formed of a semiconductor such for example as insulating resin containing particles of conducting material such for example as graphite or carbon black particles, and has its inner surface tapered into conformity with the outward taper

provided at the end of the hollow sleeve. The tapered surfaces are brought into contact and may in fact be permanently bonded together by suitable means. There is thus provided a generally conical interface which has the effect of preventing localized electrical stress when the connection is carrying high voltage current.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a longitudinal sectional view of a simplified embodiment of the present invention applied to a cable termination.

FIG. **2** is a longitudinal sectional view of a further embodiment of the present invention.

FIG. **3** is an enlarged fragmentary detail of the sleeves.

FIG. **4** is an enlarged sectional view illustrating a modification of the structure shown in FIG. **2.**

FIG. **5** is a longitudinal sectional view of structure in which the invention is applied to a connection between the ends of two high voltage cables.

FIG. **6** is a sectional view on the line **6—6**, FIG. **5.**

FIG. **7** is a fragmentary view illustrating a modification of a stress relief sleeve applied to the construction of FIG. **5.**

FIG. **8** is a fragmentary sectional view illustrating a modification of the hollow sleeve and insulation, as illustrated in FIG. **5.**

FIG. **9** is an enlarged sectional view of one of the valves providing connection to the interior of the hollow sleeve.

FIG. **10** is a fragmentary longitudinal sectional view through a construction in which a modified form of the present invention is applied to the connection between two high voltage cables.

DETAILED DESCRIPTION

The present invention may be applied to different types of electrical connections such for example as the termination of a high voltage cable or the interconnection between the ends of two cable sections. Embodiments of these two different applications of the present invention will be described under separate headings below:

CABLE TERMINATION

Referring first to FIG. **1** there is illustrated a very simple application of the present invention to a cable termination. In this Figure there is illustrated a high voltage electrical cable **10.** Cables of this type are ordinarily provided with an external conducting ground shield. To apply a terminal connection to such a cable, the shield of the cable is pencilled as indicated at **12,** providing a short tapered section beyond which the conducting shield is removed. The insulation of the cable indicated at **14** is stripped away to bare the end of the conductor as indicated at **16.** The end portion of the cable is received in the hollow interior **18** of an insulator body of usual configuration having a metal cap **22** permanently affixed to the outer end of the insulator body. The metal cap includes a tubular portion **24** through which the bared end of the conductor **16** extends. A permanent connection between the bared end of the conductor **16** and the tubular portion **24** of the cap **22** is provided by crimping the tubular portion **24** into tight permanent crimped engagement with the bared end of the conductor **16.** Electrical connection is made with the cable conductor by means of a con-

ventional clamp type connector installed around the tubular portion **24.**

The dimension of the elongated generally cylindrical cavity **18** within the insulator body **20** is proportioned with respect to the dimension of the end portion **14** of the insulation on the cable **10** so as to leave an annular space within the insulator body surrounding the cylindrical insulation on the end portion **14** of the cable.

The annular space intermediate the end portion **14** of the cable and the inner surface **18** of the insulator body is filled with an assembly made up of a hollow insulating sleeve **30** having an inner wall **32** and an outer wall **34.** The sleeve **30** is closed at its ends and the hollow interior annular chamber **36** is filled with an insulating fluid, either liquid or gas. If the fluid is a liquid, a silicone oil, polybutene oil, or the like may be employed. If an insulating gas is used, gas such as sulfur hexafluoride, nitrogen, freon and the like may be employed. These fluids must of course be chemically compatible with the material forming the hollow insulating sleeve.

Associated with the hollow insulating sleeve **30** is a stress relief sleeve **40.** The stress relief sleeve may be formed of a suitable insulating polymer such for example as the same material employed to form the hollow insulating sleeve **30** except that it will contain conducting particles such as graphite or carbon black in an amount to make the material of the sleeve **40** a semiconductor having a resistivity not exceeding 10^8 ohms × cm.

The end of the hollow sleeve **30** remote from the bared end of the conductor **16** is provided with an outer tapered surface **42** and the adjacent end of the stress relief sleeve **40** is provided with an internal tapered generally conical surface **44** which conforms to the surface **42.** The interface between the surfaces **42** and **44** is thus a tapered or substantially conical interface which provides stress relief.

The stress relief sleeve **40** may also be hollow and provided with an annular interior chamber **46** which may be separately charged with insulating fluid, either liquid or gas, as previously described. The tapered end surfaces **42** and **44** of the sleeve may be impervious or they may be provided with openings **47** provided for transfer of the insluating fluid between the hollow interior of the sleeves **30** and **40.**

In the construction as thus far described it is contemplated that the hollow sleeve **30** and the sleeve **40** if it is provided with a hollow interior, are charged with the insulating fluid and permanently sealed when they are fabricated. It will be understood that the material of which the sleeves **30** and **40** are formed is a resilient elastomer such for example as butyl or silicone rubber. As intially charged with the insulating fluid at the factory, the sleeve **30,** and the sleeve **40** if it is also hollow, are expanded by the fluid contained therein so as to be oversize with respect to the transverse dimensions of the annular chamber defined between the cylindrical interior surface of the cavity **18** of the insulator body **20** and the exterior cylindrical surface of the insulation provided adjacent the end of the cable **10.** Accordingly, after the sleeves have been inserted in the cavity, the insertion of the end portion of the cable **10** as illustrated in FIG. **1** displaces the inner surface of the sleeve or sleeves outwardly and results in a full surface-to-surface contact at a suitably elevated pressure.

In order to insure proper contact between the stress relief sleeve **40** and to control the pressure conditions existing in the fluid filled hollow sleeve **30,** an adjustable closure **50** is carried at the inner end of the insulator body **20** and is adapted to bear against the outer end of the stress relief sleeve **40.** Screws indicated at **52** are provided for attaching the closure **50** to the insulator body **20** and may be adjusted to apply the desired pressure to the sleeves **30** and **40.**

Referring now to FIG. **2** there is illustrated a second embodiment of the present invention. In this case the end portion of the cable is indicated generally at **56** and is pencilled as indicated at **58** so that the end portion **60** has an outer cylindrical surface formed of insulating material from which the conducting shield indicated at **62** has been removed.

The structure illustrated in FIG. **2** is a cable termination and the insulation **60** is stripped from the end of the cable to bare a portion of the conductor as indicated at **64.** The end portion of the cable **56** is received in an insulator body **66** including an end closure portion **68** having an aperture through which the bared end **64** of the conductor of the cable extends. Exterior of the insulator body **66** there is provided a connector cap **70** having a tubular portion **72** which is crimped or otherwise suitably secured to the end of the conductor. In assembly the enlarged head of the connector **70** engages an O-ring **73** provided in an annular groove **74** at te end of the insulator body.

Surrounding the end portion of the cable is a hollow insulating sleeve indicated generally at **76** having an inner cylindrical wall **78** in full surface-to-surface contact under elevated pressure conditions with the cylindrical surface of the insulation **60** at the end of the cable. The sleeve **76** includes an outer cylindrical wall **80** engaging the inner cylindrical surface **82** of the insulator body **66.**

The hollow interior **84** of the sleeve **76** is connected to a valve **86** extending through the end wall **88** of the sleeve, the valve including an O-ring seal **90** and a removable cap **92.** A second valve **94** is provided which may be identical with the valve **88** and also communicates with the interior annular chamber **84** within the hollow sleeve **76.** The two valves are provided so that when the insulating fluid is caused to flow into the annular chamber **84** through one of the valves, the interior chamber may be purged through the other valve.

The end of the hollow insulating sleeve **76** remote from the bared end of the conductor **64** is provided with an outer tapered surface **98** which is generally conical in shape but which as illustrated is slightly concave in axial section.

Secured to the inner open end of the insulator body **66** is a tubular shell or casing **100** which is longitudinally tapered to have a smaller diameter adjacent its upper end as illustrated in the Figure. At its upper end the shell **100** is provided with a flange **102** which is assembled to flange **104** provided at the lower end of the insulator body **66** by suitable fastening devices such as the screws **106** and the nuts **108.** At its outer end the shell **100** is provided with a second flange **110** by means of which it supports an end closure plate **112** through suitable assembly devices such as the screws **114** and the nuts **116.**

Located within the shell **100** is the stress relief device or sleeve **120** which as shown is hollow and provided with an internal annular chamber or pocket **122.** The end of the stress relief sleeve **120** adjacent the hollow insulating sleeve **76** is provided with an internal tapered

surface **124** which is conformed to the tapered surface **98** of the hollow sleeve **76.** These tapered surfaces are generally conical but as illustrated, are provided with a slight longitudinal outwardly concave/convex curvature, respectively.

To interior of the stress relief sleeve **120** is connected to valving means indicated at **94** through which insulating fluid may be introduced into the annular pocket **122.** In the event that the pocket **122** is sealed against communication with the pocket **84** provided in the sleeve **80,** two such valves will be employed, one for introducing fluid under pressure and the other for purging air from the interior. However, it is also contemplated that the adjacent wall portions of two sleeves at the tapered ends thereof may be provided with passages **128** so that fluid may flow between the hollow interiors of the sleeves. In this case of course it is only necessary to have two valves, one of which communicates with the interior of the sleeve **120** and the other of which communicates with the interior of the sleeve **76.**

With the parts of the connector assembled with the end portion of the cable, as illustrated in FIG. **2,** the insulating fluid, either liquid or gas, may be introduced into the hollow interior or interiors of the sleeves, thus tending to expand the sleeves and to force the inner walls of the sleeves into firm engagement with the outer surfaces of the end portion of the cable. It will be observed that the stress relief sleeve **120** is adapted to engage the portion of the cable provided with the ground shield **62,** whereas the hollow insulating sleeve **76** engages only the end portion of the insulation **60** from which the shielding material has been removed by pencilling as indicated at **58.**

The introduction of fluid under pressure into the hollow interior tube of the sleeve **76** and the sleeve **120** insures full perfect surface-to-surface contact between the interior surfaces of the sleeves **76** and **120** throughout the entire end portion of the cable **56.**

Referring now to FIG. **3,** a stress relief device **130** is provided in place of the stress relief sleeve **120.** In this embodiment of the invention the end of the sleeve **130** adjacent the end of the cable is provided with an inner tapered surface **132** conforming to the outer tapered surface **98** of the hollow sleeve **76.** In this case the stress relief sleeve **130** is formed of a resilient elastomeric material which may be the same as the resilient elastomeric material from which the hollow sleeve **76** is formed except it contains conducting particles such as carbon black or graphite in order to increase its conductivity. The tapered surface **132** of the sleeve **130** may be chemically bonded to the tapered surface **98** of the hollow sleeve **76** along the generally tapered interface. In this embodiment of the invention it will be apparent that when the end closure plate **112** engages the outer end of the sleeve **130,** the sleeve **130** may be sufficiently elongated so that the closure plate **112** engages the end and forces the sleeve **130** inwardly of the tapered shell **100,** thus causing the sleeve **130** to exert an inward pressure on the cable insulation as the closure plate **112** is tightened by means of the screws **114** and nuts **116.**

Referring now to FIG. **4** there is shown a different embodiment of the invention in which the structure shown in FIG. **4** is substituted for the structure located within the tapered shell **100.** In this construction the cable **56** is pencilled as indicated at **58** to expose the insulation **60,** leaving the shield **62** in place. In this embodiment of the invention the metallic shell **136** is tapered as shown with the small end of the shell located at the top of the Figure. The shell is provided with ears **138** having tapped openings **140** for the reception of screws adapted to secure the shell **136** to flanges such as those illustrated at **104** provided at the lower end of the insulator body **66.** As in the embodiment of the invention illustrated in FIG. **2,** the construction includes a stress relief structure comprising a resilient semiconducting sleeve **142** which may be formed of an elastomeric resilient insulating material provided with particles of graphite or carbon black to produce a resistivity not exceeding 10^8 ohms × cm.

The outer surface **144** of the sleeve is tapered and conforms generally to the taper of the shell **136.** The inner surface of the sleeve **142** includes a generally conically tapered surface **146** seen at the upper end of the Figure, while the inner surface **148** at the lower end of the sleeve **144** is generally cylindrical. In addition, the length of the sleeve **142** is such that in initial assembly the lower end **150** of the sleeve extends outwardly from the flange **152** provided at the lower end of the shell **136.** An end closure plate **154** is provided having a central opening **156** through which the cable **56** extends and the plate is adapted to be attached to the flange **152** by suitable fastening means such for example as the screws **158** and nuts **160.** With this arrangement, when the plate **154** is drawn toward the flanges **152** it applies compressive force to the sleeve **144** and, due in part to the tapered shape of the sleeve, produces radially inward pressure of the sleeve against the portions of the high voltage cable **56** therewithin.

In this embodiment of the invention there is provided a hollow insulating sleeve **162** which may be formed of the same material as the semi-conducting sleeve **144** except that this hollow sleeve does not include conducting particles and is fully insulating. The hollow sleeve **162** has a tapered outer surface **164** which conforms to the taper of the surface **146** of the sleeve **144** and is adapted to be engaged in full surface-to-surface pressure contact therewith in the assembled connector. The hollow interior of the sleeve **162** thus provides an annular chamber **166** adapted to receive insulating fluid, either liquid or gas, under elevated pressure, so as to insure full surface-to-surface pressure contact between the inner surface of the hollow sleeve **162** and the outer surface of the cable insulation **60.** The interior chamber **166** of the hollow sleeve **162** is provided with suitable valve means such as indicated at **168** and **170** so that the insulating fluid may be introduced into the chamber **166** through one of the valves and air initially contained therein purged through the other valve.

It will be apparent from a comparison of FIGS. **2** and **4** that when the structure of FIG. **4** is substituted for the shell **100** shown in FIG. **2,** the surface **146** and **164** provide an interface which is of generally conical shape establishing a stress relief construction. In this case, the portion of the cable termination received within the insulator body **66** may be provided with a hollow insulating sleeve substantially similar to that shown in FIG. **2** except that its lower end will conform to the upper end surfaces of the sleeves **142** and **162.**

The constructions illustrated in FIGs. **2** and **4** may be assembled in the field and after the components are assembled as shown, the annular chambers **84, 122** and **166** will be charged with insulating fluid under substan-

tial pressure adapted to maintain full surface-to-surface pressure contact between the inner surface of the sleeves and the adjacent outer surfaces of the cable through extended use during which the cable may undergo repeated expansion and contraction.

CABLE INTERCONNECTION

Application of the present invention to structure providing for electrical connection between sections of high voltage cable is illustrated in FIGS. **5–11,** which will now be described.

The Figures illustrate two types of power cable joints or connections, both using pressurized fluid sleeves. The first of these is suitable for moderately high voltage applications and is illustrated in FIGS. **5–9,** whereas the second is suitable for very high voltage applications and is illustrated in FIG. **10.**

Referring first to FIGS. **5–9** the construction comprises an enlcosure which may be formed of metal and comprises two relatively deep cup-shaped elements **200** provided with flanges **202** which may be interconnected by suitable means such for example as screws **204** and nuts **206.** The end or bottom walls of the cups are illustrated at **208** and are apertured as illustrated to receive the ends of high voltage cables **210.** The cables include conducting shields **212,** pencilled portions **214,** and end portions from which the conducting shields have been removed to expose the cable insulation **216.** The conductors are bared as indicated at **218.** The bared cable conductors are interconnected by any conventional means such for example as compressed conducting sleeves, soldered sleees, welding or the like. A split conductor clamp **220** is provided, details of which are best seen in FIG. **6.** Referring to this Figure it will be observed that the clamp comprises two portions **222** and **224** each recessed as indicated at **226** to receive the ends of the bared conductors. The portions **222** and **224** of the clamp are interconnected by suitable means such for example as screws **228** extending through openings **230** in the portion **222** and engaging in threaded openings **232** in the clamp portion **224.** Coil compression springs **234** are porvided between the portions **222** and **224** and are compressed as the portions are brought into clamping engagement by the screws **228.**

Adjacent opposite ends of the cups **200** there are provided sleeves **236** which as shown, are adapted to bottom against the end walls **208** of the cups. The sleeves **236** are formed of resilient elastomeric insulating material such for example as butyl rubber, silicone rubber, or polyurethane, but contain a small quantity of conducting particles such for example as particles of carbon black or graphite so as to render the sleeves **236** semi-conducting. The radially inner surfaces **240** at the inner ends of sleeves **236** are tapered as illustrated into generally conical configuration modified to provide the longitudinal convex configuration illustrated.

Intermediate the semi-conducting sleeves **236** is a hollow insulating sleeve indicated generally at **242.** This sleeve is formed of insulating resilient elastomeric material such for example as butyl rubber, silicone rubber, or polyurethane, but differs from the material of the sleeves **236** in that no conducting particles are included so that the material of the sleeve **242** is fully insulating.

The ends of the sleeve **242** are provided with tapered outer walls **244** shaped to conform to the tapered surfaces **240** of the semi-conductor sleeve **236,** and in assembly the surfaces **240** and **244** are in full surface-to-surface contact and it is contemplated that these surfaces may be chemically bonded together. In any case, the tapered interface provided by the surfaces **240** and **244** between the semi-conducting sleeve **236** and the hollow insulating sleeve **242** constitutes a stress relief device.

It will be observed that the semi-conducting sleeves **236** extend into contact with the shields on the cables **210.** On the other hand, the hollow insulating sleeve **242** terminates adjacent the pencilled portion **214** and extends longitudinally of both end portions of the cable where the insulation **216** is exposed and across the gap between the ends of the cable insulation where the conductors **218** of the cable are electrically interconnected.

The outer surface of the sleeve **242** is provided with a layer **245** of semi-conducting material which may be the same material from which the sleeves **236** are composed.

The inner wall of the insulating sleeve **242** is provided at its mid-section with a thin layer **246** of conducting material which when the joint is completed is caused to abut against the clamp **220.** The conducting material may be in the form a a resilient elastomer containing sufficient conducting particles to provide the requisite conductivity. This layer is just long enough to extend beyond the edges of the cable insulation **216** in such a way as to eliminate electrical stresses in the void space **248** between the ends of the cable insulation.

Valve means indicated generally at **250** and illustrated in detail in FIG. **9** are provided to communicate with the interior annular chamber or pocket **252** provided in the hollow sleeve **242.** These valves include valve elements **254** secured by suitable means such for example as threads within the interior of the threaded nipples **256.** The nipples **256** have threaded exteriors and adapted to receive sealing caps **258** which are associated with sealing means such for example as O-rings **260** to provide an adequate seal. The valves are provided in pairs so that both may be open while insulating fluid is introduced into the chamber **252** through one of the valved openings and air purged from the interior through the other.

Referring now to FIG. **7** there is illustrated a further embodiment of the invention in which the solid resilient elastomeric sleeves **236** are replaced by hollow sleeves **262,** each provided with an interior annular cavity **264** provided with valve means indicated generally at **260.** The sleeves **262** are formed of semi-conducting material as previously described and include tubular portions **268** which interconnect the sleeves **262** at opposite ends of the assembly and which engage or are bonded to the outer walls **270** of the intermediate hollow sleeve **242.** The interior annular chamber **252** provided in the hollow sleeve **242** communicates with the chambers **264** in the sleeve portions **262** through suitable passages **272.**

The advantages of this construction are: (a) there is no electrical stress in this conducting portion; therefore, the existence of the sleeve of a check valve presents no voltagerelated problem; (b) owing to the fluid in the pocket or chamber **264,** the conducting portion of the sleeve can be more effectively compressed against the cable insulation **216** and the semi-conducting shield **212** and also the pencilled portion

214; and (c) by providing a valve in communication with the chambers 264 at opposite ends of the assembly, the purging of air from the pockets or chambers 252 and 264 is facilitated.

Referring now to FIG. 8 there is illustrated a variation in the construction of the cable joint. In this case the middle portion of the hollow sleeve, here indicated at 280, is made outwardly convex as illustrated and the semi-conducting layer 282 provided at its inner surface accordingly has the tapered ends 284 to improve the electric voltage gradient in that portion of the joint and to provide better compression against the cable surfaces. In any case, the casing formed by mating cup portions 286 have the walls adjacent the ends thereof curved in conformity to the curvature of the hollow insulating sleeve as indicated at 288.

It will be understood that while valves and check valves are shown for the purpose of charging the interior of the hollow insulating sleeves as well as the hollow sleeves formed of semi-conducting material, with pressurized insulating fluid in the field, it is also contemplated that these annular chambers may be charged in the factory and the sleeves permanently sealed. In this case of course, the check valves will be omitted and the compression of the sleeves will be achieved by forces developed by drawing the cup-shaped shells 200 together in assembly after the electrical connection is established between the bared ends of the cables and the sleeve or sleeves have been brought into the relative position illustrated in FIG. 5.

Referring now to FIG. 10 there is illustrated a joint intended for use with very high voltage power cables. In this case the cables are illustrated at 300 and include outer shields 302, pencilled portions 304, and end portions at which the cable insulation 306 is exposed. The cable insulation is cut back to bare the ends of the cable conductors 308 which are electrically interconnected by conventional means 310. A capacitive device 312, details of which will subsequently be described, is positioned around the gap 314 between the ends of the cable insulation 306 in which the conductors 308 are interconnected.

A combination of insulating sleeve and stress relief assembly 313 is provided and is inserted within the tapered ends of the capacitive device 312 as illustrated. The entire assembly is housed in two rigid metallic sleeves or cup-shaped members 316 attached to each other through flanges 318 and suitable clamping means such as screws 320 and nuts 322.

The assembly 313 is provided with an annular pocket 324 formed between insulating walls 326 and 328 formed of an elastomeric resilient fully insulating material. The outer ends of the pocket 324 are bounded by curved surfaces 330, which are surfaces of revolution defining convexly curved walls having a stress relief function. The outer ends of the assembly 313 are provided by annular portions 332 formed of a resilient elastomeric essentially insulating material, which however is provided with conducting particles to render the end portions semi-conducting as previously described. It will be understood that the portions 332 may be formed of the same resilient elastomeric material as the walls 326 and 328 which define the longitudinally tapered annular chamber 324, except that the walls 326 and 328 do not include the conducting particles and hence are fully insulating.

If desired, the end portions 332 may be provided with internal annular pockets substantially as suggested in FIG. 7.

The pocket 324 provided in the assembly 313 is connected to two valve means indicated generally at 334 and 336 through which insulating fluid may be introduced and the air within the pocket 324 suitably purged.

The capacitive device 312 comprises a specially shaped tubular body having at opposite ends inwardly tapered recesses 340 for the reception of the inner tapered ends of the assembly 313 and interconnected by a cylindrical through opening 342 which receives the means interconnecting the ends of the cable conductors. The device is essentially comprised of two sets of cylindrical conducting rings 344 aligned on the same axis and embedded in an insulating mass 346 of a suitable material such for example as electrical grade epoxy. The diameters of the rings 344 are increased gradually from the center of the device toward its ends. The innermost cylindrical wall 348 is designed to be in good electrical conducting contact with the connecting clamp illustrated at 310 in FIG. 10. The outer surface of the device is conducting and may comprise a cylindrical metal shell 350. The rings 344 and the innermost cylindrical wall 348 may conveniently be formed of cylindrical metal rings or tubes.

This device will operate to distribute the voltage uniformly along the slanting surfaces of the conical end recesses 340.

With the construction illustrated in FIG. 10 it may be noted that the insulating structure within each end of the housing completely fills the space defined by the outer and end walls of the cup portions 316, the outer surfaces of the cables within the housing, and the inclined tapered surfaces 340 of the recesses at the ends of the voltage distributor 312. The inner and outer walls of the insulating sleeve which define the inner and outer limits of the chambers 324, are formed of insulating material. The chambers 324 are further defined by the curved annular end walls 330 forming a part of the sleeve portion 332. The sleeve portion 332 is also formed of resilient elastomeric material but it is rendered semi-conductive by the presence of conducting particles therein. Accordingly, the curved surface 330 constitutes a stress relief cone or device.

Where the annular sleeve 332 is itself provided with an elongated internal chamber such as illustrated at 264 in FIG. 7, the entire structure made up of the sleeves 332 and the chamber walls 326 and 328 is expansible to insure that the sleeves completely fill the aforesaid spaces, expelling all air therefrom, and maintaining full surface-to-surface pressure contact between the radial inner surface of the sleeve assembly and the outer surface of the cable throughout the period of service including repeated expansions and contractions of the cable in use.

The voltage distributor specifically illustrated in FIG. 10 is constituted by a multiplicity of capacitive devices arranged in series in which each adjacent ring 344 axially overlaps the adjacent rings and is separated therefrom by dielectric material. With this arrangement it will be observed that the inner tube 342 is at the voltage of the conductor and the outer tube 350 is at ground potential, assuming that the housing 314 and the cable shield 300 are at ground potential. Accordingly, the entire applied voltage is divided between the

series capacitances as is well understood so that the voltage drop along the inclined conical surface **340** has a uniform gradient.

From the foregoing it will be observed that the common feature present in all embodiments of the invention is the provision of one or more hollow sleeves formed of insulating or semi-conductive material and provided with elongated annular chambers for the reception of insulating fluid at elevated pressure effective to produce essentially radial inward and outward expansion of the sleeves into full surface-to-surface contact with outer restraining surfaces and the radially outer exposed surfaces of the portions of the cable or cables within the sleeves. An additional feature is the division of the sleeve structure into two separate components one of which is fully insulating and the other of which is formed of semi-conducting material, the two portions having tapered or generally conical interfaces forming stress relief cones. The two portions of the sleeves may be provided with separate and separately chargeable annular recesses or they may be interconnected by passages providing for flow of insulating fluid therebetween.

The constructions may be arranged such that the internal annular chambers are permanently charged with insulating fluid under pressure at the factory and the pressure conditions maintained and controlled by the application of external pressure to portions of the sleeve or sleeves by containing structure therefor.

Where reference is made to elevated pressure, it is intended to require a pressure sufficiently above ambient or atmospheric pressure to produce the required surface contact conditions described herein.

In all cases where the stress relief cone or device such as seen at **40** in FIG. **1** or **120** in FIG. **2** is shown as a separate member from sleeves **30** or **76**, etc., it will be understood that in all cases these may be united to form in effect a single element. What I claim as my invention is:

1. A stress relief connection designed for application to insulated high voltage electrical cable comprising a hollow tubular sleeve adapted to surround the insulation adjacent the bared end of an insulated high voltage electrical conductor and formed of resilient elastomeric electrically insulating material having at the end thereof remote from the bared conductor an inwardly tapered exterior surface, a generally tubular stress relief sleeve formed of a material which is at least semi-conductive having an outwardly tapered interior end surface in surface-to-surface contact with the tapered exterior surface of said hollow sleeve, a rigid support housing surrounding said hollow sleeve, the interior of said hollow sleeve being an elongated annular chamber adapted to be charged with a pressurized insulating fluid to expand the inner wall of said hollow sleeve radially inwardly to establish intimate contact between the inner surface of said hollow sleeve and the outer surface of the insulation surrounding the conductor adjacent its bared end.

2. A connection as defined in claim **1** in which said hollow sleeve is provided with inlet and outlet valves to provide for purging the hollow interior of the sleeve and to fill the hollow sleeve with fluid under pressure.

3. A connection as defined in claim **1** in which said tubular stress relief sleeve is formed of resilient elastomeric material and is also hollow to have an elongated annular chamber to receive insulating fluid under pressure.

4. A connection as defined in claim **3** in which passages are provided connecting the hollow interior of said hollow tubular sleeve and the hollow interior of said stress relief sleeve.

5. A connection as defined in claim **1** in which said hollow tubular sleeve is filled with insulating fluid and permanently sealed.

6. A connection as defined in claim **5** in which said connection comprises an enclosing wall movably associated with said housing, and means for moving said wall relative to said housing to apply pressure to said hollow tubular sleeve.

7. A connection as defined in claim **1** in which said fluid is an insulating liquid.

8. A connection as defined in claim **1** in which said fluid is an insulating gas.

9. A connection as defined in claim **1** in which said connection is a cable termination, and in which said housing comprises a hollow insulator body, comprising connector means exposed at the end of said body adapted to be electrically connected to the bared end of the conductor.

10. A connection as defined in claim **1** in which said connection is for connecting the ends of two insulated high voltage cables, comprising means within said hollow tubular sleeve adapted to electrically connect the bared ends of the conductors, and in which the opposite ends of said hollow tubular sleeve are both tapered as aforesaid, and stress relief sleeves as aforesaid are provided at both ends of said hollow insulated sleeve.

11. An electrical connection comprising in combination a high voltage cable having a conductor surrounded by insulation, the conductor having an end exposed and extending beyond the end portion of the insulation, a rigid housing surrounding the end portion of the insulation, a hollow tubular resilient elastomeric sleeve having an elongated annular chamber therein interposed between the end portion of the insulation and the housing, said sleeve having at the end thereof remote from the bared conductor a tapered exterior surface, a generally tubular stress relief sleeve formed of a semi-conductive material having at an end thereof a tapered interior surface in surfac-to-surface contact with the tapered exterior surface at said hollow tubular sleeve, an insulating fluid in the chamber in said sleeve under an elevated pressure sufficient to expand the chamber defined by the hollow interior of said sleeve to force the inner wall thereof into firm surface-to-surface contact with said insulation.

12. A connection as defined in claim **11** in which said hollow sleeve is provided with inlet and outlet valves to provide for purging the hollow interior of the sleeve and to fill the hollow sleeve with fluid under pressure.

13. A connection as defined in claim **11** in which said tubular stress relief sleeve is also hollow and has an annular chamber to receive insulating fluid under pressure.

14. A connection as defined in claim **13** in which passages are provided connecting the chamber in said hollow tubular sleeve and the chamber in said stress relief sleeve.

15. A connection as defined in claim **11** in which said hollow tubular sleeve is filled with insulating fluid and permanently sealed.

16. A connection as defined in claim 15 in which said connection comprises an enclosing wall movably associated with said housing, and means for moving said wall relative to said housing to apply pressure to said hollow tubular sleeve.

17. A connection as defined in claim 11 in which said connection is a cable termination, and in which said housing is in the form of a hollow insulator body, comprising connector means exposed at the end of said body adapted to be electrically connected to the bared end of the conductor.

18. A connection as defined in claim 11 in which said connection is for connecting the ends of two insulated high voltage cables, comprising means within said hollow tubular sleeve adapted to electrically connect the bared ends of the conductors, and in which the opposite ends of said hollow tubular sleeve are both tapered as aforesaid, and stress relief sleeves as aforesaid are provided at both ends of said hollow insulated sleeve.

19. An insulated connection between two high voltage cables having end portions in which bared conductor ends project beyond the ends of insulation surrounding the conductors to define a gap between the end of said insulation, connector means in the gap electrically interconnecting the bared conductor ends, a capacitive voltage distributor comprising an elongated tubular body formed of a dielectric material having elongated tapered recesses extending into opposite ends and having a central portion provided with a through opening in which are located the bared conductor ends and the connector means, an inner conducting tube in said opening in contact with said connector means, an outer elongated conducting tube covering the outer surface of the voltage distributor, a series of short circumferentially spaced, axially staggered conducting rings extending along and around each of the tapered recesses, said rings overlapping adjacent rings and spaced radially of each other, the rings being entirely embedded in said dielectric body and having the spaces between adjacent rings being filled with the dielectric material of said body.

20. A connection as defined in claim 19 which comprises in addition an outer housing formed of conducting material in contact with said outer tube.

21. A connection as defined in claim 20 in which said cables have conducting shields extending into the housing, and means electrically connecting said shields to said housing.

22. A connection as defined in claim 21 in which the means connecting the shields and housing comprise semi-conducting resilient sleeves in the ends of said housing in surface contact with said shields.

23. A connection as defined in claim 22 in which said semi-conducting sleeves have annular pockets formed therein, and insulating fluid in said pockets at elevated pressure to expand the sleeves in full surface-to-surface contact under pressure with the inner surface of the housing and with the outer surface of the cable within said housing.

24. A connection as defined in claim 20 which comprises in addition elongated hollow sleeves formed of resilient elastomeric insulating material and having an annular chamber therein extending substantially the full length thereof, the radially outer walls of the axially inner ends of said sleeves being tapered in conformity with the taper of the recesses in the ends of said voltage distributor and received therein in surface-to-surface contact, the interior of said chambers being charged with insulating fluid under pressure effective to press the inner walls of said sleeves surrounding said chambers into surface-to-surface pressure contact with the insulation surrounding the end portions of said cables within said housing.

25. A connection as defined in claim 24, the axially outer end walls of said chambers having stress relief annular surfaces tapered radially inwardly and axially outwardly from the cable ends, the material of said end walls being semi-conductive.

26. An insulated connection between two high voltage cables having end portions in which bared conductor ends project beyond the ends of insulation surrounding the conductors to define a gap between the end of said insulation, connector means in the gap electrically interconnecting the bared conductor ends, a capacitive voltage distributor comprising an elongated tubular body formed of a dielectric having elongated tapered recesses extending into opposite ends and having a central portion provided with a through opening in which are located the bared conductor ends and the connector means, a generally tubular conducting housing having apertured end walls through which the end portions of said cables extend, the space in each end of said housing defined by the tapered wall of the recess in said voltage distributor, the outer surface of the cable, the end wall of the housing, and the radially outer wall of the housing being filled by a hollow expansible sleeve portion formed of resilient elastomeric material having an elongated annular chamber therein extending subtantially for the full length of the portion of cable insulation exposed therein, said chamber being filled with insulating fluid at elevated pressure to insure full surface-to-surface pressure contact between the inner and outer surfaces of said sleeve portion and the cable insulation and the inner surface of said housing respectively.

27. A connection as defined in claim 26 comprising in addition a second sleeve portion extending axially outwardly from the outer end of each first mentioned sleeve portion, said second sleeve portions forming the axially outer ends of the annular chambers in said first mentioned sleeves and being formed of semi-conducting material and shaped to form axially tapered stress relief surfaces, the inner and outer walls of said first mentioned sleeve portions being non-conducting.

28. A connection as defined in claim 27 in which both of said second sleeve portions are also hollow and provided with annular chambers adapted to receive insulating fluid at elevated pressure to expand said second sleeve portions into full surface-to-surface contact with the outer surface of said cables and the inner surfaces of said housing.

29. A high voltage electric connection comprising an elongated generally cylindrical housing having a side wall and an end wall provided with an opening through which extends the end portion of an insulated high voltage cable, said cable having the end of its conductor bared at a point remote from said end wall and having its insulation intact for a substantial length of said cable within said housing, said housing and the insulation of said cable defining therebetween an elongated annular space, an elongated sleeve formed essentially of resilient, elastomeric insulating material occupying said space, said sleeve having an elongated annular chamber therein between radially inner and outer walls, and

insulating fluid filling said chamber under elevated pressure sufficient to maintain the inner and outer walls of said sleeve in firm surface-to-surface pressure contact respectively with the radially outer surface of the insulation of the end portion of said conductor received in said housing and the inner surface of the side wall of said housing.

30. An elongated insulating and stress relief sleeve construction for use in a high voltage cable connection, said construction comprising a first elongated sleeve section formed of resilient elastomeric insulating material provided with an elongated annular chamber therein for the reception of insulating fluid at elevated pressure, an end section operatively connected to one end of said intermediate section formed of at least semi-conducting material, said first and end sections having a tapered generally conical interface providing electrical stress relief.

31. A construction as defined in claim **30** which comprises in addition a second end section conforming to the definition of the first end section in claim **30** and operatively connected to the other end of said first section.

32. A construction as defined in claim **31** in which said end section is formed of resilient elastomeric semi-conducting material.

33. A construction as defined in claim **32** in which said end section is provided with an elongated annular chamber therein for the reception of insulating fluid at elevated pressure.

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