July 4, 1961 N. R. LAY 2,991,328

MULTICONDUCTOR CABLE

Filed April 6, 1959

3 Sheets-Sheet 1

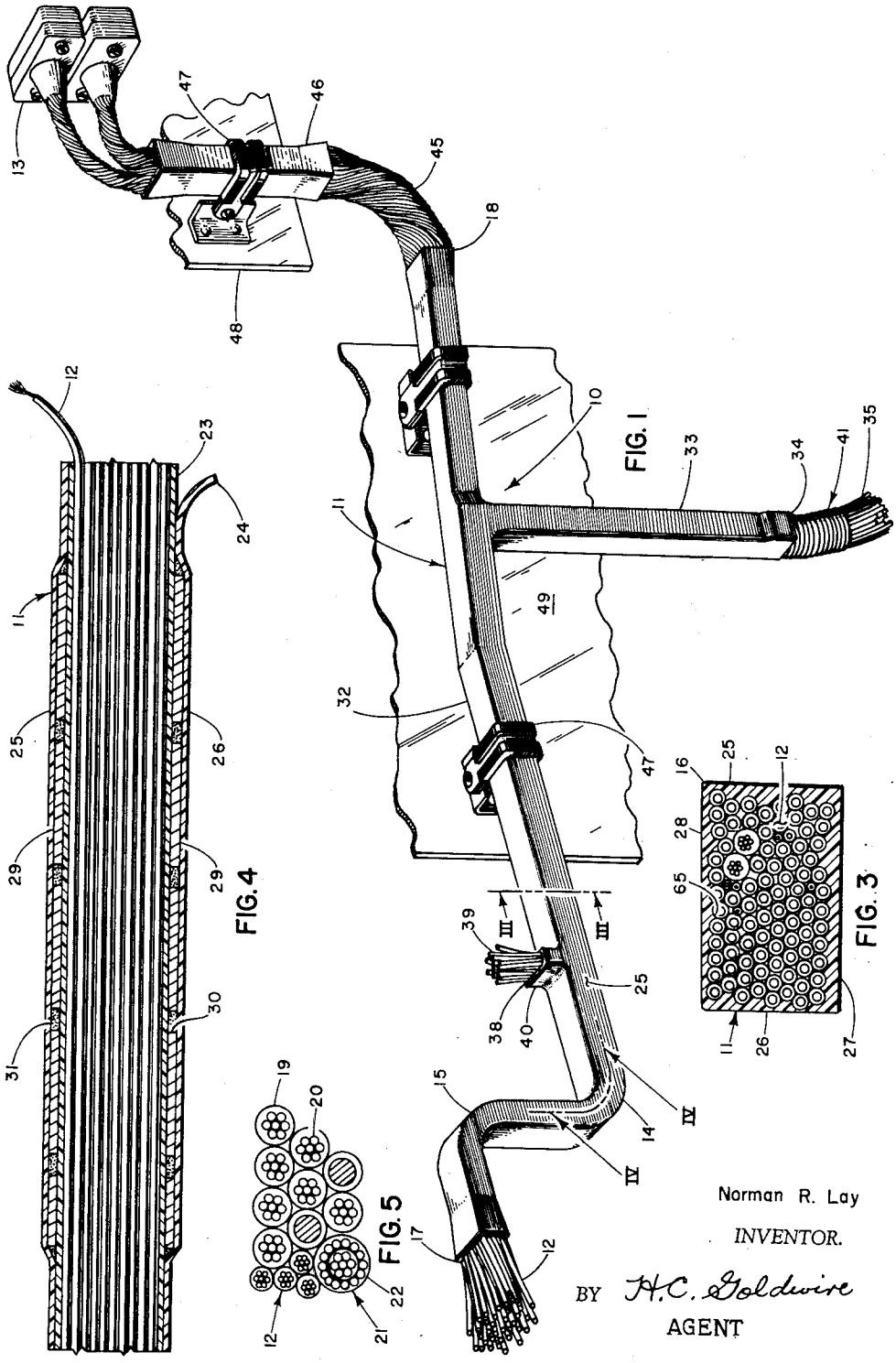


FIG. 1

FIG. 4

FIG. 5

FIG. 3

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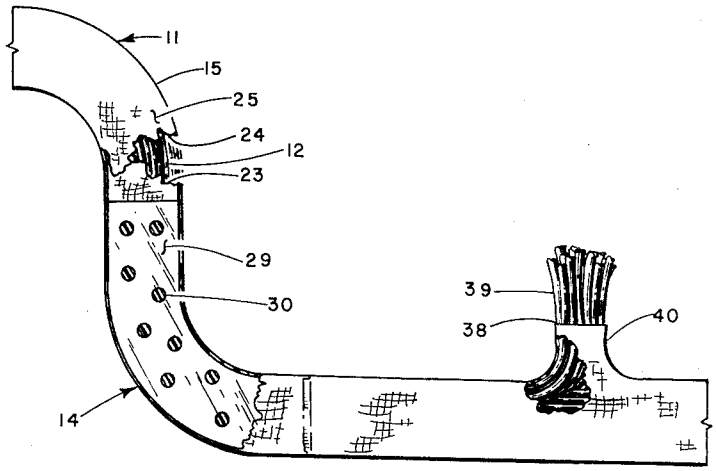


FIG. 2

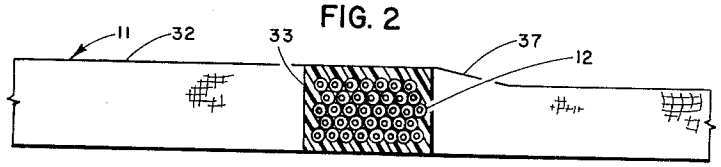


FIG. 7

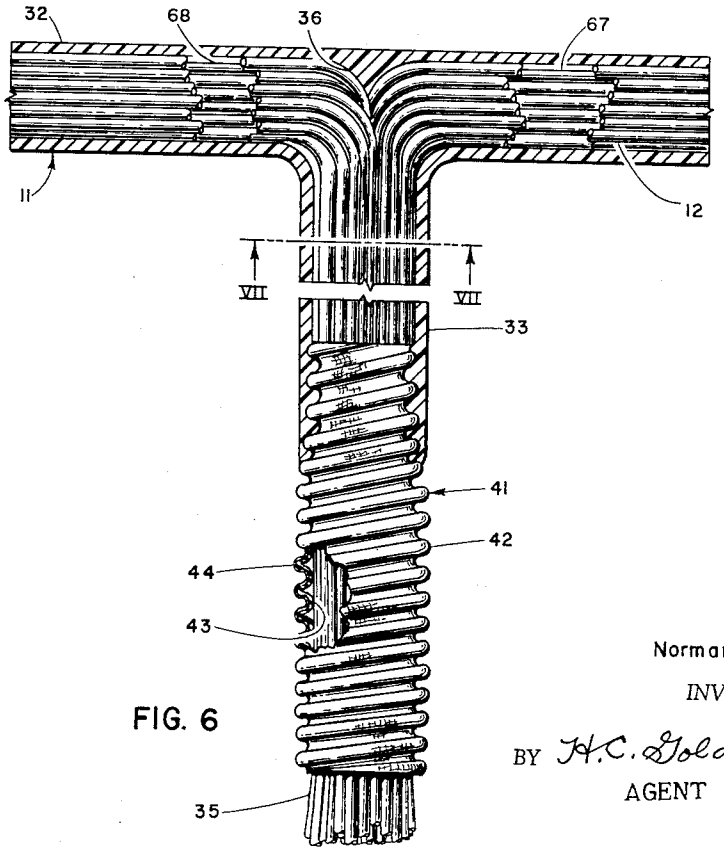


FIG. 6

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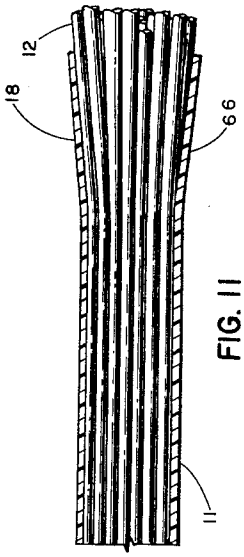


FIG. 11

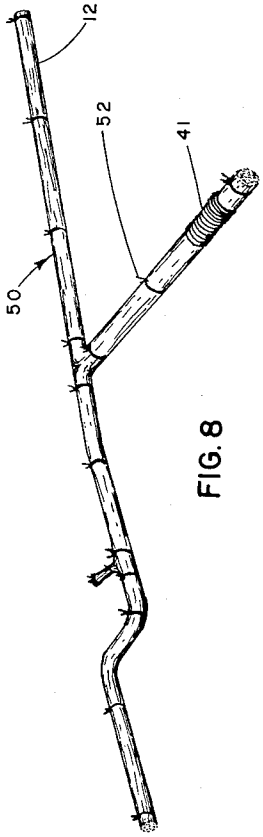


FIG. 8

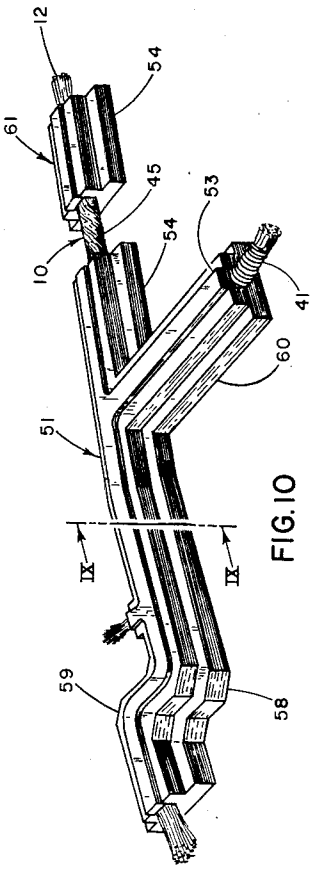


FIG. 10

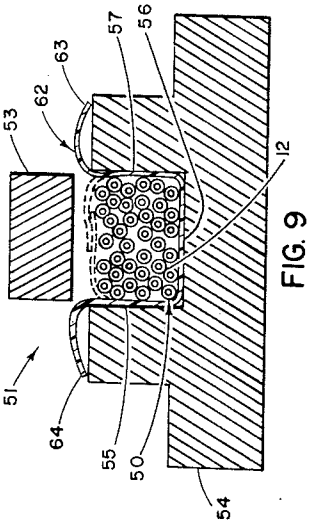


FIG. 9

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United States Patent Office 2,991,328 Patented July 4, 1961

2,991,328

MULTICONDUCTOR CABLE

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Filed Apr. 6, 1959, Ser. No. 804,177
14 Claims. (Cl. 174—72)

This invention relates to multiconductor cables and their construction and more particularly to a relatively rigid multiconductor cable and a method for making the same.

Where electrical harnesses or cables comprising grouped, generally parallel electrical conductors are used in aircraft or other structures, particularly where vibration and other factors tend to produce relative motion between the group of conductors and other items on which or near which they are mounted, chafing of wires in the group or bundle is a problem which must be surmounted. Where, as has been the common practice, each wire in the group is provided with an electrical insulating layer which lies immediately over the conductor and, in addition to this, a fabric or other layer provided for protection against chafing and which overlies the first, insulating layer, the outer, protective layers of the several wires, one on each wire in the group or bundle, add up to a considerable weight and also greatly increase the bulk of the bundle.

It previously has been proposed that the outer, abrasion-protective layers of the wires be left off and the entire bundle inserted into a protective casing. Thus, it has been the common practice to draw a bundle of wires through a flexible casing or sleeve made of vinyl plastic or some other dielectric material. The outer sleevings employed have themselves been subject to an undesirable extent to chafing and abrasion, and because harnesses made with flexible sleevings tend to sag and are easily deflected, they must be clamped at relatively close intervals to the structural items on which they are mounted, and, to prevent chafing, adequate and relatively wide clearances must be left between them and adjoining items against which they might be deflected under vibration or other conditions.

In addition, the drawing of a large group of conductors, some or all of which might be quite fragile, through a relatively long protective sleeve is a time-consuming, difficult operation which tends to stretch the wires, and there are distinct limitations upon the compactness and density which can be attained in a bundle of wires so protected.

In making a multiconductor cable of minimum size and weight, the amount of metal of the conductors and the amount of insulating material surrounding them may both be reduced to the minimum amounts giving sufficient electrical power-carrying capacity and adequately preventing shorting and arcing between the conductors. A limit is reached when the wires become so small that excessive heating is produced under normal loads or predictable overloads, and this heating tends to destroy both the wire and the insulating material about it. A fire hazard is attendant upon such a failure in a wire, and adjoining wires are apt also to be damaged. Meanwhile, the deleterious effects upon them of operation in high-temperature environments have tended to limit the usefulness of electrical cables.

Parallel, individual conductors have previously been cast into a single, homogenous block or strip or insulating material, but this mode of construction is of little or no advantage in reducing weight or cross-sectional area of the harness because it is not practically possible to space wires of any considerable length very closely together without having some of them contact or cross each other and consequently entering into a short-circuited relation which is made permanent when the wires

are cast into the insulating material. For this reason, the wires must be spaced well apart, with added spacing for safety; and a great weight and volume of insulating material must be used in making the solid block or strip into which they are cast. For reasons concerning their electrical properties and their producibility, the conductors which most often are used in electrical harnesses are made of single or stranded wires of circular cross section. Even if the spacing of wires of circular cross-section could be controlled so reliably and well that the wires could be spaced so closely that the insulation about each wire was, at its thinnest point, of the minimum thickness for preventing arc-over to an adjoining wire, the embedding of the wires in a solid, common, insulating block requires, by its very nature, the filling of all of the spaces between the round wires and thus, of course, requires the use of a great weight of insulating material above that actually necessary merely for the insulation of the wires.

A cable made of a plurality of wires cast into a single piece of insulating material tends to behave under flexure, from vibration or other causes, as a single bar and does not have the advantages which, as will become apparent, accrue to a multiconductor cable in which each wire is slideable, with its insulating sheath, lengthwise of and against adjoining wires. The same disadvantage may, and ordinarily does, appear in cables made of a large number of individually insulated wires pulled through a protective sheath: as more wires are introduced into a sheath of given diameter in an attempt to produce a highly compact cable, wire-to-wire friction becomes so high that the individual wires no longer are slideable against each other within the sheath, and the cable behaves as a solid, though not necessarily rigid, bar. This behavior becomes a defect where, for example, it causes the cable to display a resonance to mechanical vibrations and thus further aggravate the problems of chafing, clamping, etc.

The sleevings through which bundles of wires have been pulled for making jacketed multiconductor cables have been of round cross-section. Use of jackets of such cross-section has been compelled by practical considerations including the difficulties which would be encountered in pulling wires through a sleeve which, for example, had a rectangular cross-section, to the end that the bundle of wires would thoroughly fill the jacket. Further, in case of a flexible jacket, the rectangular cross-section is distorted by pressures of the wires and tends to become of circular cross-section as it becomes tightly filled with the wires. In many, probably in most, applications a multiconductor cable of circular cross-section is quite wasteful of space; for example, where it is strung along one or more substantially flat surfaces, space would be saved (in most cases) if the cable were of rectangular cross-section. Ideally, of course, space would best be conserved by making the cross-section of the cable, at any point along its length, such as best to fit against and among the other items with which it must be associated.

It is, accordingly, a major object of the invention to provide a rigid multiconductor cable of improved low weight and volume.

Another object is to provide a rigid multiconductor cable which is pre-shaped to conform to surfaces against or near to which it is to be mounted and which is accurately and stably locatable relative to such surfaces.

A further object is to provide a rigid multiconductor cable which is substantially non-resonant to mechanical vibration and which requires a minimum number of mounting points.

Yet another object is to provide a rigid multiconductor cable of improved resistance to heat and abrasion.

A still further object is to provide a multiconductor

cable of improved resistance to electrical overloading of individual wires in the cable and possessing a greater current-carrying capacity of the wires individually and as a whole.

Still another object is to provide a novel and efficient method for making a rigid multiconductor cable of smaller size and lower weight than previously practicable and of improved abrasion and heat resistances.

An additional object is to provide a rigid, multiconductor cable of high density and consequently low volume and which is substantially water-proof, air tight, and immune to the effects of acids and bases.

Yet another object is to provide a high-density multiconductor cable having branches that are of one-piece, unitary construction with each other and to supply a practical and efficient method for making the same.

Still other objects and advantages will be apparent from the specification and claims and from the accompanying drawing which ilustrates an embodiment of the invention.

In the drawing:

FIGURE 1 is a perspective view of a preferred embodiment of the multiconductor cable;

FIGURE 2 is an enlarged view in elevation of a segment of the cable in which portions of the cover have been removed to show the wires and the reinforcing plate;

FIGURE 3 is a cross-sectional view of the cable taken as at line III—III in FIGURE 1;

FIGURE 4 is a longitudinal sectional view taken as along the line and looking in the direction shown by the arrows at IV—IV in FIGURE 1;

FIGURE 5 is a cross-sectional view through several typical conductors of the cable shown in other figures;

FIGURE 6 is a plane view of a branched portion of the cable shown in FIGURE 1 in which some of the outer cover is removed to show the cover interior and installation of an outer, flexible jacket at an opening of the cover;

FIGURE 7 is a side elevation of the cable portion shown in FIGURE 6, the cable branch being shown in a cross-sectional view taken as at VII—VII in FIGURE 6;

FIGURE 8 is a perspective view of a harness of wires prepared for incorporation into a multiconductor cable such as shown in FIGURE 1;

FIGURE 9 is a cross-sectional view taken as at IX—IX in FIGURE 10 and with the male mold member shown not yet inserted into the female mold member;

FIGURE 10 is a perspective view of the mold with the multiconductor parts being molded therein; and

FIGURE 11 is a longitudinal sectional view of the cable taken at an end of the cover.

With reference now to FIGURES 1 and 2 of the drawing, the multiconductor cable **10** compirses an elongated, tubular cover **11** through which extends a plurality of elongated, individually insulated conductors such as the wires **12**. The ends of the wires **12** may be provided with suitable terminals or connectors, such as, for instance, the multiconnector plugs or receptacles **13**. Many electrical plugs, receptacles, terminals, and other suitable means for connecting the wires into electrical circuits in order that they may form parts of circuits are well known in the art and require no further explanation or description herein except to mention that they preferably should be small and light as practically possible. Self-locking frictional connectors which have been employed with excellent results on the wires and which offer good advantages of weight are those shown in the U.S. Patent 2,816,275, issued on December 10, 1957, to Kemper M. Hammell. The outer shape of the cover **11**, in the example shown, is rectangular at the location of the cross-section shown in FIGURE 3, but is by no means limited to the cross-sectional shape shown; for it may be made in square, circular, oval, triangular, or still other cross-sectional shapes as desired. Moreover, the cover **11** need not be of one same cross-sectional shape along all its length, and it is preferable that this shape be varied, in manufacture of the cable, where and if this offers a decisive advantage of giving it a predetermined cross-sectional shape which enables it to fit with best economy of space among or against items near or on which it is to be mounted. The cover **11** similarly is curved or bent along its length, as at **14**, **15** (FIGURE 1), for shaping it to lie exactly along a desired routing through a computer cabinet, aircraft or missile compartment, or other location within which it may be desired to fit it with considerable exactitude.

As seen in FIGURE 3, the cover **11** has a wall **16** whose inner surface defines an inner volume or cavity which extends lengthwise within and through the cover from one of its ends **17**, **18** (FIGURE 1) to the other, and this cavity is substantially filled with the wires **12**. The elongated conductors **20** (see FIGURE 5) included in the wires **12** are individually provided, each one of them, with a separate insulating sheath **19**. The sheaths **19** of the wires **12** are of course made of a dielectric material; and it is preferable that this material be a resilient plastic which has a low coefficient of friction and which is free of adhesive compatibility with the material of the outer cover **11** even at high operating temperatures or at temperatures which may be employed, as will be described, for curing the outer cover. The multiconductor cable **10** is better fitted, because of details of its construction which will become apparent, than previous cables for operation in environments in which the temperature is very high; and where such an environment is contemplated, the sheaths **19** of the conductors **20** should be made of a material whose electrical insulating properties do not break down at high temperatures and which is not subject to physical changes such as softening which could allow shifting of the conductors **20** within the sheaths **19** or result in welding of one of the sheaths **19** to another sheath **19** with which it is in contact or with the cover **11** where the particular sheath **19** is one which contacts the latter. Meanwhile, it is desirable that the sheath material employed, while possessing the other qualities enumerated above, should be (at least among the class of resilient, dielectric materials) in itself a fair conductor of heat.

The wires **12** need not be all of the same size, and it is entirely practicable to intermix wires which are, as shown in FIGURE 5, of radically different diameters. If desired, some shielded or coaxial conductors such as the wire **21** may be included. The wire **21** may have an outermost sheath **22** of material identical or similar to that of the sheaths **19**. For simplicity, only wires **12** are spoken of hereinafter; but it will be understood that, where their presence is appropriate, reference is intended also to wires such as **21**, and that still other kinds of wires or equivalent may be included among the wires **12**.

The specific material employed in the wire sheaths **19** may be varied according to the conditions under which the cable **10** will be expected to perform. Materials generally preferred because of their superior electrical, thermal, and mechanical properties are the tetrafluorethylene resins, marketed under the trade name of "Teflon" by I. E. du Pont de Nemours Company of Wilmington, Delaware. Though not generally capable of withstanding as high a temperature as "Teflon" and not possessing, for example, as extremely low a coefficient of friction as the latter, materials entirely suitable for many applications are found among the silicone rubbers, and still other materials are satisfactory, for instance those presently used for the insulating of electrical wires and listed in the U.S. Government Specification MIL-W-16878C (Navy) of April 3, 1958. As far as consistent with it having the other desirabilities noted herein, it is preferred that the material chosen be of the highest obtainable dielectric strength per mil of thickness since this permits the use of sheaths **19** of minimum thickness and closer spacing of the conductors **20**; and

this aids in reducing the weight and overall size of the multiconductor cable **10**. The thicknesses of the sheaths **19** must be great enough to prevent voltage breakdown between the conductors **20** at the voltages or overvoltages they may reasonably be predicted to encounter in service of the cable **10**.

The relationship of the conductors **20** and their sheaths **19** with each other and with the wall of the cover **11** shown in the cross-sectional view presented in FIGURE 3 is generally typical along all the length of the cover. Substantially every sheath **19**, in all its length within the cover **11**, has intimate contact with adjoining sheaths **19**, and all the conductors **20** are confined to this contacting relationship by contact of sheaths **19** of conductors **20** lying at the borders of the group of wires **12** with the inner surface of the cover **11**. The wires **12** are compacted, i.e., made to lie very closely against each other as tightly as is consistent with achieving an optimum relationship between the density of the group of wires **12** and a desired degree of freedom from lack of pressure-induced deformation of their sheaths **19** sufficient to squeeze any sheath **19** such that it, together with the material of adjoining sheaths **19**, would not be thick enough to provide sufficient dielectric material between its conductor **20** and adjoining conductors **20**. The density of the group of wires **12** preferably is that at which virtually no space is wasted between the wires: all the space within the interior volume of the cover **11** should be filled with wires **12** arranged to lie as closely together and preferably with as much contact with each other as their cylindrical cross-sections permit, thus reducing to a minimum the voids between them and hence making the volume occupied by the group as small as possible. Packing the wires **12** so tightly that the sheaths **19** are greatly flattened or otherwise deformed and to a significant extent made locally thinner by contact with each other is to be avoided for the reasons given above. In practice, some such deformation may be acceptable; but it must be kept within reasonable limits, for excessive pressure-induced thinning of the sheaths **19** will defeat a purpose of the invention. Since the wall thickness of the sheaths **19** is, to begin with, at (or near) a practical minimum, and since the dielectric strength of a sheath **19** tends to be no greater than that at its thinnest point, compressing the wires **12** so tightly as, for instance, to change their respective sheaths **19** from circular to hexagonal cross-section tends to defeat the invention and its object of providing a light-weight cable. Depending upon the voltages at which the wires **12** are to be used and upon the material of which the sheaths **19** are made, there is a certain minimum thickness of sheath material which must interlie adjoining conductors **20** to prevent voltage breakdown between them. When a conductor **20** of circular cross-section is spaced from the nearest-approaching points of surrounding conductors **20** of similar section by its own and other sheaths **19** whose combined thickness between adjoining conductors equals this required thickness of dielectric material, the lightest-weight, electrically effective insulation of the conductors **20** is effected by sheaths **19** of annular cross-section. To fill in, in effect, between these round sheaths until they were, for instance, hexagonal would be to add weight without increasing the effective thickness of the insulation or adding to the dielectric strength between the wires **20**, and hence is to be avoided.

The wires **20** thus are compactly grouped together within and for practical purposes completely fill the inner volume of the cover **11**, and they extend lengthwise within the cover in generally parallel, side-by-side relation with each other. The shape of the inner cavity of the cover **11** is defined by the inner surface of the cover wall **16** and generally corresponds to the exterior shape of the cover **11**; and the wall **16**, through contact with outer ones of the wires **12**, constrains them to a relationship in which mutual contact of the sheaths **19** of neighboring wires **12** is close and intimate throughout their length within the cover **11**. The cross-sectional shape of the group or core of wires **12** thus also corresponds, as seen in FIGURE 3, to that of the exterior of the cover **11**.

The materials of the cover **11** are selected to produce a rigid, unitary structure of excellent dielectric properties and resistance to high and low temperatures and to abrasion. For these purposes, the wall **16** preferably is made of dielectric fibers (for example, a glass fiber cloth) impregnated with a hard-curing resin. The resin preferably is adhesively incompatible with the material of the sheaths **19** provided on the conductors **20**. Other of its qualities being in accordance with the requirements stated herein, it is entirely suitable that the resin be of the thermo-setting or heat-curing variety. For a cable intended for operation at temperatures ranging from, for instance, −65° F. to 200° F., a woven glass fabric meeting the requirements of U.S. Government Specification MIL–F–9084 and impregnated with a polyester-type resin conforming to Specification MIL–R–7575, Type II is suitable. Adequate materials for a cover **11** made for use throughout a greater temperature range, for instance from −65° F. to 500° F. or above, include a glass cloth conforming to Specification MIL–Y–1140, No. 181 or 182 and a resin meeting the requirements of Specification MIL–R–9299, Type II. The outer surface of the cover wall **16** preferably is smooth, while its inner surface complements the shape of the group of conductors **20** and compensates for variations between the shape of the group and the outer shape of the cover **11**. The materials listed are given to provide specific examples of acceptable materials, and still others are entirely suitable.

The term "rigid," as employed in the mechanical sense, has been authoritatively defined as "absolutely invariable in shape and size under the application of force." Because literally absolute invariability of the dimensions of concrete, physically real bodies under the application of forces is not to be found, the strictly applied term probably is meaningful only in the abstract. It is commonly used, however, to designate a body whose variation and size, deflection along its length, etc. is perhaps measurable but yet is so small as to be of no practical interest or significance when the body is loaded by forces within a given and expectable range of magnitudes. It is in this latter sense that the term "rigid" is employed in connection with multiconductor cable. Other terms employed herein, for example, "dielectric," "non-resonant," "non-conductive," etc. are similarly employed in their common, practical sense rather than in their absolute sense. The construction of the multiconductor cable **10** described herein provides it with a superior rigidity which is importantly contributed to by the dielectric cover **11**; and the latter, of course, is subject to stresses imposed upon the cable **10** by bending loads. Forces urging deflections of the multiconductor cable generally are most apt to cause ultimate cracking or other failure of the cover at relatively pronounced bends in the cable, such as at **14** or **15** in FIGURE 1, if the deflections urged are such as would increase or diminish the sharpness of the particular bend.

To reinforce and add to the rigidity of the multiconductor cable at, for example, the bend **14**, there is provided the construction shown in FIGURES 2 and 4. The wall of the cover **11**, in the example shown, is made up of at least two plies of resin-impregnated fabric. The inner ply (or plies) is made to lie closely along the wires **12** which the cover **11** encloses; and in each of a facing pair of sides **27, 28** of the wall of the cover **11**, a plate **29**, preferably made of a light, strong metal and of such thickness and width as required for adding the needed reinforcement to the bent portion of the cable, overlies the inner ply **23** within and preferably somewhat beyond each end of the bend **14**. The outer ply (or plies) **24** of the cover **11**

separates from the inner ply 23 at one end of the plate 29, passes tightly over the latter, and rejoins the inner ply 23 at the other end of the plate. It will be understood that, except where they are separated by the plate 29, the inner and outer plies preferably are merged into a unified, continuous wall structure and in FIGURE 4 are shown as sharply delineated from each other, merely to aid in providing an understanding of the relationship explained in the present paragraph. The plate 29 preferably is narrower than the outer dimension of the respective side 25 or 26 which it reinforces, and thus the entire plate is enclosed between the inner and outer plies 23, 24. Rigid bonding of the plies 23, 24 of the cover 11 is ensured by providing, in the plate 29, a liberal number of holes 30 which are filled as at 31 with resin of the cover 11 and through which resin in the outer ply 24 is continuous with resin of the inner ply 23. Addition of the plates 29 necessarily adds to the thickness of the cover sides 25, 26 receiving them, and it is preferable that this added thickness result in an increase of the over-all width of the exterior dimensions of the cover 11 rather than that the inner surface of the wall of the cover 11 be displaced inwardly to any extent causing any excess of compressive deformation, as discussed above, of the sheaths on the wires 12. Reinforcement of the bend 14 is shown and described by way of illustration, and similar reinforcement of course may be employed at other portions, such as at 15, or may be omitted altogether where vibrations, etc. to which the cable 10 is submitted are not excessively heavy or severe.

It will be understood that for clarity of representation, the thicknesses of the plate 29 and of the wall of the cover 11 have been exaggerated, in the drawing, beyond the thickness generally preferred. For the same reason, the wall thickness of the individual sheaths 19 in the wires 12 preferably are much thinner and the diameters of the conductors 20 often are much less than shown; and a smaller number of wires 12 has been represented than frequently are employed within one cover 11. Certain useages of the multiconductor cable 10 have been found to require 250 or more wires 12 within a single cover 11; and many more can be employed where desired since the difficulty or impossibility of pulling a multitude of wires through a light-weight cover is eliminated in the present invention.

Thus far, the multiconductor cable 10 has been described as if it were elongated, bent as at 14, 15 or wherever necessary to shape it to fit properly along its intended route, and typified as having two ends 17, 18 between which there are no branches. The multiconductor cable 10 indeed may be made in just such manner; but an importantly advantageous feature of the cable 10 is that it may be provided with integral branches as required for dividing the wires 12 and running different ones of them to different locations. With reference also to FIGURE 6 and designating the part of the cover 11 extending between the ends 17, 18 as a first wall or cover portion 32, the multiconductor cable 10 shown by way of example is provided with a second wall or cover portion 33 which is continuous with and which branches off at an angle from the first portion 32 at a point between the two ends 17, 18 of the first cover portion. As explained, the inner cavity of the cover 11 extends through the first cover portion 32, including the bends 14, 15, from one of its ends 17 to the other end 18. The second cover portion 33 is integral with the first portion 32 and in all important respects made in exactly the same way and as the latter; and the inner cavity of the cover portion 32 branches into the second cover portion 33 and extends to its outer end 34. The cross-section of the first cover portion 32 shown in FIGURE 3 is generally typical of cross-sections which might be taken within the length of the second portion 33, and the interior cavity is bounded at all locations within both portions 32, 33 by the inner surface of the cover wall 16.

The ends 17, 18, 34 of the first and second cover portions 32, 33 define openings providing communication between the exterior of the cover portions 32, 33 and the elongated, branched cavity within it. The wires 12 within the cover cavity extend outwardly beyond the cover ends 17, 18, 34 to electrical connectors, such as 13, with which they may be provided, as required, at their ends. Wires 12 entering the cover through a first opening at, for instance, the end 17 extend through and out of the cover 11 through a second opening defined by another end 17. Again, some wires 12 may, as at 35, enter the outer end of the branch 33 and pass into the first portion 32 and toward either end 17 or 18 of the cover. Voids which would be left, as at 36, within the cover interior where a group of wires is deflected from a straight course to pass from one cover portion 32 or 33 to another preferably are filled by the complementary local thickening 36 of the wall of the cover 11.

The interchange of wires 12 from the first cover portion 32 to the branch 33 will in some cases result in there being a smaller number of wires in the cover first portion 32 on one side of the location where the second portion 33 branches from it than in it on the other side of this location. In this event, the dimensions of the cover 11 preferably should be reduced, as at 37 (FIGURE 7) in the side where there is the smaller number of wires 12 until the inner cavity within that side is sufficiently small to maintain the wires 12 in the previously described, closely compacted relationship wherein the sheath of each wire 12 is in close, intimate contact with the sheaths of other wires 12 throughout its length enclosed in the cover 11.

In some cases, a separate branch of the cover 11, such as 33, will not be needed or desired where one or more wires leave the cover 11 as at some point between its ends 17, 18. In this event, a breakout opening 39, that is, a wall opening through which a desired group 39 of the wires 12 may leave the cover 11, is provided. To prevent local weakening of the cover 11 at the breakout opening 38, it is preferable that the latter be made in a raised boss 40 which is integral with and formed of the same materials as the remainder of the cover 11. The breakout opening 38 is made of a size to enclose snugly the wires 39 which pass through it, and it communicates with the interior cavity of the cover 11.

Since the wires 12 are constrained to lie in a compact group having a minimum cross-section where they are within the cover 11, and since this constraint is lacking in segments of the group of wires 12 which extend outside the cover 11, the wires 12 lying in contact with the cover 11 where they leave an opening in the latter (for example, at the breakout opening 38 or at the openings through which the wires extend at the ends 17, 18, 34 of the cover 11) would be apt to be subjected to a localized and possibly excessive pressure imposed upon them by the edge of the cover 11 defining the opening if the transition from the fully constrained to the relatively unconstrained state were over-abrupt. To meet this difficulty, which is generally more severe where the wires 12 must experience flexure at the particular opening, a construction is provided whereby the wires pass from the fully constrained state toward the unconstrained state while they still are enclosed within the cover 11. Thus, for example, a flare 66 (FIGURE 11) is provided in the inner cavity of the cover 11 at its end 18 (FIGURES 1 and 11), and similar enlargement of the cross-section of the cover 11 may be employed as needed at other of its openings, for example, at the opening 38 through the boss 40.

For protection of the wires 12 where they extend outside the cover, it is in many cases desirable to protect them with a flexible outer jacket which lies in encasing relation to them. As a feature of the invention, the breakout opening 38 or any of the other openings at the ends 17, 18, 34, of the cover 11 are provided as desired

with a flexible jacket 41 mounted in the particular opening in firm attachment to the cover 11. A preferred material for the flexible jacket 41 is a tube 43 made of tetrafluorethylene and provided with a convolution or spiral corrugation 42 (FIGURE 7) which runs, in the manner of a screw thread, from one end of the jacket to the other. The tetrafluorethylene tube 43 preferably is covered with a glass fiber cloth 44, which conforms to the convoluted contour of the tube 43. Such a jacket 41, because of its "Teflon" interior, has very little abrasive effect on the wires 12 within it upon bending and deflections that cause its wall to rub on the wires, and the glass cloth exterior has good resistance to abrasion. The jacket 41 readily yields and shows good flexibility when there is imposed upon it forces tending to lengthen, compress, or bend it. The glass fiber outer layer 44 of the outer, flexible jacket 41 interlocks firmly with and becomes integral with the wall of the cover 11, and the latter is locally thickened to fill the convolution 42 and thus ensure an excellently secure mounting of the flexible jacket 41 in the end of the cover 11. Where the jacket 41 must withstand high temperatures, it should be made of temperature-resistant materials; and those suggested above are adequate in this respect. While a flexible outer jacket 41 is shown only for the wires 35 extending from the outer end of the second portion or branch 33 of the cover 11, it may similarly be employed at any opening of the cover, including the breakout opening 38.

Where a flexible section is desired within the length of the multiconductor cable 10, such may be provided by terminating the cover 11 (FIGURE 1) at one end of the desired flexible section 45 and employing a second cover 46 which is spaced from the first and which reencases the wires 12 where, at the other end of the flexible section 45, they pass into the second cover 46 through the opening defined at its end 34 by the wall of the cover 11. The second cover 46 may be constructed in the same general manner and of the same materials as the first cover 11. The wires 12 pass through its interior cavity and are constrained to the same relation with each other and the second cover 46 as described in connection with the first cover 11. This construction is of excellent usefulness, for instance, where the first cover 11 is mounted, by any suitable clamping means 47 or equivalent, on a structure 48 which is subjected to vibratory or other movements relative to another structure 49 on which the second cover 46 is mounted. It is preferred that the bundle of wires 12 in the flexible section 45 lying between the first and second covers 11, 46 be twisted as a group, for this greatly enhances the flexibility of the group of wires 12 where they lie outside the covers 11, 46. For the same reason, the groups of wires 12 leaving the other openings of the covers 11, 46 also may be twisted. Although it has been omitted from the drawing in order to show the wires in the flexible section 45 between the first and second covers 11, 46, the wires in the flexible section 45 preferably are covered by a flexible outer jacket which is similar to that shown at 41 at the outer end 34 of the first cover branch 33 and which has each of its ends mounted in a respective end of the first or second cover 11, 46 in the manner in which, as shown in FIGURE 6, an end of the jacket 41 is mounted in the end opening of the branch 33.

The multiconductor cable 10 described above may be made in any way known or which may be devised which will produce the article described. One method, for instance, includes laying up into a harness the desired wires 12 which are to be included in the cable 10 and then covering them with a substantially rigid tubing made of one of the various pre-stressed plastics which will shrink upon being heated above its thermal relaxation temperature. By the controlled application of heat, then, the outer tubing enclosing the harness may be caused to contract and compact the wires 12 to the condition and relationships previously described.

According to a preferred method of making the multiconductor cable, however, the wires 12 which it is desired to include in it are built up into a harness 50 as shown in FIGURE 8. The wires 12 employed should of course conform to the requirements as to materials, etc. set forth in previous paragraphs. The wires 12 preferably should not be marked by stamping since this tends to cause mechanical and electrical weakening of the insulating sheaths of the wires. Care should be taken that neither the conductor 20 (FIGURE 5) or the insulating sheath 19 of any wire 12 used is broken, cut, or nicked. Assembly of the wires 12 should be such as to produce a harness 50 of a shape which generally fits the applicable mold 51 (FIGURES 9, 10) in which, as will be described, the harness 50 is brought to its final, desired shape. Since the intricacies of assembly of a wire harness are well known in the art, no further description of this step is required beyond mentioning that the harness 50 preferably is held together by mechanical means such as, for instance, temporary spot ties of twine 52 made at, for example, 10- to 12-inch intervals along the harness 50 and preferably removed therefrom prior to the step of molding described below. In the completed harness 50, wires which are intended to pass through a break-out opening 38 (FIGURE 1) or into a branch 33 of the multiconductor cable 10 should branch away from the main body of the harness 50 (FIGURE 8) approximately as they will in the completed cable. Within the harness 50, the wires 12 should lie as nearly as practicable in parallel relation to each other, and excessive crossing of wires should be avoided, though some crossing of the wires 12 is acceptable and generally will not diminish the quality of the finished cable.

The mold 51 (FIGURES 9, 10) employed for making the multiconductor cable should be shaped, branched, etc. as required to cause the materials of the cable 10, when formed in it, to have the shape desired at all points in the finished article. Deviations from plane surfaces on the multiconductor cable 10 are best made on its upper side 25 (FIGURE 1) since it is generally more feasible to make corresponding variations in the surface of the male part 53 of the mold 51 which forms this side 25 of the cable 10. The mold 51 shown in FIGURE 9, for example, is intended for making a multiconductor cable 10 of square or rectangular cross-section as shown in FIGURES 1 and 3. Accordingly, the female part 54 of the mold 51 (FIGURE 9) contains a channel whose three sides 55, 56, 57 have the shape and dimensions of the three sides 26, 27, 28 of the cable 10 (FIGURES 1 and 3), and the lower surface of the male piece 53 of the mold is shaped and dimensioned to correspond to the remaining, upper side 25 of the cable. Similarly, the parts of the complete mold 51 (FIGURE 10) are bent as at 58 and 59 and branched as at 60 in correspondence with the bend 14 and 15 and branch 33 of the completed multiconductor cable 10 (FIGURE 1). Whereas one mold section 51 with male and female parts 53, 54 is used for making the first section 11 of the cable 10, a second mold section 61, spaced from the first by an interval equal to the length of the flexible section 45, is employed for the second section 46 of the cable.

The impregnated fabric previously described is wrapped about the harness 50, or, according to a preferred procedure, it is laid up in the female mold sections to form a lining in the latter as shown at 62 in FIGURE 9. The width of the material 62 should be sufficient to provide an overlap of its edges 63, 64 when, as will be described, it is folded over the wires 12. As many plies of the fabric 62 as required should be employed for making a cover 11 or 46 (FIGURE 1) with adequate wall thickness. Since this requirement will vary with the fabric employed and with the cross-section and other dimensions of the cable to be made, and since

known technics laying up impregnated fibers in molds are well developed, specific instructions will not be given in regard to the number of plies to be used nor of the manner of laying them one over the other since one skilled in the art can readily proceed without such direction. Several procedures peculiar to the making of the multiconductor cable **10** require specific explanation, however, in connection with laying the materials of the cover **11** in the mold female parts **54**, and these explanations follow.

Where required at bends in the cable, as at **14** (FIGURE 1), the reinforcing plate **29** (FIGURES 2, 4) is introduced during the laying up of the impregnated cloth **62** in the molds. At least the outer ply or plies **24** of the cloth **62** are laid in the mold female part **54**, then the plate **29** is set in place. Next, the inner ply or plies **23** are laid up over the plate **29** to produce the relation shown in FIGURE 4 between outer plies **24**, plate **29**, and inner plies **23**. If the cloth **62** is not heavily enough impregnated to ensure filling of the holes **30** of the plate **29** with resin **31** when the wires **12** and cloth **62** are placed under pressure in the mold, it is helpful, for securing best bonding of the plate **29** with the cover **11**, to add more resin locally, as needed, at the plate **29** for complete filling of the holes **30**.

If a flexible jacket **41** is to be employed in the multiconductor cable **10** at one of the openings of the cover **11**, a piece of tubing, preferably of the kind described above and shown at **41** in FIGURE 8, is placed on the part of the harness **50** which will lie at the opening concerned. Other jackets such as **41** similarly are placed as desired on the harness **50** at locations corresponding to other openings of the cover **11**.

With the lay-up of the impregnated cloth **62** complete, and with the edges **63**, **64** of the cloth laid aside, for example as shown in FIGURE 9, the wire harness **50** is laid in it within the mold female part **54** and the edges **63**, **64** of the cloth are folded over the wires **12** and lapped over each other as shown in dotted lines in the drawing. Before or as this is done, the flexible jacket or jackets **41**, if such are employed in the particular multiconductor cable **10** under construction, are checked for location and slipped along the harness **50** as necessary to bring them into proper overlapping relationship with the material of the cover **11** at the cover opening or openings involved as shown in FIGURE 8.

The male part **53** of the mold then is brought down on the cloth-wrapped wires **12** with pressure enough to compact and form them and material of the cover **11** to the shape and relationships with each other previously described. Any gaps which occur between ones of the wires **12** lying next to the cover **11** are filled in the molding process by resin and fabric squeezed into them as at **65** in FIGURE 3; thus, the inner surface of the cover **11** complements the outer periphery of the group of conductors **12**, and the outer surface of the cover **11** is smooth and of a shape predetermined by the shape of the mold parts **54**, **55**.

The molded multiconductor cable **10** is kept under pressure in the molds **51**, **61** until the resin of the cover **11** has set and solidified to a substantially rigid, dimensionally stable state. Where a thermosetting resin is employed in the cover **11**, the curing should of course be done during the application of heat to the cable **10** while it is retained in the mold. The temperature employed should be appropriate for proper curing of the resin and should not be high enough to be a factor resulting in permanent dimensional or other changes in the individual insulating sheaths **19** of the conductors **20**. When the cover **11** is properly cured, the cable **10** is removed from the mold. Some or all of the plugs **13** or other connectors or terminals provided on the wires **12** may be added thereto before the molding step, or, as may be expedient, they may be added after the wires **12** are molded into the cover or covers **11**, **46**, the latter mode of procedure being preferred in the majority of instances.

The multiconductor cable **10** whose form and mode of construction as described above is of superior low weight and volume since the individual sheaths **19** of the conductors **20** preferably contain only the amount of material necessary, with adequate safety margin, for preventing shorting and arc-over between the wires **12** and since the weight of individual abrasion-resistant covers on the wires is eliminated, the cover **11** providing excellent abrasion protection, at great saving in weight, for all the wires **12**. The wires **12** preferably are held by the cover **11** in as close association with each other as is practically possible without so deforming the individual insulating sheaths **19** of the wires **12** by excessive wire-to-wire pressures that their insulating ability would be significantly reduced; consequently, they are held by the cover **11** in a group of as high a density and low a volume as is practically possible. Pre-shaped by the molding process, the cable **10** conforms to the surfaces of bodies such as **48**, **49** against or near which it is designed to be mounted; of rigid construction, it is not deflectable when clamped to a fixed body and consequently remains in a fixed, accurately known location relative to that and other bodies of accurately predictable position.

Several factors combine to make the multiconductor cable **10** substantially non-resonant to mechanical vibrations. The cover **11**, because of the materials of which it is made, is inclined to be relatively free of resonance. Within this cover **11**, the wires **12** lie in generally parallel relation to each other, and adjoining wires **12** are closely in contact with each other. Upon the cable **10** being subjected to a vibratory force which tends to make it oscillate in resonance with the vibration, any deflection of the cable **10** away from its normal position would cause a small bending of the cable **10**. Wires of the cable **10** at the outside of the bend would tend to be stretched and wires on the inside to be compressed. Because of their low coefficient of friction, the wires **12** in such case slide upon each other, thus expending much of the energy that causes the bending in friction losses and making it unavailable for causing a rebound to and/or beyond the normal position of the cable **10**. The multiconductor cable **10** thus is non-resonant as compared with a cable in which the wires are all embedded in one common block of insulating material or in which their coefficient of friction is so high that the individually insulated wires are bound to each other by friction and behave as if enclosed by a solid block of insulating material; for, in such a construction, the energy expended in forcing a cable segment through one half-cycle of a vibratory motion is stored in the material of the wires and their insulating sheaths and supplies energy causing or aiding the cable to move through the next half-cycle of vibration. Previous cables, for this reason, have had to be clamped at quite close intervals to prevent the formation of standing waves which otherwise would form as the cables came into resonance with vibrations of bodies on which they might be mounted. Because of its rigidity, which prevents its drooping or sagging between clamps, and because of its substantial freedom from resonance with vibrations of the objects with which it is associated, the multiconductor cable **10** requires a quite favorably small number of clamps **47**, and these may be spaced at wide intervals; thus, the cable **10** is much more easily, quickly, and inexpensively mounted than previously employed cables.

Well able to withstand abrasion, blows, etc. because of its hard, rough cover **11**, the multiconductor cable **10** has greatly improved resistance to electrical overloading of its wires **12**. When an excessive current is passed through one or several of the wires **12**, they of course tend to overheat. The individual sheaths **19** of the conductors are, however, (among the class of resilient insulating materials) fair conductors of heat, while the metallic conductors **20** are themselves excellent heat conductors.

Each wire **12** is preferably in intimate contact, all along its length, with other wires **12**; and these other wires act as heat sinks which carry off the excessive heat produced by overloaded ones of the wires. If a wire **12** is overloaded so greatly that it eventually fails, the heat-sink relationship between the wires **12** prevents failure within the cover **11**; and it is a great advantage of the multiconductor cable **10** that the failure consistently occurs outside the cover **11** at the uncovered, accessible ends of the wires. In the same manner, a segment of the cable **10** locally exposed to what would otherwise tend to be excessive ambient temperatures is cooled by the heat-sink action of other segments of the cable located in cooler areas. High ambient temperatures and/or heavy electrical loading of the entire cable is well withstood by virtue of the heat-resistant materials of the cover **11** and of the individual insulating sheaths **19** of the wires **12**. The multiconductor cable **10**, when made of the materials suggested, furthermore may easily be made substantially water-proof and airtight, and it is substantially immune to the effects of acids and bases and their reaction products. It thus is able to stand up well in chemical environments in which other cables could not survive. For this reason, the multiconductor cable is excellent, for example, for use underground as well as in many other applications including those previously mentioned.

While only one embodiment of the invention has been described herein and shown in the accompanying drawing, it will be evident that various modifications are possible in the arrangement and construction and in the method of making the multiconductor cable without departing from the scope of the invention.

I claim:

1. A multiconductor cable comprising: individually insulated, elongated conductors; a tubular, rigid, one-piece cover made of a dielectric material molded about the conductors and having a wall, the cover further having an elongated inner volume enclosed by the wall, the conductors being compactly grouped together within and extending along the length of the inner volume of the cover and lying in generally parallel relation with each other, the conductors tightly filling the cover inner volume and being confined through contact of at least some of the conductors with the wall in a relationship wherein substantially every one of the insulated conductors, throughout substantially all its extension through the interior volume of the cover, has mechanical contact with others of the insulated conductors.

2. A multiconductor cable comprising: a plurality of elongated conductors lying in generally parallel relation with each other; a plurality of individual, resilient, insulating sheaths, substantially every one of the conductors being individually covered by a respective one of the sheaths; and a rigid, tubular, dielectric, unitary cover molded about the conductors and sheaths, the cover having a wall enclosing an interior volume substantially completely filled by the conductors and of a smallness sufficient to maintain substantially every one of the sheaths in close contact with others of said sheaths throughout substantially all their coextension through the interior volume of the cover.

3. A high-density multiconductor cable comprising: a plurality of elongated conductors having individual insulating sheaths and lying in generally side-by-side, parallel relation with each other; a substantially rigid cover molded about the conductors, the cover being of predetermined outer shape in cross-section and having a wall made of a dielectric material of high abrasion resistance, the wall enclosing an elongated cavity and constraining the insulating sheaths to a closely contacting, compacted relation with each other, the conductors being grouped to form a core with an outer cross-sectional shape generally corresponding to that of the cover and substantially filling the elongated cavity of the cover, the thickness of the cover wall being varied inwardly of the cavity

in complement to variations in the cross-sectional shape of the core and in compensation for any differences between that shape and the outer shape in cross-section of the cover.

4. A multiconductor cable comprising: a plurality of elongated conductors lying in generally parallel relation with each other; a plurality of sheaths, each of the sheaths being on a respective one of the conductors, the sheaths being made of a resilient, heat-conductive, dielectric material; and means for maintaining said conductors in heat-exchanging relation with each other, said means including a rigid, tubular, untary cover having a wall molded about the sheathed conductors and enclosing an elongated interior volume of the cover substantially filled by the conductors and of a smallness sufficient to maintain substantially every one of said sheaths in intimate contact, throughout substantially all its respective length within the interior volume of the cover, with others of said sheaths.

5. A non-resonant, substantially rigid multiconductor cable comprising: a plurality of elongated conductors disposed generally parallel to each other; a plurality of sheaths of tubular, single-layered construction, each of the sheaths being on a respective one of the conductors and made of a dielectric material substantially free of adhesive compatibility with the materials of the cover; a substantially rigid, electrically non-conductive cover comprising a wall molded about the sheathed conductors and made of dielectric fibers impregnated with resin, the conductors being confined by the wall through contact of the latter with at least some of the sheaths to a relationship wherein substantially every one of the sheaths, throughout substantially all its length within the cover, has intimate contact with others of the sheaths, the material of the sheaths having a coefficient of friction small enough to permit, upon flexure of the cable, a sliding of ones of said sheaths along others of said sheaths with which they are in contact within the cover.

6. A high-density, low-weight, temperature-resistant multiconductor cable highly immune to abrasion, said cable comprising: a plurality of elongated conductors; a respective sheath on each of the conductors, the sheaths being made entirely of a resilient, temperature-resistant plastic and being of minimum thickness for safely preventing arc-over between adjoining ones of the conductors when the conductors are subjected to intended service voltages; a rigid, electrically non-conductive cover comprising a wall molded about the sheathed conductors and made of a dielectric, temperature-resistant, hard-curing resin reinforced with inorganic fiber, a plurality of elongated conductors disposed generally parallel to each other and along the length of the cover within the interior cavity of the latter; and a respective sheath on each of the conductors, the sheaths being made of a resilient, temperature-resistant plastic and being of minimum thickness for safely preventing arc-over between adjoining ones of the conductors when the conductors are subjected to intended service voltages, the interior dimensions of the cover being substantially completely filled by the sheathed conductors and of interior dimensions small enough to provide a constant, inwardly imposed constraint on substantially all of the conductors along substantially all the length of the cover through contacts which exist between the cover wall and sheaths of the conductors, said constraint being sufficient to hold substantially every one of the sheaths, throughout its length lying within the interior cavity of the cover, in close contact with others of the sheaths.

7. A multiconductor cable comprising: a rigid, elongated, one-piece cover having two ends and made of a dielectric material, said cover having a wall with an outer surface and enclosing a cavity extending between the two ends of the cover, said cover having between its two ends a bent portion through which the cavity extends; a plurality of elongated conductors with individual, di-

electric sheaths, the conductors and sheaths substantially completely filling the elongated cavity, the wall extending around the conductors in a closely contacting relationship therewith which maintains the conductors in closely packed, substantially parallel relation with each other; and a metallic plate disposed between the conductors and the outer surface of the cover at the bend of the latter, the metallic plate being rigidly bonded to the cover and the cover being molded about the conductors.

8. The cable defined in claim 7, the cover comprising inner and outer layers of an inorganic fabric and a cured resin impregnating the layers, and the metallic plate being disposed between inner and outer layers of the fabric and being pierced with a plurality of holes filled with resin continuous with resin impregnating the layers of the fabric.

9. A multiconductor cable comprising: individually insulated, elongated conductors; a tubular, rigid, unitary cover having a wall molded about the conductors, the wall being made of a dielectric material and having two ends; and a breakout opening formed in the wall between said two ends and communicating between the exterior and interior of the cover, some of the conductors extending out of the cover interior through the breakout opening, the conductors, where they lie within the cover, being confined, by contact of at least some of the conductors with the wall, in a compactly grouped, generally parallel relationship wherein substantially every one of the conductors, throughout substantially all its length lying within the cover, has close contact with others of the conductors.

10. A multiconductor cable comprising: a tubular, unitary cover having a wall including a first wall portion with two ends and a second wall portion continuous with and extending at an angle from the first wall portion at a place between the two ends of the latter, the first wall portion enclosing a first elongated, interior cavity extending between the two ends of the first wall portion and the second wall portion enclosing a second elongated, interior cavity continuous with and branching from the first; individually insulated, elongated conductors having extension within and lengthwise of the first interior cavity of the cover, the conductors being compactly grouped in generally parallel relationship where they lie within the first interior cavity of the cover, some of the conductors extending out of the first into and along the second interior cavity, the conductors, where they lie within the first and second interior cavities, being confined, by contact of at least some of the conductors with the cover wall, in a relationship wherein substantially every one of the conductors, throughout substantially all its length lying within the cover, has close contact with others of the conductors, the cover being made of a rigid, dielectric material molded about the conductors.

11. The multiconductor cable claimed in claim 10, at least one of the wall portions having formed therein, within its length, a breakout opening communicating between one of the interior cavities and the exterior of the cover, some of the conductors extending out of one of the interior cavities through the breakout opening.

12. A multiconductor cable comprising: a tubular, rigid, unitary cover having a wall enclosing an elongated interior cavity and defining openings communicating between the interior cavity and the exterior of the cover; a plurality of individually insulated, elongated conductors entering the interior cavity through a first one of the openings and leaving the cavity through at least a second one of the openings, a flexible, tubular, dielectric jacket firmly mounted in at least one of the openings and in encasing relationship to ones of the conductors passing through that opening, the jacket extending outwardly of the cover from the opening, the conductors, where they lie within the interior cavity, by contact of at least some of them with the wall, being confined in a relationship wherein substantially every one of the conductors, throughout substantially all its length lying within the interior cavity of the cover, has close contact with others of the conductors, the cover being made of a rigid, dielectric material molded about the conductors.

13. The multiconductor cable claimed in claim 12, the cable further including a second, tubular, rigid, unitary cover made of dielectric materials and spaced from the cover called for in claim 12 by an interval, the second cover having a wall enclosing an elongated cavity and defining an opening communicating between the exterior and the interior cavity of the second cover, at least some of the conductors passing through the opening of the second cover and extending within and along its interior cavity, the conductors, by contact of at least some of said conductors with the wall of the second cover, being confined in a generally parallel relationship with each other wherein substantially every one of said conductors, along substantially all its length lying within the interior cavity of the second cover, has close contact with others of the conductors, the conductors which pass through the opening of the second cover being twisted together throughout the interval separating the two covers and passing through one of the openings of the cover called for in claim 12.

14. A high-density multiconductor cable comprising: a plurality of elongated conductors having individual insulating sheaths and lying in generally side-by-side, parallel relation with each other; a substantially rigid cover molded about the conductors, the cover being of predetermined outer shape in cross-section and having a wall made of a dielectric material, the wall enclosing an elongated cavity and constraining the insulating sheaths to a closely contacting, compacted relation with each other, the conductors being grouped to form a core with an outer cross-sectional shape generally corresponding to that of the cover and substantially filling the elongated cavity of the cover, the cover having at least one end provided with an opening through which said conductors extend out of said cavity and the cover wall having adjacent said opening an outwardly flared portion wherein the wall, at successive points approaching the opening, exerts progressively less constraint on the conductors, whereby there is a progressive transition between the closely compacted relation of the conductors inside the cover and a less closely compacted relation of the conductors where they lie outside the cover.

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