THIN PAPER INSULATED ELECTRIC CABLE

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Fig. 1.

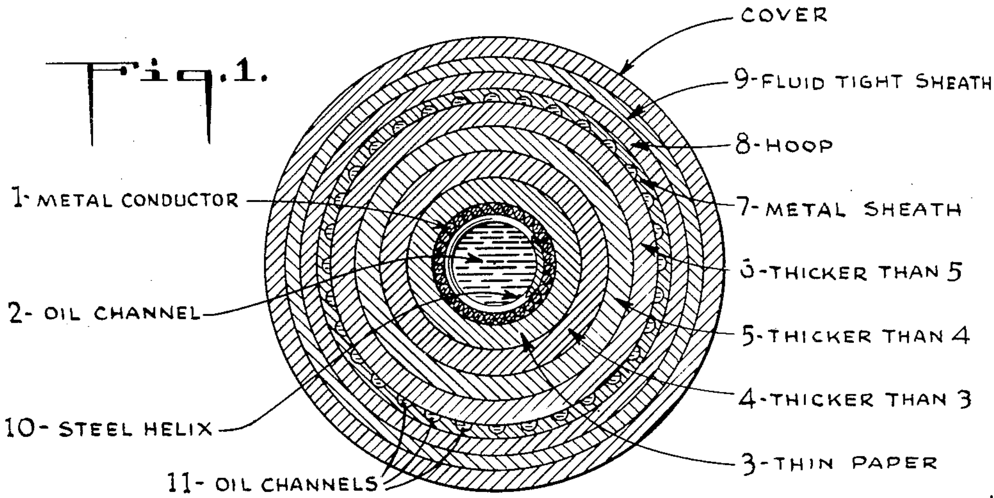
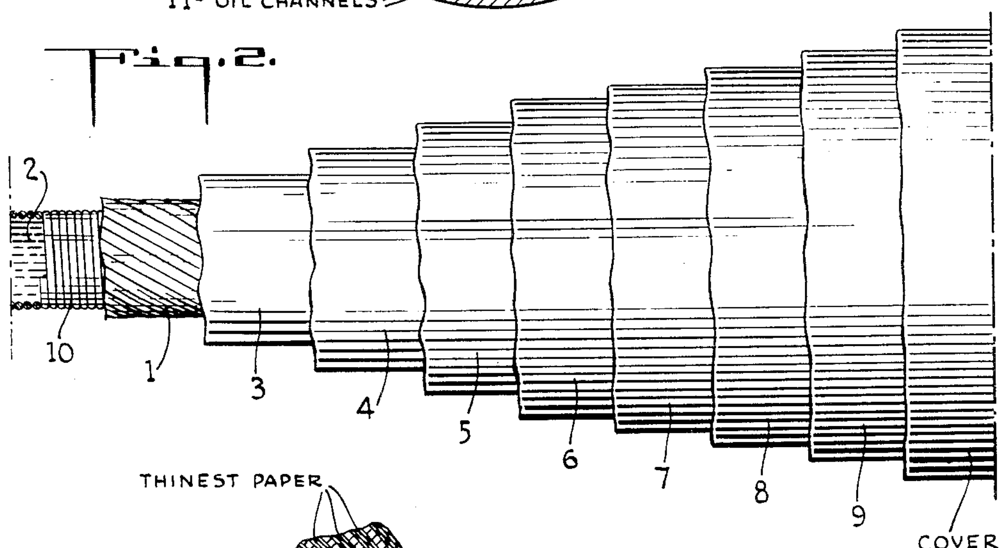


Fig. 2.



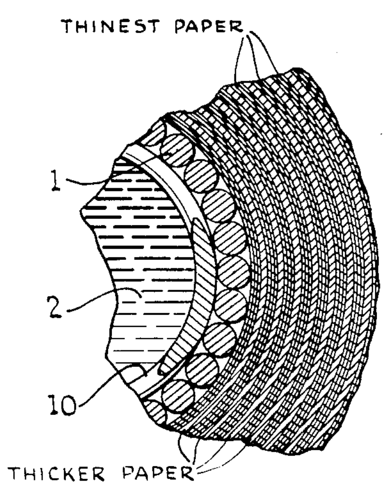


Fig. 3.

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THIN PAPER INSULATED ELECTRIC CABLE

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12 Claims. (Cl. 174—25)

Our invention relates to electric cables for high voltages of the type obtained by winding strips of impregnated insulating paper or a number of layers thereof round the conductor member.

It is a well known fact that for a predetermined thickness of the insulation, its disruptive strength increases considerably with the number of paper layers and that consequently it is desirable in order to reduce the thickness of the insulation of an electric cable, to use paper sheets as thin as possible. However there is a limit, from this standpoint, due to the fact that it is necessary to avoid at the moment of the making of the cable and of its laying, the breaks and tears of the paper material arising through the mechanical stresses to which the paper is submitted at such moments. Thus it has not been possible to use heretofore in the manufacture of high voltage cables, paper the thickness of which is less than 5 to 6 hundredths of a millimeter.

It has been attempted, it is true, to use thinner papers by using multi-folio paper constituted by the superposition of a plurality of elementary thin sheets assembled through glueing. Such special paper has however not been capable of application heretofore, in the case of high voltages as it forms gaps or out of register irregular portions of considerable thickness which reduce considerably the dielectric resistance of the cable by reason of the breaking gradients growing weaker in a gap when the thickness of this gap is greater.

Our present invention removes these drawbacks. It is based on the fact that for a given radius of curvature the tensile stresses which have a tendency of producing tears breadthwise are smaller when the breadth of the strips is smaller. As to the transverse stresses which produce longitudinal tears by reason of the elongation of the outer fibres of the cable, it is apparent that the sliding of the strips over one another under the action of a common transverse tensile stress becomes more and more easy when the surface through which the strips engage one another is more reduced, whereby the tearing of the thin paper under the action of transverse stresses may also be avoided through the use of narrow paper strips.

Our invention has thus for its object to provide electric cables for high voltages, which cables are insulated with impregnated paper the strips of which are wound so as to form a number of layers round the cable conductors. The cables according to our invention are provided with insulating material constituted at least in the vicinity of the conductors of thin paper strips the thickness of which is equal to or less than 0.04 millimeter, said strips being cut in small widths in order to avoid or at least to reduce the risks of tearing.

Taking into account the properties of thin paper as manufactured today, the latter condition is satisfied when the strips have a width equal to or less than 14 mms. On the other hand we have found that the narrowness of the strips is not detrimental to the dielectric properties of the insulation in contradistinction to conventional design, as long as the breadth of the strips is sufficient for avoiding in practice the superposition of two gaps. Experience has shown as a matter of fact that the limit of the resistance of the insulation to puncturing is defined by the break down strength of the gap which is the thickest, considered alone, whatever may be the number of gaps. With the machines normally used for cable winding purposes, the minimum breadth required for practically avoiding the superposition of the gaps is of the magnitude of 7 mms.

Consequently, in the present state of the art, the breadth of the strips will be chosen in accordance with our invention preferably between 7 and 14 mms.

Our invention has particularly for its object, cables insulated by means of paper impregnated with viscous material or fluid oil, and it is particularly applicable in the case of cables the insulation of which is maintained under the pressure either through the action of a compressed gas contained inside the fluid-tight sheath and forming part of the dielectric material, or else through the action of a compressed gas on the outside of the fluid-tight sheath, or again by means of oil communicating with the channels inside the cables as in the case of cables containing fluid oil.

Our invention produces thus complementary possibilities which are of particular importance. It is a known fact that it is possible to considerably increase the dielectric strength of cables under alternating voltages at commercial frequencies by submitting their insulation to increasing fluid pressures. But this increase in the pressure increases only very little the strength to surges, whereby it has not been possible heretofore to make use of the improvement of the gradient of the breakdown potential at commercial frequencies for increasing the gradient of the working voltage of the cables under service voltage and reducing thereby the thickness of the insulation, without reducing the safety coefficient with reference to voltage rises due to surges. Now we have found that the use of thin paper considerably increases the electric strength of the insulation to surges. This considerable improvement of the safety coefficient with reference to voltage rises allows the application for the service gradient at commercial frequencies of the improvements provided by the application of increasing pressures at such frequencies, and provides therefore a reduction in the thickness of the insulation which has been unsuccessfully sought for heretofore by attempting merely an increase in service pressure of fluid.

Starting from the above considerations, the relative values of the pressure and of the thicknesses of the paper strips to be chosen, are related to one another by the value required for the safety coefficient of the cable with reference to voltage rises. This coefficient may be expressed as a ratio between the breakdown gradient Gc with reference to the surges and the working gradient g under the service voltage at commercial frequencies, said operating gradient g being itself a fraction of the breaking gradient Gr at usual service frequency.

By increasing the fluid pressure exerted on the insulating material, Gr is considerably increased without any substantial variation of Gc; by reducing the thicknesses of the paper strips which surround the conductor, Gr is slightly increased it is true, but Gc is increased considerably. It is thus apparent that the association of the values of the oil pressure, and of the reduced thickness of the paper strips, allows an increase in the working gradient g of the insulation, while the safety coefficients selected both for dielectric strength against surges and against voltages at commercial frequencies are retained.

Preferably, the cables submitted to oil or gas pressure and including a dielectric material made of thin paper are, in accordance with our invention, submitted to absolute working pressures above 5 kgs. per sq. cm. throughout their length. As a matter of fact, the electric capacity of the insulation per unit length is in our improved cable greater than in any known cables, and the radial circulation leads to a difference in pressure or loss of head which is greater between the conductor and the metal sheath. Thus it is possible to make the cables operate under a working fluid pressure which is at least equal to that required for making up for the loss of head due to the longitudinal and radial circulation of the oil under the worst conditions.

It is generally desirable to choose working pressures of a very high value, between 10 and 20 kgs. per sq. cm. in the case of cables produced in accordance with our invention. The use of these fluid pressures considerably increases the dielectric strength of the cable. The pressure exerted on the insulating material may then vary by a few kilograms per sq. cm. without any undesired result, for instance between 14 and 21 kgs. per sq. cm. for an absolute working pressure of 16 kgs. per sq. cm.:14 kgs. per sq. cm. will be allowed in the case of a sudden release of the load or of a considerable length of pipe between two pressure containers, while 21 is allowed in the case of a short circuit or of a considerable difference in level which will lead in the latter case to a greater spacing between the junction joints. It is sufficient therefore to provide for a binding of the cables resisting 21 kgs. per sq. cm. instead of 16 which will not lead to a substantial increase in expenditure.

The desirability of applying pressures above 20 kgs. per sq. cm. appears doubtful because if the increase of the service frequency breakdown voltage gradient Gr is of a magnitude of 5 to 9 between 1 and 15 kgs. per sq. cm., it is only of a magnitude between 9 and 10.5 between 15 and 30 kgs. per sq. cm.

Returning to the constitution of the paper insulation according to our invention, it should be noticed that it is possible to use throughout the thickness of the insulation, thin papers the thickness of which is equal to or less than 0.04 mms. and which are cut into narrow strips. However in order to reduce to a minimum the use of such costly paper, it is possible in many cases, as well in the case of cables including an insulation made of paper impregnated with viscous material as in the case of cables impregnated with fluid oil, to use narrow strips of thin paper only in the immediate proximity of the conductors and to increase their thickness and also their breadth when the strips are used nearer the outer portions of the cables. These increases in size may be provided in a gradual manner or stepwise.

In the case of cables impregnated with viscous material, said increase in the thickness of the paper should preferably be executed so as to retain a constant ratio between the working gradient in the different layers of insulation and the break-down gradient in the corresponding gaps.

In the case of cables impregnated with fluid oil, the progressive variation in the thickness of the paper will be advantageously provided in a manner such that, taking into account the pressure applied, it may be possible to obtain throughout the thickness of the insulation and for the working gradient thereof, substantially the same safety coefficient with reference to voltage rises of internal and atmospheric origin.

The paper used in the vicinity of the conductor is preferably constituted by paper made with rags of flax paste, cut into sufficiently narrow strips; it is possible to use in usual ribbon winding machines such papers under a thickness of 15 thousandths of a millimeter. It is also possible with greater care, to make use of thinner papers such as those used in the manufacture of condensers and the thickness of which may be as low as about 7 thousandths of a millimeter. Rag papers having a flax paste basis possess the advantage of having a mechanical strength and an elongation which are greater than those of the kraft paper normally used in the case of high voltage cables. Their dielectric losses are also smaller.

When, by increasing the thickness of the paper, it is possible to reach a thickness for which the gradient of working is that of normal paper, we wind over the layer of thin paper made of flax paste, normal kraft paper. By reason of its thickness, the latter does not require possessing mechanical properties as good as those of the thin paper. Its thickness which is first equal to about 4 to 5 hundredths of a millimeter may increase up to 13 to 15 hundredths of a millimeter on the outside of the insulation. The breadth of the thin paper strips in the vicinity of the conductor is advantageously comprised between 7 and 14 millimeters according to the cross-section of the conductors. As in this design the thickness and consequently the mechanical resistance of a strip of paper increases with its distance from the center of the cable, it is possible to increase without any disadvantage the breadth of the strips in the outer parts of the insulation. This is in fact of considerable advantage in order to avoid any disjoining between the paper layers when the cable is being bent, as soon as the total thickness of the insulation reaches about 10 mms.

In certain cases it is possible, in order to lower the cost of the cable and to make the loading of the winding machines easier, to reduce the total amount of thin paper provided hereinabove by using in alternation two or more strips of thin paper and a strip of paper of greater thickness. Thus it is possible to constitute the totality of the insulation of the central portion of the insulation near the conductor, by winding two or three paper strips the thickness of which is of about two hundredths of a millimeter after which a paper strip of a thickness of four hundredths of a millimeter is used, the former being made with a basis of flax paste and the latter with a kraft paste. However there should be at the most a difference in thickness of about two to three hundredths of a millimeter between the paper strips used in alternation, in order to avoid the introduction in the insulation of gaps having too great a thickness, which would reduce to a too considerable extent the dielectric resistance of the cables.

We have shown by way of examples in the accompanying drawing a form of design of a cable operating with fluid oil in accordance with our invention.

In the drawing:

Fig. 1 is a cross-sectional view of the cable; and

Fig. 2 is a perspective view of the cable with the several elements broken away;

Fig. 3 is an enlarged partial sectional view showing a few of the metal conductors of the cable and some of the cable insulating paper nearest to them which is constituted according to the above-described modification in which that portion of the paper is made up of groups of a few layers of the thinnest paper and the groups are separated from one another by layers of thicker paper, the thickness of all of the layers of paper being greatly exaggerated to enable legible showing in cross-section of the relative thicknesses of the layers.

In said drawing, 1 designates the central channel of the cable for the oil while 2 designates the copper or aluminium conductor made of suitably shaped wires assembled together, or else of cylindrical wires wound over a steel helix 10. The thinnest paper ribbons surrounding the conductor are illustrated at 3; the breadth of said strips is comprised between 7 and 14 mms. according to the value of the radius of the conductor. Their thickness is equal to or less than 4 hundredths of a millimeter and they are made of rag paper having flax paste as a basis. As the point considered is further from the conductor, the working gradient is gradually reduced, whereby the thickness of the paper may be rapidly increased while retaining in the layers furthest removed from the conductor 2, the same coefficient of safety for the working gradient as that which exists in close proximity with the conductor.

However in order to avoid a continuous variation of the thickness of the ribbons or strips which would make the manufacture of the cable too difficult, it is possible to increase the thickness of the paper stepwise. Thus we may wind a further layer 4 of strips having a greater thickness, and so on for the layers 5 and 6, the breadths of the ribbons increasing in these latter layers in order to reach values above 14 mms.

The cable is manufactured and impregnated by any known method. The fluidtight sheath of lead or aluminum is shown at 7; over this sheath is applied a hoop 8 for binding same, which hoop is protected in its turn by a fluidtight sheath 9 protected by the usual cover. The pressure required is kept up inside the cable by means of containers of oil under pressure distributed at intervals along the pipe and connected with the inner central channel 1 of the cable through junction joints and terminal boxes.

The central oil channel 1 of the cable may be supplemented or else replaced by peripheral channels 11 provided in any suitable manner at the inner surface of the metal sheath 7 in contact with the impregnated insulating material.

All these channels instead of being filled with oil under pressure may contain a compressed gas acting on the insulation made of impregnated paper according to our invention.

What we claim is:

1. A high voltage electric cable comprising a conductor, an enclosing sheath, and a dielectric layer between said conductor and said sheath, said layer comprising wound narrow strips of thin paper and oil under heavy pressure, said paper being rag paper made with flax paste, and at least near said conductor including a substantial number of strips not exceeding 0.015 millimeter in thickness, and said pressure being substantially in the range of 10 to 20 kilograms per square centimeter.

2. A high voltage electric cable comprising a conductor, an enclosing sheath, and insulation between said conductor and said sheath, said insulation comprising wound narrow strips of thin paper and oil under heavy pressure, at least the layers of said insulation near said conductor being constituted by winding in alternation, first two strips of paper substantially 0.02 millimeter thick, and then one strip of paper substantially 0.04 millimeter thick, and said pressure being substantially in the range of 10 to 20 kilograms per square centimeter.

3. A high voltage electric cable comprising a conductor, an enclosing sheath, and a dielectric layer between said conductor and said sheath, said layer comprising wound narrow strips of thin paper and oil under heavy pressure, said paper being rag paper made with flax paste, and at least near said conductor including a substantial number of strips substantially 0.007 millimeter in thickness, and said pressure being substantially in the range of 10 to 20 kilograms per square centimeter.

4. An insulated electric conductor including an electrically conductive element having insulation surrounding said conductive element, said insulation including paper and oil under pressure, said paper being disposed in a plurality of superposed layers, a plurality of said layers of said paper being thin paper the maximum thickness of which it not substantially in excess of 0.04 millimeter, and a substantial number of said layers of thin paper being adjacent to said conductive element, and said oil pressure being substantially in excess of atmospheric pressure.

5. An insulated electric conductor including an electrically conductive element having insulation surrounding said conductive element, said insulation including paper and oil under pressure, said paper being disposed in a plurality of superposed layers, a plurality of said layers of said paper being thin flax paste paper the maximum

thickness of which is not substantially in excess of 0.04 millimeter, and a substantial number of said layers of thin paper being adjacent to said conductive element, and said oil pressure being substantially in excess of atmospheric pressure.

6. In combination, an insulated conductor including an electrically conductive element and an insulating element surrounding said conductive element, and a liquid-tight enclosure surrounding said elements, said insulating element including paper and oil under pressure, a substantial proportion of said paper being thin paper the maximum thickness of which is not substantially in excess of 0.04 millimeter, and a substantial portion of said thin paper being adjacent to said conductive element, and said oil pressure being substantially in excess of atmospheric pressure.

7. An insulated electric conductor including an electrically conductive element having insulation surrounding said conductive element, said insulation including paper and oil under pressure, said paper being disposed in a plurality of superposed layers, a plurality of said layers of said paper being thin paper the maximum thickness of which is not substantially in excess of 0.04 millimeter, and a substantial number of said layers of thin paper being adjacent to said conductive element, and said oil pressure being substantially within the range of 5 to 20 kilograms per square centimeter.

8. An insulated electric conductor including an electrically conductive element having insulation surrounding said conductive element, said insulation including paper and oil under pressure, said paper being disposed in a plurality of superposed layers, a substantial number of said layers of said paper adjacent said conductive element being thin paper the maximum thickness of which is not substantially in excess of 0.04 millimeter and said layers increasing in thickness in the successive strata from the stratum of layers adjacent said conductive element to the stratum of layers at the outer periphery of said paper insulation, and said oil pressure being substantially in excess of atmospheric pressure.

9. In combination, an insulated electric conductor including an electrically conductive element and an insulating element enclosing said conductive element, and a liquid-tight enclosure surrounding said elements, said insulating element including paper and oil under pressure substantially in excess of atmospheric pressure, said paper including strips of paper wound in layers about the axis of said conductive element, a substantial number of said layers of paper being thin paper the maximum thickness of which is not substantially in excess of 0.04 millimeter and the maximum width of which is not substantially in excess of 14 millimeters, and a plurality of said layers of thin paper being adjacent to said conductive element.

10. In combination, an insulated electric conductor including an electrically conductive element and an insulating element enclosing said conductive element, and a liquid-tight enclosure surrounding said elements, said insulating element including paper and oil under pressure, said paper including narrow strips of paper wound in layers about the axis of said conductive element, a plurality of said layers of paper being thin paper the maximum thickness of which is substantially within the range of 0.007 to 0.04 millimeter and a substantial number of said layers of thin paper being adjacent to said conductive element, and said oil pressure being substantially within the range of approximately 10 to 20 kilograms per square centimeter.

11. An insulated electric conductor including an electrically conductive element having insulation surrounding said conductive element, said insulation including paper and oil under pressure substantially in excess of atmospheric pressure, said paper including a plurality of groups of layers of thin paper which has a thickness not substantially in excess of 0.04 millimeter and layers of substantially thicker paper respectively separating each group of layers of thin paper from its next adjacent groups, at least one such group of layers of thin paper being adjacent to said conductive element.

12. In combination, an insulated electric conductor including an electrically conductive element having an insulating element enclosing said conductive element, a liquid-tight sheath surrounding said elements, and a fluid-tight enclosure surrounding said sheath and containing fluid under a pressure in excess of 5 kilograms per square centimeter, said insulating element including paper impregnated with fluid oil and disposed about the axis of said conductive element in a plurality of layers, a plurality of said layers of said paper being thin paper the maximum thickness of which is not substantially in excess of 0.04 millimeter, and a substantial number of said layers of thin paper being adjacent said conductive element.

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