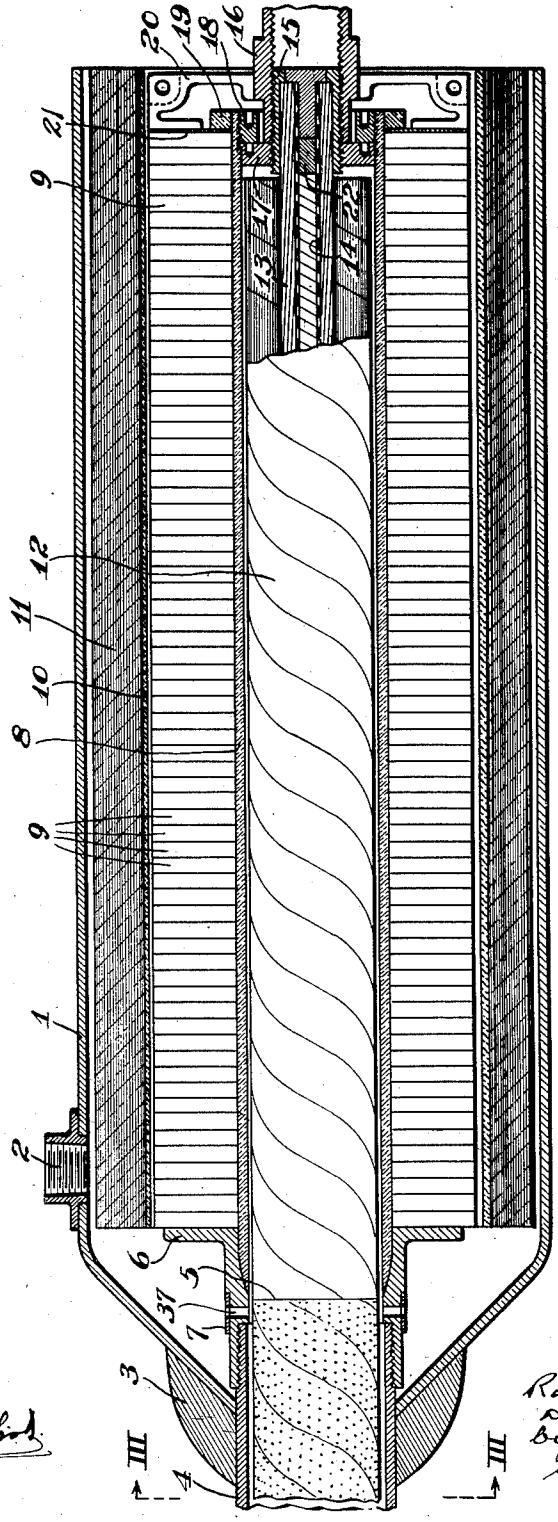
Feb. 16, 1937. R. W. ATKINSON ET AL 2,071,102

OIL-FILLED CABLE

Filed June 19, 1923 4 Sheets-Sheet 1

Fig. I.



WITNESSES

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OIL-FILLED CABLE

Filed June 19, 1923 4 Sheets-Sheet 2

Fig. III.

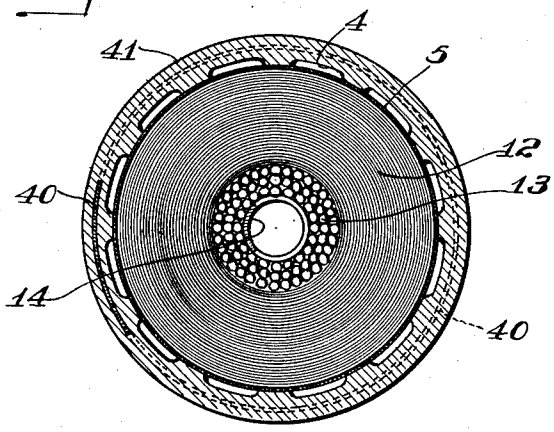
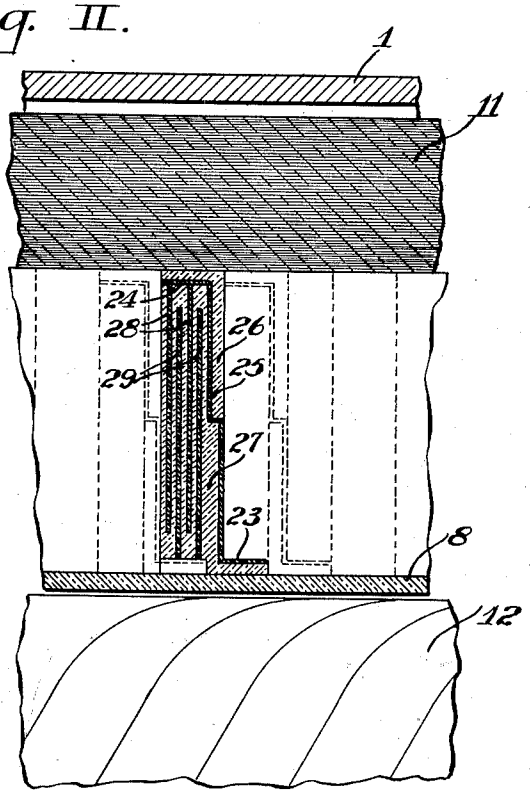


Fig. II.



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OIL-FILLED CABLE

Filed June 19, 1923 4 Sheets-Sheet 3

Fig. IV.

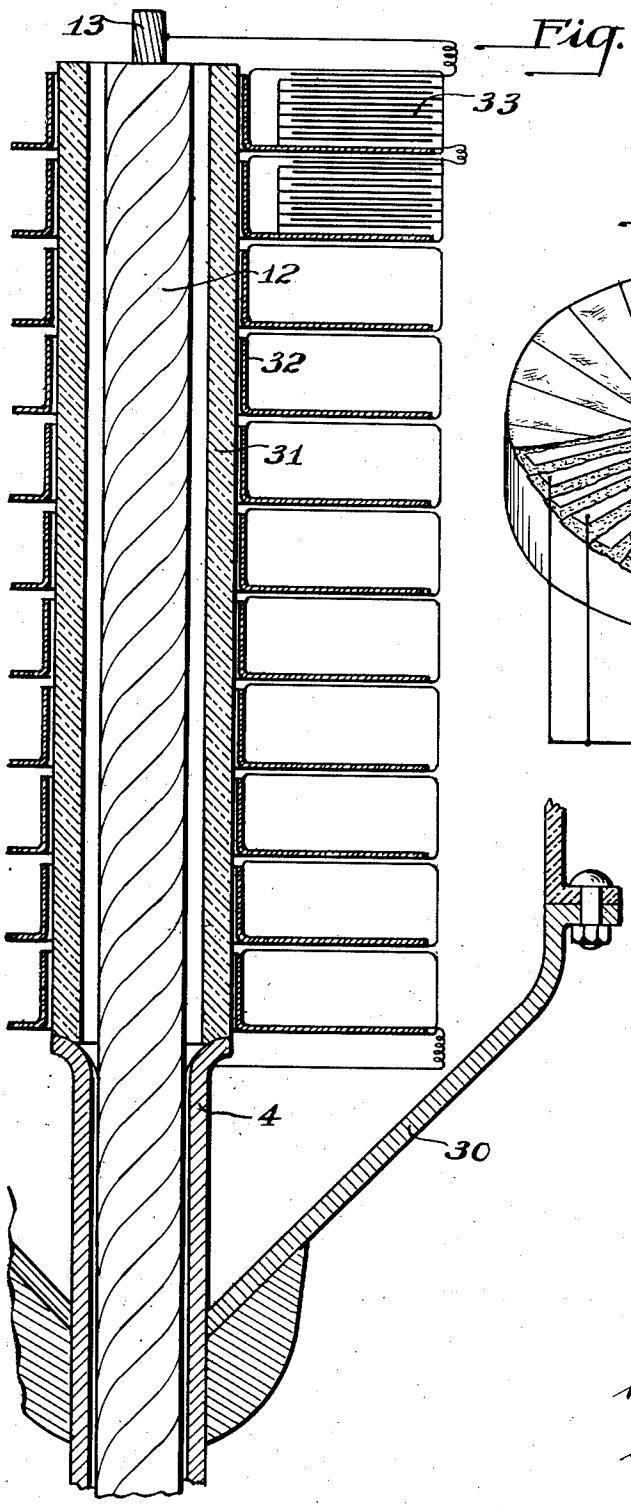
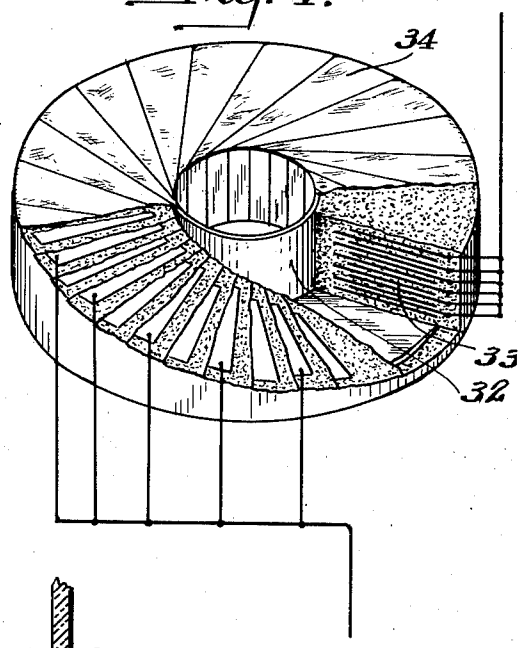


Fig. V.



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OIL-FILLED CABLE

Filed June 19, 1926 4 Sheets-Sheet 4

Fig. VI.

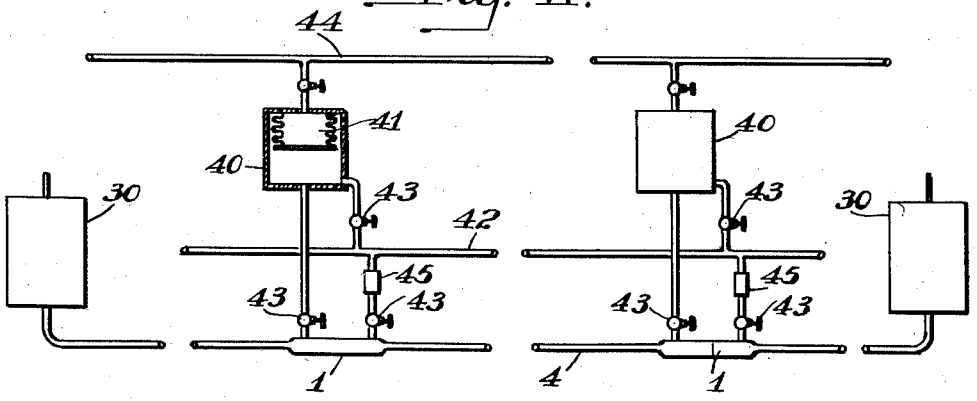


Fig. VII.

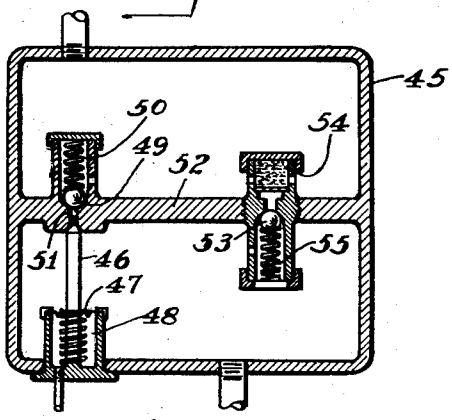
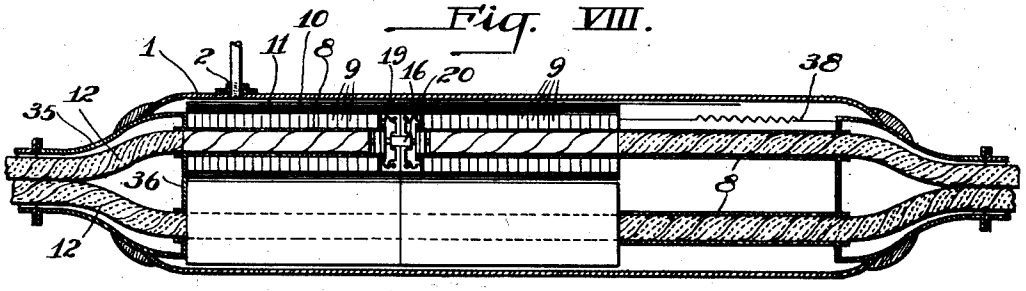


Fig. VIII.



WITNESSES

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2,071,102

UNITED STATES PATENT OFFICE

2,071,102

OIL FILLED CABLE

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Application June 19, 1928, Serial No. 286,517

12 Claims. (Cl. 173—268)

This invention relates to the construction, installation, and maintenance of electric cables; specifically, it relates to liquid-insulated cables intended for high-tension service. A liquid-insulated cable is one whose conductor, spaced (usually by a body of laminate material) from an impervious surrounding envelope, is immediately enveloped in liquid insulation. Ordinarily the conductor is arranged within and in spaced relation to the surrounding envelope by being immediately surrounded by a fibrous body and the liquid insulation penetrates and fills the fibrous body. The fibrous body is usually built of laminated paper tape and the liquid insulation is usually an oil which at normal operating temperatures is fluid. Herein the term oil-filled cable will be used to designate cables whose conductor is spaced from the sheath and the space filled or flushed with a liquid insulating material.

In the accompanying drawings Fig. I is a fragmentary view in axial section of a joint structure in place upon the end of a length of cable, in which structure our invention centers. Fig. II is a view to larger scale, illustrating a detail of the structure of Fig. I. Fig. III is a view in transverse section through the cable, on the plane indicated at III—III, Fig. I. Fig. IV is a fragmentary and somewhat diagrammatic view in vertical section and on an axial plane of a terminal such in character as we have found to be practicable in the working out of the invention. Fig. V is a view in perspective, showing somewhat diagrammatically and by the breaking away of parts, the minute structure of certain details of the terminal. Fig. VI is a diagrammatic representation of a cable installation embodying the invention. Fig. VII is a view in section and to larger scale, illustrating a certain valve arrangement which constitutes a detail of the installation shown in Fig. VI. Fig. VIII is a view corresponding to Fig. I, and illustrates the joint of a multi-conductor cable.

For many years the theoretical advantages of an oil-filled cable have been recognized. First among these advantages is the fact that when the cable in service becomes heated, oil will flow lengthwise within the cable and out into reservoirs provided for its reception, and when the cable cools the oil will flow back again. Thus the stretching of the lead sheath and the opening of voids within the insulation are prevented. Practical difficulties, however, have until recently prevented the use of the oil-filled cable. In the cable system here described the difficulties are overcome. It is one characteristic of the cable of the invention that it is made and filled and impregnated with oil at the factory in individual lengths, and is installed in the ground without draining and without serious loss of oil. In installation a cable is of indefinite length,—perhaps miles long; and in actual practice cables are built in factory lengths, wound on reels, shipped, and jointed in the field length to length. It is quite possible that the length of cable on a reel as it leaves the factory may be made up of more than one continuously formed piece; but by the term factory length as it is used in this specification we mean, more explicitly, a single continuous piece as it comes integrally formed from the lead press. The whole line of oil-filled cable of this invention, when installed in a system, is made up of factory lengths, whose conductors are electrically united, one with another. Oil under pressure is supplied at suitable intervals by means external to the cable.

Referring to Figs. I–III, the cable shown will be understood to be oil-filled cable. For the freer circulation of oil, it is shown, as advantageously (though not necessarily) it may be, as a hollow-core cable. The copper strands **13** which constitute the cable conductor are assembled upon a central supporting, conduit-defining, spiral coil **14** of spring steel. The assembly of these parts is freely penetrable by the oil with which the cable is filled. The cable insulation **12** may be understood to be of wrapped-on paper filled with oil. To the same end of freer circulation of oil, the sheath **4** of the cable is advantageously (though not necessarily) fluted interiorly. A cable having such characteristics will be found to be shown and described in U. S. Letters Patent No. 1,574,076, granted February 23, 1926, on the application of Henry W. Fisher.

Inasmuch as in the practice of our invention we maintain the body of oil within the cable under pressure, we find it advantageous to wrap the sheathed cable with a tape of a metal of greater tensile strength than extruded lead—of bronze, for example,—and in Fig. III we show the sheath **4** to be so wrapped with a tape **40**. Additionally, the wrapped-on tape may be protected with an outer sheath **41** of lead. A cable having such characteristics will be found to be shown and described in U. S. Letters Patent No. 1,524,124, granted January 27, 1925, on the application of Henry W. Fisher and Ralph W. Atkinson.

In the cable here chosen for purposes of illustration the insulated conductor is immediately surrounded in a snugly adherent, permeable,

metallic envelope, and such envelope, being present, is grounded at intervals by the contact of the fluted lead sheath 4 immediately upon it. Such cable structure will be found to be described in U. S. Letters Patent No. 1,199,789, granted October 3, 1916, on the application of Martin Hochstadter. In the specification of that Hochstadter patent various specific forms which the metallic envelope may take are described, and in Fig. I we indicate it to be in this case a perforated metallized tape 5. In the practice of our invention the cable may or may not possess such a metallic envelope.

Fig. I shows one end of a factory length of cable constituting one member of a joint. The sealed end of the length has been opened and has been prepared for jointing by the cutting away of insulation 12, metallic envelope 5, and sheath 4 to successively greater distances, leaving the conductor 13 at the end of the cable length exposed. The end of the cable length is capped with a cap through which electrical continuity with the exposed conductor end is established. The conductor is, it will be understood, electrically united within the joint casing through a copper thimble 15 with the conductor end of the adjacent cable length, and the capped and united ends of the two cable lengths are immediately surrounded within the joint casing by insulating and strain-distributing structures. The joint casing 1 at its ends is shaped and mechanically united to the lead sheath in suitable manner, as by the wiped joint 3.

The thimble is secured in suitable manner upon the end of the conductor, and if the conductor be stranded, it forms an oil-tight closure upon the end of the conductor. In this instance the thimble 15 may be understood to be soldered to place upon the hollow, stranded conductor. In the course of installation the end of the cable length, after having preferably been brought to vertical position, is opened, and preferably no more than two or three inches of sheath and insulation are initially cut away. A plug 22 is driven into the core space, the thimble is brought to position, and the soldering operation performed. The molten solder will not only effect electrical union of the thimble to the conductor, it will close the core space and so will form with the thimble an oil-tight closure upon the conductor end.

The cap upon the end of the cable length comprises a rigid tube 8 of insulation, surrounding at a narrow interval the body of cable insulation 12 where that body has by the cutting away of the metallized envelope 5 and of the lead sheath 4 been uncovered. The tube 8 is connected in oil-tight union to the cable sheath 4 by means of a bushing 6, conveniently of brass, the form of connection of tube to bushing and of bushing to cable sheath being such as may be found preferable. In the structure illustrated the tube makes frictional engagement with the bushing, and the bushing makes screw-threaded engagement with the cable sheath. It will be understood that if the brass bushing be provided with an interior threaded surface which tapers slightly, it may be screwed securely to place upon the softer metal of the sheath. The tube 8 is essentially impervious to oil, and it may be formed of wrapped paper impregnated with some synthetic resin condensation product.

The tube 8 at its opposite end is secured in oil-tight union upon the thimble 15, which thimble applied in the manner described constitutes a closure upon the end of the hollow stranded conductor. The thimble 15 and the tube 8 are adjacently screw-threaded, the one over its external, the other over its internal surface. A nut 17 borne externally upon the thimble is, as installation progresses, screwed to position within the end of tube 8, and a nut 18 borne internally by tube 8 is screwed to surface-to-surface abutment upon the previously positioned nut 17, completing the closure. The nuts 17 and 18 are formed of suitable material, and advantageously, though not necessarily, of insulating material.

After the thimble 15 has in the manner described been soldered to place, the end of the cable length already opened may be closed again temporarily by a rubber cap, and may then be immersed in oil. The temporary cap may then be removed, and the further cutting away, if any, of sheath and of metallic envelope, and the assembly upon the end of the cable length of the cap, consisting of bushing 6, tube 8, and nuts 17 and 18, may be effected under oil. The capped end of the cable length may then be removed from immersion.

Alternatively, under particular conditions of fluidity of oil and penetrability of paper, the whole operation of opening the end of the cable length, securing the thimble to the conductor, and capping, may be performed in the open air, the end of the cable length being preferably maintained meanwhile in vertical position. There will be no appreciable loss of oil. And, after bushing 6 and tube 8 have been applied, and before closure has been effected by nuts 17 and 18, oil may be poured into the open tube, filling all spaces within the tube.

Again, the cable being a hollow-cored cable, the cable end may be opened, and then a delivery pipe from a source of oil under pressure may be introduced into the central hollow, and made snug, as the experienced workman will make it. Further joint-building operations may then proceed, with replenishment through the introduced pipe of such oil as may ooze from the exposed body of insulation.

Again, alternatively, the whole operation, including the initial opening of the cable end, may be performed under oil, with the modification that the thimble will be secured by other means than soldering, to effect electrical union upon the end of the conductor, and, if need be, oil-tight closure as well.

The opening under oil of the end of a length of oil-filled cable and the application under oil of fittings upon the opened cable end will be found to be described in U. S. Letters Patent No. 1,613,910, granted January 11, 1927, on the application of Donald M. Simons.

If the insulated conductor be covered with a metallized envelope (as is true of the cable chosen for illustration) the metallization will in the preparation of the end of the cable length for capping, be cut back so far that in the ultimate assembly it will terminate within bushing 6. This is indicated in Fig. I.

When the adjacent ends of two lengths of cable which are to be united have been capped, the thimbles 15 of the two lengths may be united electrically. Fig. I shows a connecting sleeve 16 as the means to that end. It may be understood that the thimbles 15 upon the adjacent ends of the two cable lengths are threaded oppositely, and that the sleeve 16 is interiorly threaded in like manner, with oppositely directed threads at

its two ends. Then, after the manner of a turnbuckle, rotation of the sleeve will cause it to advance upon and to make mechanical and electrical union upon the two thimbles simultaneously.

Through the cap upon the end of the cable length and conveniently through the bushing 6 an orifice or orifices 37 may be formed, opening communication with the interior. A ring 7, conveniently of brass, and properly orificed is rotatable upon bushing 6, alternately to close and to open the orifices 37. In making installation a window may be cut in the joint casing at a point adjacent the ring, and when the joint has been assembled and the sleeve has been applied and filled with oil to a level submerging the capped cable end, the band may be turned from the closed position thitherto maintained, to open position, and thus communication may be established between the body of oil which fills the cable length and the body which fills the joint casing. The ring 7 may be secured in opened position. The window in the joint casing may then be closed, and, the joint casing being completely filled with oil, it may be closed.

The union so effected and enclosed within the casing 1 is made secure against breakdown by insulation and preferably by stress-distributing means. The caps upon the two ends of the cable lengths consist, as has been explained, essentially of tubes 8 of insulating material secured at the ends in oil-tight union upon cable sheath and conductor. These tubes are encircled by successions of spaced-apart bands of conducting material; impedances are arranged between successive bands, and the impedances are such in absolute and in relative values as to effect proper distribution of strain. The impedances in turn are surrounded within the joint casing by tubes of insulation; and, precisely as the tubes 8 are encircled externally by bands of conducting material, the tubes last mentioned are encircled internally by bands of conducting material; and the impedances serve to distribute stress longitudially over both tubes. The minute structure in preferred form is shown in Fig. II.

In Fig. II the tube 8 is fragmentarily shown, surrounding the cable insulation 12, and an outer tube 11 of insulation is fragmentarily shown, within the joint casing 1. Between the tubes 8 and 11 the stress-distributing means are arranged. These means include bands 23 of metal, encircling exteriorly the tube 8, and insulated in succession one from another; bands 24 of metal, encircling interiorly the tube 11, and also insulated in succession one from another, and impedances in the form of condensers arranged between the bands. The structure of Fig. II is suited to conditions of production and installation in that a pair of bands, an inner and an outer, is made up as a unit with a condenser, and is capable of being handled and applied as a unit.

A band 23 and a band 24 may be formed in one piece with an intervening and connecting annulus, the whole constituting an element approximately Z shaped in cross-section. The connecting annulus 25 is provided intermediate its extent with a right-angled offset, of a depth corresponding to the thickness of two facing layers 26 and 27 of insulation which cover exteriorly the two bands 23 and 24 and adjacent portions of annulus 25. Within the rim afforded by the outer band 24 the condenser unit is built. It includes alternate metallic plates 28 and 29 separated by plates of dielectric, the plates 28 at their outer edges being electrically continuous with band 24, and the plates 29 at their inner edges adapted in the assembly to come to electric continuity with the inner band 23 of the next adjacent unit.

The succession of units arranged as shown in Fig. II is held as shown in Fig. I between a flange upon brass bushing 6 at one end and a metallic washer 21 at the other end and the whole is secured by a washer 19 pinned to tube 8. Through the flanges upon bushings 6 the bands 24 at the remoter ends of the assembly are electrically united with the cable sheath; through pairs of semi-annular contact pieces 20 the bands 23 at the proximate ends of the two series when assembled are electrically united with connector 16 and through it with the cable conductor. It will be understood that in Fig. I half of a complete joint is shown, and that in the complete joint the structure shown is duplicated, but in opposite arrangement. By the provision of the tubes 8 and 11 of insulation, and by the bands 23, 24, and the impedances, the union of the conductors within the joint casing may be protected; the stress may be distributed with substantial uniformity along the joint; and breakdown is prevented. All spaces within the joint casing are eventually filled with oil.

In Fig. II the outer tube 11 is indicated to be of uniform structure throughout, and may be understood to be formed of rolled paper filled with oil. In Fig. I the tube consists of an inner relatively thin portion 10 and an outer portion to which the numeral 11 is immediately applied. The inner portion 10 may be understood to be a rigid molded sleeve and the outer portion 11 a wrapped-on and fluid filled body of porous material. As will be apparent, the compound tube of Fig. I is, in part if not in its entirety, preformed and applied as a preformed member; the uniform tube of Fig. II may be wrapped in place in the field.

The jointing of a multi-conductor cable in the practice of this invention is illustrated in Fig. VIII. The joint casing is made up of the sleeve 1 and of bells 35, formed like the sleeve preferably of metal. The bells are secured to the sleeve 1 and at their remote ends to the cable sheath. Manifestly the sleeve might surround and extend beyond the bell and be secured immediately to the cable sheath. Within the bell the individually insulated conductors 12 are spread. The bell has a base plate 36 with flanged orifices, through which the insulated conductors 12 extend and in these orifices the tubes 8 may be seated. With these qualifications the structure and the procedure in joint building are such as have been described. Careful consideration of Fig. VIII will make plain the fact that the joint casing must be a little more than half again as long as that required for the single-conductor cable, unless the sleeves 11 of insulation be built in situ. This necessity rises from the fact that there must be sufficient straight-away extent of each separated conductor to permit of the slipping aside of the sleeve of insulation 11 to allow electrical connection to be made, after which the sleeve is brought to its permanent position, covering the whole. The tubes 8 upon the ends of the cable lengths to one side of the union—those to the right, Fig. VIII—are correspondingly lengthened. The stress-distributing structure may be brought to position as the drawings show, spaced at an interval from the bell 35 on the right. Electrical

connection will, however, be established, as is diagrammatically indicated at 38. The cable end may be opened, the conductors spread, and the bell 35 applied under oil and capped with tubes 8, and in such case the union of the bell upon the cable sheath may be by a mechanically secured stuffing box.

In installation successive factory lengths of cable are united by joints such as that described. At its ends the installed cable is equipped with terminal structures, to protect the cable conductors there exposed for union with aerial lines or with such other conductors as circumstances may require. As seen in Figs. IV and V the terminal includes, within a casing 30, to which the cable sheath 4 is secured, a sleeve 31 of insulation surrounding the cable insulation 12, where, by the cutting away of the sheath 4, it has been exposed. This sleeve is conveniently a preformed rigid tube of coiled paper, filled with a phenol condensation product. The sleeve 31 is encircled by a succession of belts 32 of conducting material, and between successive belts impedances, conveniently in the form of condensers 33, are arranged. The structure is more minutely illustrated in Fig. V, where the belts 32 with their condensers 33 are shown to be built into units, adapted to be applied each as an integer in making assembly. The alternate plates of each unit are connected in groups, and the successive units are electrically connected in series between cable sheath 4 and conductor 13. Each unit is wrapped in insulation 34, and is thus insulated from adjacent units. These condensers are of such actual and relative size as to afford proper distribution of electrical stress as between grounded sheath 4 and exposed conductor 13. In the completed assembly the terminal casing 30 will be filled with and the details of structure which have been described will be immersed in oil. Such a terminal of adequate electrical strength for the intended high-tension service may be built within reasonable dimensions.

It will be observed of the units for the terminal that they differ from the units for the joint. Bands 32, which encircle the tube 31, and which correspond to the bands 23 of the joint, are present; but there are no bands corresponding to the bands 24 of the joint. This is because the casing of the terminal, unlike the casing of the joint, may be made essentially of insulating material, and there is no region of high radial stress tending to break down, except that adjacent to tube 31.

A complete installation is diagrammatically illustrated in Fig. VI. The cable consists of factory lengths 4, united length to length in joints 1, and at the ends of the line introduced into terminals 30. By joints formed in the manner described flow of oil through the cable from length to length may be prevented. This is desirable, to the end that, in case of escape of oil from one section, due perhaps to failure of the retaining sheath, the danger to further injury may be limited to that section or cable length. The body of oil within the cable, or the several bodies of oil within the lengths which make up the cable, are brought into communication with an external source or with corresponding external sources of oil supply, to the end that as in service the body or bodies of oil within the cable expand and contract, there may be flow of oil out from and into the cable and a consequent saving of the cable from deterioration. In Fig. VI a reservoir 40 for oil is shown, which may be brought into communication with a joint casing 1; and it will be perceived that, if one of the caps upon the ends of the cable lengths within the joint casing be ported in the manner described, the body of oil within that factory length of cable may be brought into communication with and indeed into continuity with the body of oil within the reservoir.

In Fig. I an orifice 2 in the joint casing will be noted, through which communication may be established with such external source of oil supply.

In order to segregate the body of oil and to prevent ingress of air or moisture, the reservoir may be a closed chamber and may be completely filled with oil, and provision for the desired migration of oil may be made by making the walls of the reservoir expansible and contractible. The body of oil so segregated may and advantageously will be maintained under pressure. In the form of reservoir specifically shown in Fig. VI expansibility and collapsibility of wall and provision for maintenance of pressure are achieved by arranging within a rigid-walled chamber 40, a chamber 41 with expansible and collapsible walls,—a chamber formed of a length of sylphon tube. Chamber 40 is filled with oil, chamber 41 with air. The pressure at which the body of air within chamber 41 is maintained may be such as is desired. In the expansion and contraction of the body of oil, the chamber 41 then serves as a cushion.

Preferably, though not necessarily, each factory length is, with respect to its contained body of oil, segregated from the lengths immediately adjacent. In each joint of the installation one factory length may by its cap be closed, and the cap will constitute a barrier, to prevent immediate oil communication from length to length of the cable. If the end of the other factory length within the joint has not been capped, the oil within it will form one body with the oil which fills the joint casing, and with this body the external oil supply will be in immediate communication, and within the cable length so arranged the integrity of the body of oil will at all times by these means be maintained. If both the cable-ends within the joint be capped, and one or both of the lengths are to be fed through this joint casing then an opening or openings must be provided through one or both of the caps, through which to establish communication with the oil supply. Two factory lengths united within a joint casing may at their remote ends be closed by impervious caps, and at their adjacent ends be in communication, both of them with the interior of the joint casing in which they are united, and so in communication one with another. We prefer, however, as we have said, to isolate each factory length from adjacent lengths.

The supply of oil within each isolated portion of the system may be maintained, and procedures for maintaining the supply may be various, according to the conditions of installation. A structure adapted to make effective one or another particular procedure is shown in Fig. VI. As here indicated, an installation ordinarily includes a plurality of joints 1, and, an oil reservoir 40 may be provided for each joint, with a suitable pipe connection between reservoir and joint casing. An oil pipe 42 is shown, extending throughout the length of the installation, and communications are indicated extending between pipe 42 and each of the reservoirs 40, and between pipe 42 and each of the joint casings.

Each line of communication, between reservoir and joint casing, between oil pipe and reservoir, and between oil pipe and joint casing, is provided with a manually controlled cut-off valve **43**. If communication between reservoirs and joint casings be open and communication between oil pipe and joint casings be closed, each reservoir will serve a joint casing. If, in addition, oil pipe **42** be in communication with a more remote oil supply under pressure, then, controlled by the valves in the lines of communication, the oil pipe may be employed as a feed pipe, to maintain in the reservoirs severally their desired volumes of oil under pressure. If, on the other hand, communications between reservoirs and joint casings be closed and communication between oil pipe and joint casing be open, then the joint casings will be fed immediately from the oil pipe. Then, by opening the valves in the lines of communication between oil pipe and reservoirs, one or more of the reservoirs may be caused to serve the oil pipe and maintain it at all times filled with oil under pressure.

Similarly as the supplies of oil in the reservoirs may be maintained by oil pipe **42** serving as a feed pipe, the supplies of air (or other gas) under pressure may be maintained in air chambers **41** by an air feed pipe **44**, with valve controlled communication to the several air chambers. And in such cas oil pressure may be maintained either through oil pipe **42** or through air pipe **44** or through both.

In Fig. VI the positions of certain valves are diagrammatically indicated at **45**, situated in the lines connecting the cable lengths with their common source of oil supply, in this case the pipe **42**. It will be apparent that the valves here alluded to, might alternatively be introduced in the pipe leading from the reservoir **40** to the joint casing **1**. In Fig. VII the valve structure is indicated. Within the chest **45** a partition **52** extends, dividing the space within the chest into inner and outer chambers. The oil supply has access to the outer chamber; with the inner the cable is in communication. In the partition two orifices are formed; one of these orifices is controlled by two valves, **49** and **46**; the other by the single valve **53**. The outwardly opening valve **49** backed by spring **50** is a simple check valve, so arranged as to permit flow through the partition **52** only from the inner to the outer chamber; that is, from the cable toward the reservoir. The inwardly opening valve element **46** is a sliding piston. In its normal position this piston blocks the orifice **51**, through the partition, thus preventing any exchange of oil through the orifice. The element **46** is borne by a diaphragm **47** which forms one end of a small chamber, arranged within but closed from the inner chamber of the valve chest, but communicating with the air as shown. A spring **48** tends to raise the diaphragm and to hold the valve **46** to its seat, closing the orifice **51**.

In case the pressure upon the oil within the cable and consequently in the inner chamber of the valve chest, increases above a predetermined value, the diaphragm is depressed, the valve **46** unseated. If the pressure in the outer chamber of the valve chest is then less than that in the inner chamber, the valve **49** is raised, permitting oil to flow from the inner chamber of the chest and from the cable, until the pressure difference is equalized.

The valve element **53**, normally held by a spring **55** to a closed position, opens when the pressure in the outer chamber of the valve chest exceeds that in the inner chamber. In general, it is not required nor desirable that oil flow rapidly into the cable. The orifice then which is controlled by the valve **53** may be made small, or the opening may be covered by porous material, which will permit the flow of oil but only at a low rate. The drawings show a cage **54** filled with such material (it may be glass wool or cotton waste) and serving the end indicated.

If two successive factory lengths, jointed in such manner that there is no direct oil communication from one to the other, be fed from a common source (as from the oil pipe **42**, Fig. VI); or if two lengths of cable which are parts of different lines be fed within one manhole from the same source (an arrangement which will be recognized to be entirely feasible), there would, but for the preventive device indicated at **45**, be oil communication through the source from one length to another. In normal operation of the cable the movement of oil between cable and source is slow, but under abnormal conditions a tendency to rapid movement may be brought about. If, for instance, there be sudden increase of electric current, due to short circuit, the cable may heat rapidly, and there may be a sudden and relatively great increase of pressure within the cable length. If, again, a section fails,—if a hole should be blown in the cable sheath at a particular point,—there will (in the absence of preventive means) be great and rapid flow from reservoir or feed pipe to cable. In the case of such great and rapid flow from source to cable, the tendency would arise for an adjacent and sound cable length to drain, in response to the drain upon the source of supply. Given, however, the arrangement of Fig. VII, these valve openings will be so controlled as to permit desirable movement of oil and to prevent undesirable movement. In case of an increase in pressure of the oil in the cable due to any cause as by increased load, either slow or rapid, the diaphragm **47** is depressed against the spring **48** throwing the piston **46** and opening the orifice **51**. The amount of pressure required to open the orifice is governed by the proportioning of the strength of spring **48** to the area of the piston **47**. The pressure within the outer chamber of the valve chest will be maintained by the reservoirs or supply line at a value which is suited to the cable and, when the pressure in the cable exceeds the pressure in the reservoirs, the valve **49** is lifted, to relieve the excess.

If the pressure in the outer chamber of the valve chest falls below the pressure which it is desired to maintain in the cable and for which the adjustment of the parts **47** and **48** is made, the valve will be closed by the return of the piston **46** to its seat, and further loss of pressure of the oil in the cable will be stopped. In this way, a break in the supply line or in the sheath of another section of cable, cannot cause drainage from undamaged sections of cable, or cannot even cause reduction of pressure in such undamaged sections below that for which the valve is set.

At any time that the pressure of the oil in the cable is lower than that in the reservoir or supply, the valve **53** is forced from its seat, permitting flow from the reservoir into the cable. This flow is controlled at a lowe rate by the small size of the opening or by the porous material covering it. This flow is at a controlled, low rate to the end that the reservoir or supply may not be

drained rapidly by damage to the sheath of a section of the cable. Such restriction of the rate of flow is permissible, since the rate of inward flow required will never be great when the sheath of the section is not perforated by a considerable opening, such as would quickly drain the reservoir or supply except for the restriction of rate of flow.

If oil under pressure be piped from a central point, it may be maintained at constant pressure by means known to the art; by means of a hydrostatic column, for example, which may be open above or capped by a closed length of sylphon tube; or, it may be, by means of a motor operated pump. The actual value of the pressure may then be regulated, either by regulation of the torque of the motor, or by means of a by-pass around the pump, set to open when a critical pressure has been attained. In such case without diminution of motor speed a constant pressure may be maintained.

Each cable length as it comes from the factory will be lead-covered, oil-filled, and sealed at the ends. The factory lengths will be shipped on reels. Inasmuch as each length is tested before it leaves the factory, and inasmuch as for testing purposes the length must be provided at the ends with terminal structures, it may be found convenient to build in the factory upon each end of a cable length a half joint such as that shown in Fig. I, to serve in the factory as a terminal for test purposes, and to serve eventually in the field as part of a joint structure. An incidental advantage of such procedure will be this, that the joint structure to that extent, as well as the cable length, will have been subjected to factory test. Before shipment, and in order that in installation the length of cable may be drawn through a conduit, one of the half joint structures will be cut away and the cut end sealed in the usual manner. When the length has been brought to position the half joint structure may be reapplied. The half joint structure remaining on the cable may be partially disassembled for practical convenience in shipping, but in any case the structure will be protected from injury in shipment and will eventually serve in the installation as part of the joint or terminal structure.

Preferably, even while on the reel and in shipment, each length of cable will have in communication with it an oil reservoir, expansible and contractible in size; a reservoir, for example, whose walls are formed of a length of sylphon tube, so as to allow the body of oil which fills the cable structure to expand and contract under changing conditions, as of temperature, without injury to the cable.

In making installation, the individual factory lengths of cable are pulled into ducts from manhole to manhole, ready for jointing. The extremities at the ends of the cable system are provided with terminals beyond which the line may continue, perhaps in air, perhaps in such connecting apparatus as a transformer or a switch.

In making installation, and particularly when opening and capping the ends of the factory lengths, special provision must be made if the difference of elevation between the two ends of a length be very great. In such case, if it be the lower end which is opened, the oil will tend to flow from the cable, and if the difference in elevation be great enough (about forty feet) oil will flow out and a barometric vacuum will be formed in the higher end of the cable length. This condition may be met by the provision of an oil reservoir, brought into communication with the cable length at its upper end. Oil may be allowed to pass from the reservoir into the cable length after the cable length at its lower end has been opened and capped, and then the vacuum which has been created in the upper end of the cable length will be occupied by entering oil; and the insulation, to the extent that it had been emptied of oil, will be reimpregnated. Alternatively and preferably, the oil reservoir will be in open communication with the cable length throughout the operation of opening and capping the farther, lower end. In such case, if the cable be a hollow-core cable, or if it be provided with oil channels immediately beneath or in the sheath, these larger spaces may be more or less completely blocked, for the purpose of minimizing the bleeding from the lower end of the cable.

In the completed installation, if a cable length lies with one end at a higher level than the other, and particularly if the difference in level should exceed the height of a barometric column of the oil employed, it is preferable that communication with the oil supply be at the higher end.

We claim as our invention:

1. The method herein described of preparing a length of oil-filled cable for inclusion in an electric circuit which consists in cutting away a short portion of the sheath and a co-extensive portion of the envelope of insulation at the end of the cable length to expose the end of the conductor, applying a connector closure to the conductor end, removing a further portion of the sheath, and applying over the exposed insulation at the cable end and in oil-tight union with the cable sheath and the connector a cap of insulating material impenetrable to oil, all while maintaining the integrity of the fluid insulation within the cable.

2. The method herein described of preparing a length of oil-filled cable for inclusion in an electric circuit which consists in first bringing another body of oil into continuity with the body of oil within the cable and then opening the cable end, cutting back the envelope of insulation and the cable sheath from the conductor end, and effecting oil-tight closure over the end of the envelope of insulation, leaving the conductor end electrically accessible beyond such closure.

3. The method herein described of installing an oil-filled cable which consists in applying to the adjacent ends of two lengths of oil-filled cable and uniting to the cut-away ends of the sheaths oil-filled caps, through which caps means extend for establishing electrical continuity with the cable conductors, uniting the said means with which the adjacent ends of the two lengths are equipped, and forming joint structures upon the adjacent ends of the two lengths and around the union of the conductors, all while maintaining the integrity of the fluid insulation within the cable.

4. The method herein described of dealing with an oil-filled cable which consists in opening one end of the cable under oil, cutting back the sheath and the insulation, and applying to the opened cable end and around the conductor end, while still under oil, an insulating closure through which closure the conductor is electrically accessible, and while maintaining such closure in place effecting electrical union of the conductor with a companion conductor external to the cable.

5. The method herein described of making con-

nection with a length of oil-filled cable which consists in cutting away short portions of the sheath and insulation to expose the conductor end, uniting upon the so exposed conductor end a connecting device, capping the cable end, immersing the cable end in oil, removing under oil the cap previously applied, cutting away under oil to greater distance the cable sheath, recapping the cable end under oil with an insulating cap through which the conductor is electrically accessible, removing the cable end from immersion in oil, and completing through such cap electrical union with another conductor.

6. In an oil-filled cable installation and in combination with a length of cable, a source of oil under pressure in communication with such length of cable, a barrier provided with two orifices controlling such communication, an inwardly opening check valve controlling one of said orifices, an outwardly opening check valve and an inwardly opening valve both controlling the other of said orifices, and means operating in response to increase of pressure upon the oil within the length of cable and adapted to unseat said inwardly opening valve.

7. A factory fabricated length of oil-filled cable sealed at its ends ready for test and shipment to the point of ultimate installation, the sealing structure at one end including a tube of insulation having oil-tight connection at its ends to the cable conductor and the cable sheath, and a series of impedance units arranged in succession externally of said tube for distributing electrical stress substantially uniformly longitudinally along the tube from end to end when a difference of potential exists between the cable conductor and the cable sheath, the said tube and impedance units entering into the make-up of a terminal for testing the cable length in the factory and also entering into the make-up of a joint for the cable length in its ultimate installation without reopening the cable end subsequent to the factory test.

8. An oil-filled cable installation including at least two connected lengths of cable whose contained bodies of oil are segregated against direct passage of oil from one to another, an external source of oil under pressure, separate pipes connecting said external source of oil with the bodies of oil-filled insulation within each of the said cable lengths for normally supplying oil to the cable lengths, and a valve arranged in each of said pipes opening in response to an increase in pressure in excess of a predetermined value in the connected cable length due to expansion of the oil therein to permit a return flow of oil outwardly from the cable length through the pipe to the common external source of oil.

9. An oil-filled cable installation including at least two connected lengths of cable whose contained bodies of oil are segregated against direct passage of oil from one to another, an external source of oil under pressure, separate pipes connecting said external source of oil with the bodies of oil-filled insulation within each of the said cable lengths for normally supplying oil to the cable lengths, and valve means arranged in each of said pipes opening in response to a decrease in pressure in the connected cable length below the pressure in the common external source of oil due to contraction of the oil therein to permit a limited flow of oil inwardly to the cable length through the pipe from the common external source of oil, and also opening in response to an increase in pressure in excess of a predetermined value in the connected cable length due to expansion of the oil therein to permit a return flow of oil outwardly from the cable length through the pipe to the common external source of oil.

10. An oil-filled cable installation including at least two connected lengths of cable whose contained bodies of oil are segregated against direct passage of oil from one to another, an external source of oil under pressure, separate pipes connecting said external source of oil with the bodies of oil-filled insulation within each of the said cable lengths for normally supplying oil to the cable lengths, and a valve arranged in each of said pipes closing in response to a decrease in pressure in the common external source of oil below the pressure in the connected cable length due to failure of the oil pressure of said source to prevent flow of oil outwardly of the cable length through the pipe to the common external source of oil.

11. An oil-filled cable installation including at least two connected lengths of cable whose contained bodies of oil are segregated against direct passage of oil from one to another, an external source of oil under pressure, separate pipes connecting said external source of oil with the bodies of oil-filled insuluation within each of the said cable lengths for normally supplying oil to the cable lengths, and valve means arranged in each of said pipes closing in response to a decrease in pressure in the common external source of oil below the pressure in the connected cable length to prevent flow of oil outwardly of the cable length through the pipe to the common external source of oil, and opening in response to an increase in pressure in excess of a predetermined value in the connected cable length due to expansion of the oil therein to permit a return flow of oil outwardly from the cable length through the pipe to the common external source of oil.

12. An oil-filled cable installation including at least two connected lengths of cable whose contained bodies of oil are segregated against direct passage of oil from one to another, an external source of oil under pressure, separate pipes connecting said external source of oil with the bodies of oil-filled insulation within each of the said cable lengths for normally supplying oil to the cable lengths, and valve means arranged in each of said pipes opening in response to a decrease in pressure in the connected cable length below the pressure in the common external source of oil to permit a limited flow of oil from said external source through the pipe inwardly to the cable length, and closing in response to a decrease in pressure in the said external source below the pressure in the connected cable length to prevent a flow of oil outwardly of the cable length through the pipe to the said external source, and also opening in response to an increase in pressure in excess of a predetermined value in the connected cable length due to expansion of the oil therein to permit a return flow of oil outwardly from the cable length through the pipe to the common external source of oil.

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