An annularly corrugated outer conductor is adhesively bonded to the foam dielectric of a coaxial cable at the corrugation roots and adhesively bonded to its tubular plastic sheath at the corrugation crests. Longitudinal passage or migration of fluid is blocked both along the inside and along the outside of the outer conductor without impairment of electrical or mechanical characteristics or complication of attachment of connectors.
COAXIAL CABLE RESISTANT TO HIGH-PRESSURE GAS FLOW

This invention relates to coaxial cable, and more particularly to coaxial cable which is highly resistant to migration of high-pressure gases along its length.

In some uses of coaxial cable, a highly important performance requirement is blockage of entering gases from progression along the cable length. For example, a cable employed in telemetering data from a region containing biologically hazardous gases is desirably internally secure against leakage of gas through the cable, reliance on a seal effected at the end of the cable being inadequate assurance. So-called "air dielectric" cables, wherein the inner conductor is maintained in axial position by some form of small cross-section insulator, such as a spiral insulated spacer, are poorly suited for such use. Accordingly the best coaxial cables for such applications are of the type having a closed-cell dielectric foam filling the annulus between the inner conductor and the outer conductor, such a foam being itself substantially impervious to longitudinal fluid-flow.

At low gas pressures, the prevention of gas leakage along a foam-dielectric cable presents little problem. At pressures only moderately above atmospheric pressure, no substantial gas leakage occurs through most known forms of construction of foam-dielectric cable. Even in the case of a helically corrugated outer conductor, having a continuous helical void along the corrugation crest, gas-flow is blocked by a simple barrier such as is provided against moisture in U. S. Pat. No. 3,394,400. With a smooth-wall outer conductor, mere reasonably tight fit of the outer conductor on the foam dielectric generally suffices to prevent gas-flow.

In addition to the possibility of leakage along the interior of the outer conductor, leakage of gas between the outer conductor and the protective jacket in which it is usually enclosed can also occur. Here again, no substantial problem is encountered with gases at low pressures. The protective jacket is normally extruded onto the outer conductor and is sufficiently tight to prevent leakage even though it is not bonded to the outer surface of the outer conductor, such bonding being normally avoided to permit ready stripping of the jacket at the cable end for joining the cable to a suitable coaxial connector.

At high gas pressures, the seals against gas leakage which inhere in general-purpose foam cables are found to be wholly inadequate, and various efforts have been made to devise a construction practical for such purposes. The most satisfactory of these known before the present invention is described in U.S. Pat. No. 3,567,846. There is there shown a construction wherein an adhesive bond is formed between the foam dielectric and a smooth-wall outer conductor to block passage of high-pressure gas. A similar adhesive bond may be employed between the jacket and the outer conductor and, if found necessary, between the foam dielectric and the center conductor.

The present invention provides a foam-dielectric coaxial cable construction for high-pressure gas sealing with substantial improvement over prior constructions in a number of respects. In the present construction, the outer conductor is annularly, rather than helically, corrugated and is adhesively bonded to the foam dielectric at the roots of the corrugations but not at the crests. The protective jacket is adhesively bonded to the crests of the corrugations but not to the roots.

The employment of annular corrugation of course eliminates the continuous helical passage which exists along the crest of a helical corrugation, while at the same time providing the mechanical strength and flexibility which are known advantages of corrugated construction. It is found that the repetitive interruption of the adhesive bonds not only produces no impairment of the seal as compared with a smooth-wall construction but solves a number of problems which occur with such a construction.

As recognized in the patent above mentioned, a firm bond cannot be practically effected between the foam and the smooth-wall metallic outer conductor without measurably increasing the dielectric constant in the annulus between the conductors, as compared with an unbonded construction. Where a supplemental adhesive layer is employed with a smooth-wall construction, the thickness of this layer after completion of the bond is essentially the same as the thickness upon application of the adhesive. (An adhesive, as that term is herein used, is a substance producing adhesion at relatively low temperature, so that the heating employed to set the adhesive produces no substantial melting of the foam, as well as producing a better bond to the metal than can be achieved with the polymers most advantageously used as the foam dielectric, which have relatively poor direct adhesive bond to the metal conductor.) Both because the adhesive is solid, and because the dielectric properties, particularly loss factor, are slightly inferior, minimization of the thickness of the adhesive is fairly critical to the electrical performance of the smooth-wall construction. In theory, the adhesive can be applied in a layer of the minimum thickness required for effecting the bond, and this can be closely approached in extruding a foam onto an adhesive-coated center conductor. As a practical matter, however, it is very difficult to produce an adhesive bond of the outer surface of the foam to a smooth-wall tube without appreciable impairment of the electrical performance as compared with a corresponding unbonded smooth-wall construction, the uniform application of such a minimum-thickness adhesive film in this region being relatively prohibitive in a commercial production process.

In addition to the degradation of electrical performance produced by the internal adhesive, such sealing of a smooth-wall cable involves substantial sacrifice of ease of preparing the end of the cable for joining to a connector. The employment of an adhesive bond between the jacket and the outer conductor makes stripping of the end of the jacket extremely difficult. With the present construction, wherein the jacket is not bonded to the outer conductor at the corrugation roots, the adhesive bond regions are in essence in the form of spaced rings. It is found that with the "breaking up" of the adhesive bond in this manner there is produced relatively little impairment of ease of stripping as compared with the unbonded constructions in common use, the intermittence of the bonding simplifying stripping in a manner more or less analogous to the effect of perforation of a sheet upon simplicity of tearing. Further, where the end of the cable is cut off at a corrugation crest, the unfilled region at this point provides an annular void wherein the wholly clean inner surface of the outer conductor is exposed for ready conductive con-
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connection to the corresponding portion of the terminating connector.

The above and further aspects and advantages of the invention will be better understood by reference to the embodiment illustrated in the drawing, in which:

FIG. 1 is a view in elevation, and successively broken away sections, of a coaxial cable constructed in accordance with the invention;

FIG. 2 is a transverse sectional view taken along the line 2—2 of FIG. 1;

FIG. 3 is a transverse sectional view taken along the line 3—3 of FIG. 1;

FIG. 4 is an enlarged detailed sectional view corresponding to a portion of FIG. 1; and

FIG. 5 is a more or less schematic view showing successive stages in the process of manufacture of the cable of FIG. 1.

The illustrated coaxial cable has an inner conductor 10, an outer conductor 12, a foam dielectric 14, and a plastic jacket 16. The dielectric 14 is surrounded by an adhesive layer 18, which forms a bond between the foam 14 and the outer conductor 12 at the roots 20 of the annular corrugations. The crests 22 of the corrugations have an internal void free of the dielectric and adhesive. (As will be recognized by those skilled in the art, dimensions of the corrugations, jacket thickness, and the like are somewhat exaggerated in the drawing for clarity of illustration.)

The jacket 16 is adhesively bonded to the outer conductor 12 at the crests 22, but is not bonded at the roots 20 of the corrugations. If so desired, the bonding of the jacket to the corrugation crests may be made by a separate adhesive employed with an ordinary non-adhering jacketing material, but an even more reliable bond is assured, along with simplification of manufacture, by employing an adhesive plastic for the jacket itself.

As best seen in FIGS. 1 and 2, cutting off of the cable at a corrugation crest exposes the clean and somewhat flared internal surface of the outer conductor. Upon longitudinal slitting of the end of the jacket, it is readily peeled off to permit simple attachment of a coaxial connector.

The process of manufacture is schematically illustrated in FIG. 5, involving relatively minor modifications of processes heretofore used for production of corrugated foam coaxial cable. The first stage of manufacture is fabrication of the core consisting of the inner conductor 10 and the surrounding uniform-diameter dielectric foam 14a. Although direct extrusion of the foam onto a heated center conductor by processes now conventional forms a reasonably secure bond, gas-leakage performance is desirably enhanced by a minimum-thickness adhesive coating layer (not shown) applied just before extrusion of the foam.

The foam dielectric is then covered with a layer 18a of an adhesive plastic. As later amplified, precision and uniformity of application of this layer is substantially less critical to ultimate cable performance than in prior constructions using such an adhesive layer. The layer 18a, shown schematically as a uniform coating in the drawing, may most easily be applied by continuous winding of a tape of dry adhesive polymer. (As earlier indicated, the description of a plastic material as an adhesive does not necessarily imply the liquidity or tackiness at the time of application often associated with such a description in other arts, the adhesion properties of such a tape being displayed upon melting and subsequent solidification to form the adhesive bond.) After application of the adhesive layer 18a, a conducting tube 12a is formed and seam-welded around the cable core and thereupon annularly corrugated to compress the dielectric at the corrugation roots. Heating of the corrugated outer conductor 12 then heats and melts the adhesive layer at the corrugation roots, forming a firm bond upon subsequent cooling. It will be observed that the exerting of comparable pressure in forming of the bond is not practical with smooth-wall construction, and, in addition, that such pressure in a smooth-wall construction would in any event result in an excessively high effective dielectric constant for any given extruded foam density.

The jacket 16 is extruded over the corrugation crests. Particularly if this is done immediately after the heating of the outer conductor to produce the internal bonding to the foam, a firm bond of the jacket to the corrugation crests results.

As best seen in FIG. 4, when the interface at the corrugation roots is heated to effect the bond, any excess of adhesive thickness over the minimum amount required for effecting of the bond is squeezed outward from the smallest-diameter portion of the roots by slight expansion of the compressed foam. Both these squeezed-out portions and the longitudinal portions of the adhesive layer which correspond to the crests and are not in contact with the metal are thus outward of the corrugation roots. Both as regards attenuation loss and as regards effective dielectric constant, the consequences of the presence of the adhesive on electrical performance of the cable are thus minimized.

A typical test for gas leakage employs a gas pressure of approximately 100 p.s.i. applied to the end of a cable of a length such as 50 feet, for an extended period such as 24 hours, with a suitable specification of maximum leakage rate, such as 1 cc. per hour. It is found that a freshly manufactured annularly corrugated cable does not require an internal adhesive to meet such a test if the compression of the foam is substantial at the roots of the corrugations. However, it is found that after temperature cycling of a cable between temperature extremes such as −20°F. and 165°F., leakage develops in the absence of the adhesive. This finding is presently attributed to the development of permanent deformation or set of the foam dielectric, which thus no longer exerts compressive sealing force on the corrugation roots. Where the adhesive layer is used, such temperature cycling produces no comparable effect, the gas-seal being unimpaired.

The construction parameters other than the annularity of the corrugations and the addition of the internal adhesive and the substitution of an adhesive as the material of the jacket are generally the same as those heretofore employed in helically corrugated cable. The invention may be applied to cables employing any of the metals used for conductors, normally copper or aluminum, with any of the known closed-cell foams, normally foamed polyolefins. In one exemplary construction, a nominal 7/8 inch cable has been made with an inner conductor of 0.313 inch diameter copper-clad aluminum rod. The dielectric is foam polyethylene, blown by use of a chemical blowing agent to a specific gravity of approximately 0.46. The outer conductor, of 0.016 inch thick aluminum, is annularly corrugated to a major outer diameter of 0.970 inch and a minor outer
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1. In a coaxial cable comprising an inner conductor, a foam dielectric surrounding the inner conductor and adhesively bonded thereto, a corrugated outer conductor surrounding the dielectric and compressing the dielectric at the corrugation roots, and a protective jacket surrounding the outer conductor, the improved construction for sealing the cable against longitudinal high-pressure fluid-flow characterized by the corrugations of the outer conductor being annular, the foam being adhesively bonded to the outer conductor at the roots of the corrugations but not at the crests, and the jacket being adhesively bonded to the crests of the corrugations but not to the roots.

2. The coaxial cable of claim 1 having an adhesive surrounding all longitudinal portions of the foam but free of contact with the outer conductor in the corrugation crests.

3. The coaxial cable of claim 1 having the jacket formed of an adhesive plastic free of contact with the outer conductor in the corrugation roots.

4. In a coaxial cable comprising an inner conductor, a foam dielectric surrounding the inner conductor and adhesively bonded thereto and a corrugated outer conductor surrounding the dielectric and compressing the dielectric at the corrugation roots, the improved construction for sealing the cable against longitudinal high-pressure fluid-flow characterized by the corrugations of the outer conductor being annular and having an adhesive surrounding all longitudinal portions of the foam dielectric within the outer conductor and bonding the roots of the corrugations to the foam, the corrugation crests being free of dielectric and adhesive.

5. In a coaxial cable having a corrugated outer conductor and a protective jacket surrounding the outer conductor, the improved construction for sealing the cable against longitudinal high-pressure fluid-flow characterized by the corrugations of the outer conductor being annular and the jacket being adhesively bonded to the crests of the corrugations but not bonded to the roots of the corrugations.

6. The cable of claim 5 having the jacket formed of an adhesive polymer.

What is claimed is:

1. In a coaxial cable comprising an inner conductor, a foam dielectric surrounding the inner conductor and adhesively bonded thereto, a corrugated outer conductor surrounding the dielectric and compressing the dielectric at the corrugation roots, and a protective jacket surrounding the outer conductor, the improved construction for sealing the cable against longitudinal high-pressure fluid-flow characterized by the corrugations of the outer conductor being annular, the foam being adhesively bonded to the outer conductor at the roots of the corrugations but not at the crests, and the jacket being adhesively bonded to the crests of the corrugations but not to the roots.

Various plastic adhesives may be employed, as in the case of the smooth-wall construction. One found highly suitable is the ionomer (ionized copolymer) of methacrylic acid and ethylene commercially available as Surlyn A 1652 of duPont in the form of pellets and tapes. In the manufacture of the cable just described, the adhesive is applied to the center conductor as a very thin film of liquid formed by the melting of pellets, just prior to extrusion of the foam onto the center conductor to form the cable core. A tape of 2 mil thickness is wound on the finished core prior to the forming from strip and seam-welding of the outer conductor. After the corrugation, the same adhesive, with black coloring material and antioxidant added, is extruded at about 500° F. as a generally tubular jacket, air trapped in the annular corrugations preventing complete following of the corrugation-root configuration. Just prior to the jacket-extrusion location, the outer conductor is heated to approximately 600° F. to melt the inner adhesive, the temperature remaining sufficiently high at the point of extrusion of the jacket to aid firm bonding thereof. The cable has no measurable degradation of performance as compared with a cable having no adhesive.

Although the use of the same adhesive at all sealing points is advantageous, it is not wholly necessary for utilization of the invention. Likewise, although the jacket is conveniently made from the adhesive itself, a non-adhering jacket may be employed with a supplemental adhesive deposited on the corrugation crests. Constructions further differing from the embodiment illustrated and described will readily be devised by persons skilled in the art which nevertheless utilize essential teachings of the invention. Accordingly, the scope of the patent protection to be afforded should be determined only in accordance with the definitions of the invention in the appended claims and equivalents thereto.

What is claimed is:

1. In a coaxial cable comprising an inner conductor, a foam dielectric surrounding the inner conductor and adhesively bonded thereto, a corrugated outer conductor surrounding the dielectric and compressing the dielectric at the corrugation roots, and a protective jacket surrounding the outer conductor, the improved construction for sealing the cable against longitudinal high-pressure fluid-flow characterized by the corrugations of the outer conductor being annular, the foam being adhesively bonded to the outer conductor at the roots of the corrugations but not at the crests, and the jacket being adhesively bonded to the crests of the corrugations but not to the roots.