Aug. 10, 1971 F. PASINI 3,598,691

MULTI-PLY PAPER FOR INSULATING HIGH TENSION ELECTRIC CABLES

Filed March 8, 1968

FIG. 1.

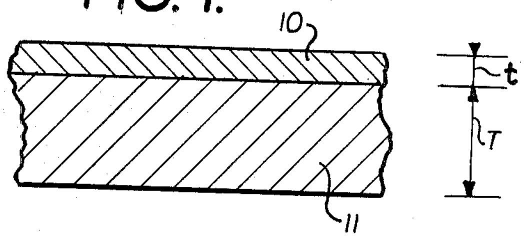


FIG. 2.

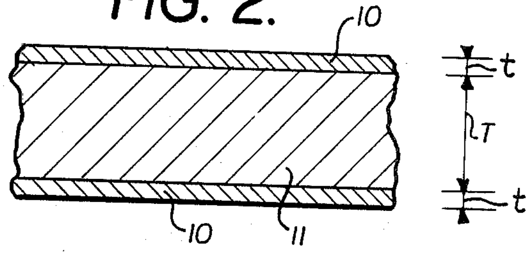


FIG. 3.

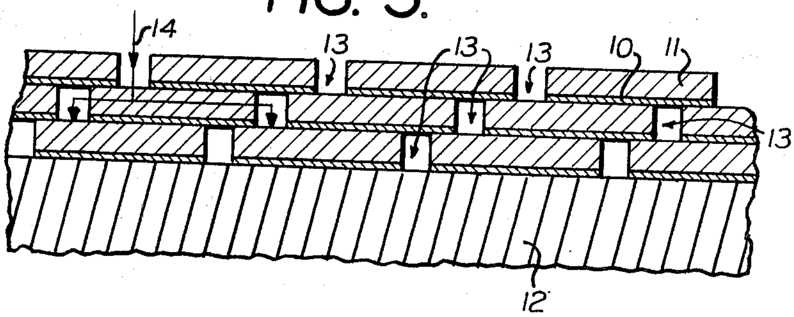
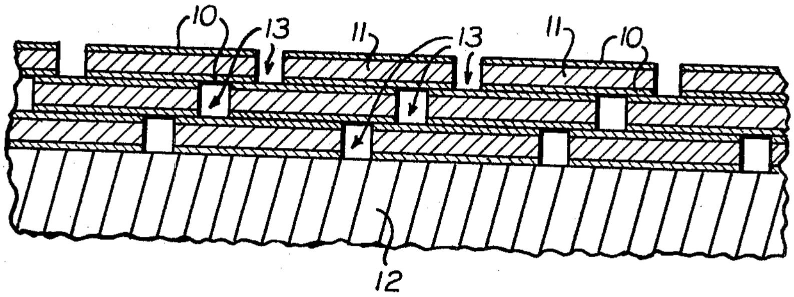


FIG. 4.



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United States Patent Office 3,598,691
Patented Aug. 10, 1971

3,598,691

MULTI-PLY PAPER FOR INSULATING HIGH TENSION ELECTRIC CABLES

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Filed Mar. 8, 1968, Ser. No. 711,582
Claims priority, application Italy, Mar. 25, 1967, 14,189/67
Int. Cl. B32b 7/02
U.S. Cl. 161—166 12 Claims

ABSTRACT OF THE DISCLOSURE

Paper tape for insulating high tension cables is produced with a multi-layer construction. A low density core layer is faced on one or both sides with thin high impermeability layers. The dielectric strength is a function of the latter while the impregnability and loss factor is a function of the former. Also, an electric cable insulated with such a tape is disclosed.

The present invention relates to an improved type of paper suitable for insulating high tension electric cables. More particularly, it relates to paper tape which is helically wrapped about a conductor and thereafter impregnated, and to the cable so insulated.

The present trend to transmit electric energy at ever increasing voltages—over 500 kv.—has created a need for power cables adequately insulated for this purpose. One of the main problems which is encountered in the manufacture of very high voltage cables is the selection of the material to be used for their electric insulation. A good cable insulator must primarily posses: (a) a high dielectric strength (in order to withstand high electric gradients and, therefore, enable cables to be fabricated with reasonable radial dimensions); and (b) a low dielectric loss factor (in order to maintain within tolerable limits the power losses in the dielectric which, the loss factor being constant, increase proportionally with the square of the voltage).

In the case of paper which is to be impregnated, the paper must possess certain additional physical characteristics. For instance, the impermeability of the papers must not be so great as to prevent its becoming completely impregnated by the usual impregnating fluids, such as mineral oils, synthetic fluids or their mixtures. As used herein, the expression "impermeability of the paper" refers to the paper's resistance to the passage of liquid or gaseous fluids. It is a quantity that can be measured and represented in terms of Emanueli units (E.U.). In addition to its impermeability the paper must possess sufficient mechanical strength and the like to permit its application to the conductor by modern wrapping machinery.

To provide insulation that can withstand higher electrical gradients, one might consider the use of thinner papers, thereby employing the known property of such papers that its dielectric strength increases with decreased thickness, all other factors remaining constant. Unfortunately, in order to obtain an appreciable increase in the dielectric strength the paper would have to be made too thin and too weak structurally for satisfactory handling by the wrapping equipment.

A suggested solution to avoid the foregoing disadvantage is described in French Pat. No. 1,404,209. As described therein, thin paper is used and the elementary sheets are joined together at fixed points. In this way it is possible to reach a total thickness value nearly equal to that of the normally used papers, and at the same time to impart to the resultant paper mechanical characteristics sufficient to ensure a correct wrapping operation. A paper

of this type, however, besides requiring a complicated manufacturing process, does not solve the problem of reducing the dielectric loss factor since it is not affected by the variation of the paper thickness.

To obtain high electrical gradients, a further possible solution would be to exploit the fact that the dielectric strength of paper varies in propertion to its impermeability; however, this solution also has limits in its practical application. A paper having very high impermeability would have, in fact, so high a dielectric loss factor that its employment for very high voltage cables would be impossible from a practical standpoint. Moreover, such paper, on account of its considerably high impermeability, could not be totally impregnated when wrapped on the cable conductor in a compact manner.

An object of the present invention is to provide insulating papers for use in very high voltage electric cables having considerable dielectric strength, equal to or higher than that of paper normally used for the insulation of electric cables, and a substantially lower dielectric loss factor.

In accordance with the present invention there is provided a paper for insulating high tension electric cables comprising a plurality of layers whose individual physical characteristics fall into one or the other of two categories, there being at least one layer in each category, the first category being distinguished by an apparent density less than that of the second with a maximum value of 0.7 gram per cubic centimeter, the second category being distinguished by an impermeability greater than that of the first and equal to at least 10×10^6 Emanueli units, the ratio of the total thickness of the layers in the second category to the total thickness of the layers in the first category being no higher than 1:1.

Although satisfactory results are obtained with the limits recited above, it is preferable that the low density of the first category not exceed 0.6 gram per cubic centimeter, that the impermeability of the second category be no lower than 50×10^6 E.U., and that the mentioned ratio be no higher than 1:2.

As used herein, the term "density" as it applies to the paper means the apparent density, namely, that obtained by dividing the mass of a given paper volume by the volume itself, thereby taking into account the air gaps between the cellulose fibres.

Better values of the dielectric loss factor are obtained by gradually decreasing the density of the paper constituting the low density layer in the first category and by lowering the ratio between the total thickness of the high impermeability layers in the second category and that of the low density layers. Very good results are obtained with density values about 0.5 g./cm.^{3} and thickness ratios lower than 1:3.

As mentioned above, in the manufacture of very high voltage cables it is necessary to employ insulating paper having a dielectric loss factor as low as possible while high values of dielectric strength are required. The paper according to the present invention is admirably suited to this purpose since it can be produced with very high values of dielectric strength without exceeding the dielectric loss factor values of conventional papers used for the insulation of very high voltage electric cables. This result is obtained by imparting to the high impermeability layers extremely high impermeability values, over 200 $\times10^6$ E.U. and preferably over 500×10^6 E.U.

In spite of its being characterized by values of dielectric strength analogous to those of the very high impermeability paper, the paper according to the invention can be easily impregnated when it is tightly wrapped on the conductor. To facilitate impregnation it is sufficient to impart to the low density layers int he first category an impermeability value lower than 1×10^6 E.U. and preferably lower than 0.5×10^6 E.U.

The papers according to the invention may be constituted by two layers, namely, one impermeability layer in the second category and one low density layer in the first category. Alternatively, it may have three layers, namely, one low density layer sandwiched between two high impermeability layers. With the two-layer type it is advantageous to dispose the paper in such a way that the layer having high dielectric strength is directed towards the conductor. The use of paper constituted by three layers is advantageous when still better performance is required with respect to the electric gradient which can be withstood whent he papers are wrapped on the cable. In the latter case, the sum of the thickness of the two high impermeability layers is equal or approximately equal to the thickness of the single high impermeability layer used in the paper constituted by two layers. A further advantage of the three-layer paper is it symmetry which facilitates the wrapping operations.

Finally, it is advisable to wrap the paper which is in the form of tape on the conductor in helical fashion with the pitch sufficiently greater than the width of the tape to leave a gap between adjacent turns.

The invention will be better understood after reading the following detailed description of the presently preferred embodiments thereof with reference to the appended drawings in which:

FIG. 1 is a sectional view through a paper constructed in accordance with the invention;

FIG. 2 is a view similar to FIG. 1 showing a modification of the paper therein;

FIG. 3 is a view in longitudinal half section of a conductor wrapped with the paper of FIG. 1; and

FIG. 4 is a view in longitudinal half section of a conductor wrapped with the paper of FIG. 2.

Turning now to the drawings, the same reference numerals are used throughout to designate the same or similar parts. A two layer paper is shown in FIG. 1. The high impermeability layer is designated **10** and the low density layer is designated **11**. The letters t and T indicate the thickness of the layers **10** and **11**, respectively. Similiarly, a three layer paper is illustrated in FIG. 2 having a high impermeability layer **10** on each face of the low density layer **11**.

Actual tests have demonstrated that the paper in accordance with the invention has: (a) a dielectric strength very near to that of a homogeneous paper having an equal total thickness and an impermeability equal to that of the high impermeability layer; (b) dielectric losses practically equal to those of a homogeneous paper having an equal thickness and a density equal to that of the low density layer; and (c) an impregnation capacity equal to what it would have if it were constituted by the low density layer only. It is believed that the impregnation capacity is affected by the disposition of the paper layers in the winding on the conductor. In particular, referred to the arrangement of FIG. 3 in which the paper is helically wrapped on a conductor **12** with an interval or gap **13** between the turns, the path of the impregnant during the impregnating process is that indicated by the arrows **14**. This path, in the low density layers **11**, follows in part a longitudinal direction and in part a perpendicular direction with respect to said layers. In the longitudinal direction, the paper, which can be easily impregnated per se, offers very little resistance to the passage of the impregnant. This is due to the fact that the cellulose fibres constituting the paper lie for the most part parallel to the cable conductor and create, therefor, longitudinal ducts within which the oil may flow. Following the path indicated by the arrows **14** in FIG. 3, the impregnating agent can reach in a very short time the layers nearest to the conductor, even admitting that the layers **10** are quite impermeable.

Passage of the impregnatng liquid, however, also takes place through layers **10** which, although having a high

specific impermeability, even exceeding 500×16^6 E.U., have a reduced thickness (preferably less than ⅓ of that of layers **11**) so that their resistance to the passage of oil, which is directly proportional to the thickness, is very reduced. This permits the use of paper comprising a high impermeability layer **10** on both faces of layer **11**, as illustrated in FIG. 4. In this case, in view of the particular dielectric strength of the paper, the layers **10** may have a thickness of half the value of that employed in FIG. 3, and thereby further facilitate the passage of oil. This arrangement, moreover, is easier to handle since the paper tapes are symmetrical on both sides and it is not necessary to be concerned with the position of the high impermeability layer. The best feature of this arrangement is, however, its ability to withstand very high electric gradients when the cable is in service.

It is a known fact that the weak points in cables having a stratified and impregnated dielectric are the butt spaces **13** between the turns of the insulation. These spaces are also called "oil gaps," since they are totally filled with the impregnating fluid. As the radial extent of the oil gaps increases, the maximum electric gradient which can be withstood by the stratified and impregnated dielectric of an electric cable decreases. The presence of a high impermeability layer on both sides (in the radial direction) of the oil gaps **13** gives rise to a better definition of the radial extent of the latter and, therefore, increases the maximum electric gradient which can be withstood by said dielectric. In fact it is to be noted that in the case of FIG. 3, the oil gaps **13** are bounded on one side by the low density layer **11** (low impermeability layer) which can be considered as an effective extension in the radial direction of the oil gap.

As noted above, the papers according to the invention have a value of dielectric strength practically equal to that of the material constituting the high impermeability layers and virtually independent of the value of the dielectric strength of the low density layers. Thus, by reducing the density of the material constituting the low density layers and reducing the thickness ratio between the high impermeability layers and the low density layers, it is possible to obtain a paper whose value of dielectric strength remains unvaried and is equal to that of the high impermeability material but which is almost totally constituted of low density material. Consequently, such paper has a low dielectric loss angle and a low dielectric constant (together defining the loss factor) since, as known, these quantities decrease with decreasing paper density. These features are particularly advantageous as can be appreciated from a consideration of the formula for the dielectric power losses with alternating current, to wit:

$$P=K\times\epsilon\times V^2\times\tan\delta$$

where:

K is a constant depending on the size of the dielectric
V is the applied voltage
δ is the dielectric loss angle of the dielectric, and
ϵ is the dielectric constant.

From the formula, it is evident that the only way of countering the rapid increase of the losses with increasing voltage is to reduce the loss factor ($\epsilon\times\tan\delta$).

To illustrate the considerable advantages of the paper according to the invention, some examples are given below comparing the results of power factor and dielectric strength tests performed on capacitors perfectly impregnated and prepared from: (1) paper according to the invention, indicated with the letter C, and constituted by one high impermeability layer A and one low density layer B; (2) papers constituted by a single layer of type A or B; and (3) papers conventionally used for the insulation of cables having stratified and impregnated dielectric. In the table below the column headings are represented by letters in accordance with the following key:

D=Impermeability;
E=Thickness [an asterisk (*) indicates total thickness];
F=Density;
G=Thickness ratio between paper layer A and paper layer B;
H=The result obtained for tan δ at 25° C.; and
I=The result obtained for dielectric strength (impulse) kv./mm.

Paper	D (E.U.)	E (mm.)	F (g./cm.³)	G	H (tan δ)	I (kv./mm.)
Example 1:						
A	10×10^6	0.135			2.73×10^{-3}	105
B		0.135	0.7		2.4×10^{-3}	90
C		*0.135		1:1	2.5×10^{-3}	102
Example 2:						
A	10×10^6	0.135			2.73×10^{-3}	105
B		0.135	0.5		1.75×10^{-3}	80
C		*0.135		1:1	1.91×10^{-3}	100
Example 3:						
A	50×10^6	0.135			3.4×10^{-3}	120
B		0.135	0.6		2.1×10^{-3}	85
C		*0.135		1:2	2.5×10^{-3}	119
Example 4:						
A	200×10^6	0.135			4.02×10^{-3}	140
B		0.135	0.5		1.8×10^{-3}	80
C		*0.135		1:3	2.1×10^{-3}	134

Tests carried out on papers having a thickness very near to 0.135 mm. and chosen from the types most generally used for the insulation of electric cables have given the following results:

Impermeability, E. U.	$(1\text{ to }3)\times10^5$	$(6\text{ to }10)\times10_5$
Tan δ at 100° C.	$(2\text{ to }2.5)\times10^{-3}$	$(2.5\text{ to }3)\times10^{-3}$
Dielectric strength (impulse), kv./mm.	90	100

From the examples it is evident that the papers according to the invention have: (a) a dielectric strength very near to that of a very high impermeability paper; and (b) a dielectric power factor equal to that of a low density paper. No paper among those at present in use shows a combination of values of high dielectric strength and low power factor comparable with that of paper constructed in accordance with present invention.

The papers described herein can be made in any suitable way. Advantageously, they can be manufactured by employing the technology already in use for conventional multi-ply papers. That is, use can be made of conventional paper machines of the multi-wire type, either equipped with Fourdrinier or cylinder forming devices. These machines, with the simultaneous manufacture of the individual layers, also provide for the uniting of said layers which, joining spontaneously to one another, results in a perfectly compact finished product.

It is to be understood that, while for the conventional multi-ply papers the forming wires are generally supplied with a single pulp stock, for the manufacture of paper according to the present invention each wire is to be supplied with different pulp stocks intended to provide the desired characteristics of impermeability and/or density in the individual layers and consequently in the final product.

When the foregoing description has made reference by way of example to certain preferred embodiments of the invention, it is to be understood that various changes may

be made therein, as will appear evident to one skilled in the art, without departing from the true spirit of the invention as defined in the appended claims.

What is claimed is:

1. A multi-ply paper for insulating high tension electric cables, said paper being divided internally into a plurality of adjacent layers extending generally parallel to the surfaces of the paper and each layer being united with the adjacent layer throughout the extent thereof, said layers having different physical characteristics which fall into one or the other of two categories, there being at least one layer in each category, the first category being distinguished by an apparent density less than that of the second with a maximum value of 0.7 gram per cubic centimeter, the second category being distinguished by an impermeability greater than that of the first and equal to at least 10×10^6 Emanueli units, the ratio of the total thickness of the layers in the first category being no higher than 1:1.

2. A paper according to claim **1**, wherein said apparent density which distinguishes the first category does not exceed 0.6 gram per cubic centimeter.

3. A paper according to claim **2**, wherein said impermeability which distinguishes the second category is equal to at least 50×10^6 Emanueli units.

4. A paper according to claim **3**, wherein the first category is further distinguished by a maximum impermeability of 1×10^6 Emanueli units.

5. A paper according to claim **3**, wherein the first category is further distinguished by a maximum impermeability of 0.5×10^6 Emanueli units.

6. A paper according to claim **5**, wherein there is only one layer in each of said categories.

7. A paper according to claim **5**, consisting essentially of one layer in said first category sandwiched between two layers in said second category.

8. A paper according to claim **1**, wherein said impermeability which distinguishes the second category is equal to at least 50×10^6 Emanueli units.

9. A paper according to claim **1**, wherein the first category is further distinguished by a maximum impermeability of 1×10^6 Emanueli units.

10. A paper according to claim **1**, wherein the first category is further distinguished by a maximum impermeability of 0.5×10^6 Emanueli units.

11. A paper according to claim **1**, wherein there is only one layer in each of said categories.

12. A paper according to claim **1**, consisting essentially of one layer in said first category sandwiched between two layers in said second category.

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PHILIP DIER, Primary Examiner

U.S. Cl. X.R.

161—268; 156—53, 185; 174—25, 122

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,598,691 Dated August 10, 1971

Inventor(s) FRANCO PASINI

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 1, "500×16^6 E.U." should read -- 500×10^6 E.U. -- .

Signed and sealed this 23rd day of July 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

ɪM PO-1050 (10-69)

USCOMM-DC 60376-P69
☆ U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334.