June 6, 1933. T. F. PETERSON 1,912,794

HIGH TENSION CABLE

Filed Nov. 10, 1925

Fig. 1.

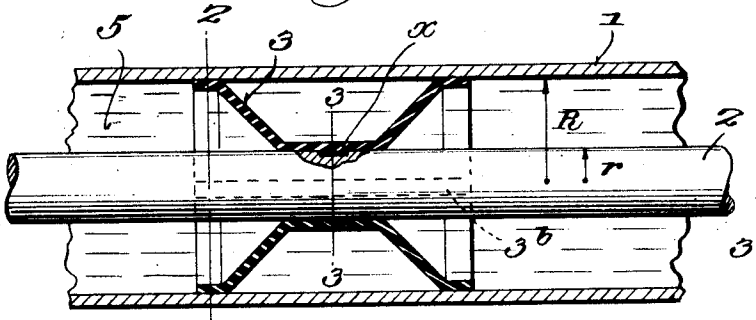


Fig. 2.

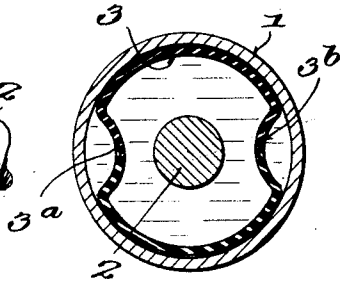


Fig. 3.



Fig. 4.

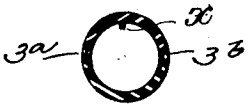


Fig. 5.

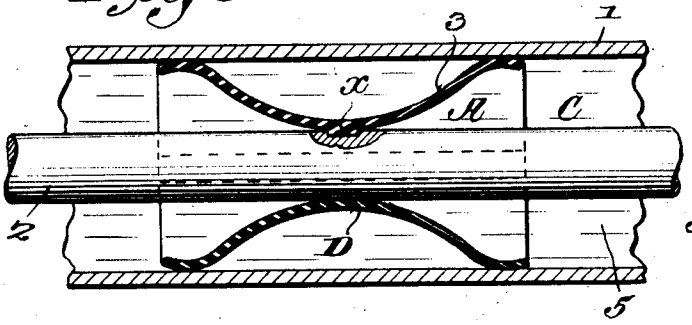


Fig. 6.

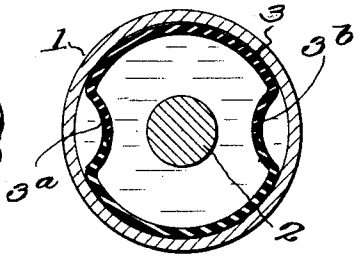
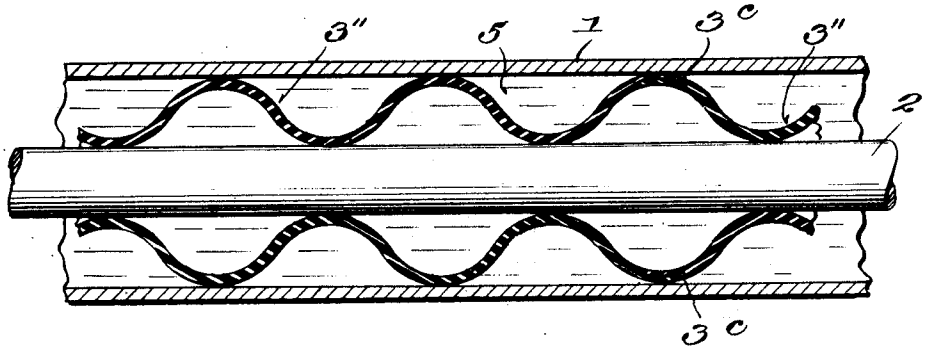


Fig. 7.



Inventor

Thomas F. Peterson

By Edward E. Clemens

Attorney

Patented June 6, 1933

1,912,794

REISSUED

UNITED STATES PATENT OFFICE

THOMAS F. PETERSON, OF BROOKLYN, NEW YORK

HIGH TENSION CABLE

Application filed November 10, 1925. Serial No. 68,089.

My invention relates to high voltage cable for electrical power transmission, and has for its objects, among others, the following:

(1) To produce a cable which may be used for transmission at voltages considerably higher than those used at present; (2) to increase the allowable current density in copper; (3) to decrease the dielectric losses; and (4) to make the dielectric renewable. I attain my objects in the manner and by means of the apparatus and methods hereinafter set forth:

Very briefly stated, this cable comprises as its essential features a single conductor with an enclosed fluid dielectric, preferably compressed air, and the cable may be assembled, so to speak, when it is installed. More specifically stated, the cable in one form may consist of a tube or pipe, of metal, lead, or the like, preferably flexible tubing, in the axis of which a round copper conductor is held by means of hard rubber, or equivalent molded spacer, the space between the tube and the conductor being filled with compressed air or oil. The material to be used for the outer casing will depend on subway conditions, e. g., for new installations of subway, iron pipe, brass or the like would be indicated, but on the other hand for existing subways, lead pipe, reinforced with steel tape, would be preferable for pulling into ducts, (the difficulty of such pulling in being taken into consideration). In so pulling in, or in installing in new subway, the external tube or casing is first put in, then the copper conductor is drawn in, and spacers are attached thereto during the process. These spacers are preferably made in two halves of a design which will prevent break-down of the insulation, and eliminate surface leakage troubles. They are placed on the copper conductor during the pulling in operation, at intervals depending on the configuration of the line, that is to say, whether the duct is straight or curved, and to what degree.

My invention is illustrated in the accompanying drawing, in which:

Figure 1 is a longitudinal section of a fragment of cable embodying my invention.

Figure 2 is a cross-section on the line 2—2 of Fig. 1, with spacer shown therein.

Figure 3 is a section of the spacer on line 3—3 of Figure 1.

Figures 4, 5 and 6 are corresponding figures showing a modified form of spacer, and

Figure 7 is a longitudinal section showing a further modification in the form of a continuous spacer made in sections linked together.

In my design, the important features are:—

(1) Approximately a 3-1 ratio of diameters—pipe to conductor; (2) a spacer, either individual or continuous, of such shape as to make any path of electric flux have but a small fraction of its length in solid dielectric of the spacer. (The fluid dielectric is at all points the essential and major insulation.) Usually in insulator design it is considered necessary to have the surfaces of dielectrics coincident with the electric flux. Divergence from this rule is allowable when solid substance is of such proportions as not to cause too material a lowering of the break-down of other insulating substance such as compressed gas. In addition, the slope of the spacer at various distances from the center, as will be described, may be made such as to have flashover along its surface occur at a higher voltage than across the fluid itself. Since there may be some corona at points along the conductor, with accompanying formation of ozone, which is injurious to most materials, it is to be understood that CO_2 may be used as a substitute for compressed air. The main points to be kept in mind are: That compressed gases have their dielectric strength increased practically in direct proportion to the increase in pressure, and my device, now to be described, constitutes a

means of applying this principle to high tension cables in order to increase working voltages, reduce dielectric loss, eliminate aging characteristics of different cables, increase the current carrying capacity, and to make the dielectric renewable.

Referring to the figures, first to Figures 1, 2 and 3, (1) is the external pipe or casing enclosing the cable elements; (2) is the current carrying conductor related to the tube 1 in respect of diameters so that if $r=1/2''$ then $R=1\frac{1}{2}''$; and (3) is the spacer formed of molded or pressed dielectric material, such as hard rubber, mica, etc.

The spacer 3 is made preferably in two halves, as clearly indicated by the division lines 3*a* and 3*b* in Figures 2, 3, 4 and 6. The tube 1 is first drawn or placed in position, and then the conductor 2 is drawn into it, the spacers 3 being applied to the conductor as it is inserted in the tube section by section. Referring to Figures 4, 5 and 6, it will be observed that while the general arrangement is the same, the shape of the spacer is different, for reasons which will be presently explained, but the junction lines 3*a* and 3*b* are greater in extent than the thickness of the walls of the spacer as in the first form.

Referring to Figure 7, the spacer 3'' is here shown in an entirely different form, being run longitudinally of the pipe, along the conductor, in sections linked together at 3*c*. Any suitable linking device may be employed, provided it is simple and insures a firm joint. In Figures 1 and 5 it will be observed that longitudinal displacement of the spacer on the conductor 2 is prevented by a barb or projection *x* entering a depression in the conductor. These depressions may be made at regular intervals, sufficiently frequent in their recurrence to permit of variable spacing.

In both forms of cable the space 5 between the conductor 2 and the casing or pipe 1, after the conductor is drawn in, is filled at the cable end with air or gases under pressure, or with oil, as a continuous dielectric, the tube 1, of course, being sealed in any suitable manner, which I have deemed it unnecessary to illustrate.

Assuming that the round conductor is held at the center of the tube, with fixed radius R for tube, it is easily shown mathematically that when

$$\frac{R}{r}=E=2.73$$

the potential gradient at surface of conductor is a minimum. This would seem to indicate that the most desirable ratio to use would be 2.7, for this value breakdown occurs without corona formation. However, some divergence from this must be made in practice. A gas surrounding a circular conductor does not go into corona until the potential gradient at a distance of $.301\sqrt{r}$ from surface is = to 21kv/cm; i. e., the voltage E may be obtained from 21=

$$\frac{E}{(r+301\sqrt{r})\log_e\frac{R}{r}}.$$

E is a maximum (for $R=1\frac{1}{2}''$) when

$$\frac{R}{r}=3.05.$$

This is the most efficient ratio but should not be used for reasons indicated below. On any line there are numerous surges, rises in voltage, etc. These may attain value sufficient to break down cable despite designing with a fair safety factor. With 3.05 as the ratio, the breakdown would occur exactly as in a sphere gap, i. e., instantaneously, since there would be no dielectric time lag of breakdown.

To overcome this difficulty, I make $\frac{R}{r}$ somewhat greater than 3.05. Then corona will precede breakdown. This furnishes a means of dissipating the energy of the surge before actual failure voltages occur.

For these sizes, $R=1\frac{1}{2}$ and $r=\frac{3}{8}$, voltage may rise to approximately $1\frac{1}{3}$ times the corona forming value before sparkover occurs. This gives a good range for dissipating surge energy.

With oil as dielectric, previous tests show that $\frac{R}{r}$ should be about 7 for most satisfactory results.

With the spacer 3 between the conductor 2 and the pipe 1, different conditions arise. The breakdown along the surface of the insulating material 3 is influenced by slight conducting films, etc., and so, at times, breakdown may be reduced to one half the value for an ordinary air column.

For the spacer shown in Fig. 1, the potential gradient along the surface of same at any point is $\frac{de}{dr}\cos\theta$ (where $\frac{de}{dr}$ is gradient in air, and θ is angle between tangent to spacer surface and perpendicular to conductor). To make surface of insulator as safe as air column, cos θ should be $\frac{1}{2}$ or less at surface of conductor. It may increase as distance from axis increases to a point halfway between conductor and envelop. I have made cos $\theta=\frac{1}{4}$ at the surface of the conductor and $\frac{1}{2}$ for point half way between the conductor and the casing. The latter is to make the path of the flux lines in the spacer but a short part of their total path. Since the spacer will invariably have a higher dielectric constant than a gas, it is obvious that stresses at "A" will be higher than those at "C". Corona will form there at A first, but break-

down will not in general occur there because of the high strength of the solid dielectric. The amount contributed in such way will also have to be taken care of by the creepage path along the joint 3*a*—3*b* of the two halves of the spacers. The spacer design is therefore as shown. Instead of making these spacers individual, a series may be made and interlocked as shown in Figure 7, and pulled in with the conductor, thus forming a connected system of spacing. Such type is to be used where "barrier" protection against breakdown is needed.

Some of the advantages of this design for use in say 3 phase high voltage system are: (1) Low dielectric loss. Compressed gas below corona forming voltage is practically at zero loss. Loss in the spacers is negligible. (2) High current carrying capacity due to exceptional cooling possibilities by convection currents in fluid and the fact that the spacers may be made for safe operation at a higher temperature than paper and the like. (3) High voltage possible. Limited only by the pressure which can conveniently be maintained, or by strength of oil. (4) Dielectric renewable—either gas, oil or spacers. (5) Simplicity of splicing—making possible welding or brazing of joints, due to absence of paper, etc., which may be charred in ordinary types. (6) With resistance grounded neutral system, failure may occur without doing very much damage to lead pipe, conductor, etc., thus making renewal of the cable possible by replacement of the spacers. (7) Design eliminates the aging characteristics of paper and rubber cables. (8) Although air has no breakdown time lag, operating with suitable safety factor and with means of dissipating surge energy, this point may be passed by.

Losses in sheath constitute an item for consideration. In one case these may be looked upon as similar to losses in ordinary single conductor armored cable.

Sample computations (atmospheric pressure). Voltage for corona formation at "C".

$$e_c = g_0\left(1+\frac{.301}{\sqrt{r}}\right) r \log_e \frac{R}{r} \quad (r \text{ in cm.})$$

$$e = 21\left(1+\frac{.301}{\sqrt{.375\times 2.54}}\right).952 \log_e \frac{1.5}{.375} +$$

36.4 k.v.

Flash over voltage = corona forming voltage for $r=\frac{R}{3}$ + voltage drop thru corona belt =

$$21\left(1+\frac{.301}{\sqrt{.5''\times 2.54}}\right).5\times 2.54 \log_e \frac{1.5}{.5}$$

+ approx. 6.6 = 44 k.v.

To be very safe, it is well to compute voltage assuming that gradient at air film at "D" is 21 kv.

To allow for thermal expansion and contraction of the copper conductor, it may be made in sections with gaps or spaces between the adjacent ends of sections conductively bridged with sections of flexible jumper cable. This jumper cable may take the form of several flat, flexible conductors brazed or soldered around the periphery of the adjacent cable core ends, or it may be spring like, or of any known or other form capable of electrically connecting the adjacent ends of the cable core sections while permitting relative longitudinal movement thereof.

A system using such cable as this would obviously include certain necessary auxiliaries, such as, air compressor, filters, oil pumps and devices of that order.

Splices, ends, bends, etc., may be designed in a way similar to that of the rest of the cable.

The term "cable" is used herein for convenience and is to be construed as a term of inclusion and not of limitation, particularly as it would ordinarily connote an idea of flexibility.

I claim:

1. A cable adapted for high transmission voltages with large current density in the conductor and with low dielectric losses comprising a core, a surrounding envelop coextensive in length with said core, a fluid dielectric medium under pressure between the core and the envelop and having recurring spacer elements between the core and the envelop with surfaces sloping from the normal to the core and with the total thickness of spacer material measured along any normal to the core but a fraction of the length of said normal through fluid dielectric.

2. A cable adapted for high transmission voltages with large current density in the conductor and with low dielectric losses comprising a core, and a surrounding envelop coextensive in length with said core, a fluid dielectric medium under pressure between the core and the envelop and a spacer element between the core and the envelop, said element having a surface oblique to the lines of flux emanating from the core, the degree of obliquity being such that the flashover voltage along surface of spacer is equal to or greater than the flashover voltage through the fluid, and said element having a thickness measured along any line of flux substantially less than the length of this line of flux in the fluid dielectric.

3. A cable adapted for high transmission voltages with large current density in the conductor and with low dielectric losses comprising a core and surrounding envelop coextensive in length with said core, a fluid dielectric medium under pressure between the core and the envelop and a spacer element

between the core and the envelop, said spacer having a surface curvature such that the cosine of the angle between any tangent to the surface of the spacer at any given point and the perpendicular to the axis of the core at that point is equal to or less than one half the ratio of the distance from the point to the core axis and the radius of the core and the walls of said spacer being sufficiently attenuated to make any path of electric flux pass thru it in a length substantially less than one half the length of the spacer.

4. A cable adapted for high transmission voltages with large current density in the conductor and with low dielectric losses comprising a core, a surrounding envelop coextensive with said core, a fluid dielectric medium under pressure between the core and the envelop, and recurring spacer elements between the core and the envelop, each having a curvature such that the cosine of the angle between any tangent to the surface of the spacer at any given point and a perpendicular to the axis of the core at that point is approximately one half or less for a point at surface of core, the value of said cosine increasing as the distance from the axis increases to a point approximately halfway between core and envelop and then decreasing, the walls of said spacers being so attenuated as to thickness that for any line of electric flux the length thereof in spacer dielectric may be but a fraction of the length in fluid dielectric.

5. A cable adapted for high transmission voltages with large current density in the conductor and with low dielectric losses comprising a core, a surrounding envelop coextensive in length with said core, a fluid dielectric under pressure between the core and the envelop, a spacer element between the core and the envelop, said envelop being a metallic tube and said spacer having a thin wall of formed insulation extending from the core longitudinally of the cable in an expanding figure and into engagement with the envelop.

6. A cable adapted for high transmission voltages with large current density in the conductor and with low dielectric losses comprising a core, a surrounding envelop coextensive with said core, a fluid dielectric medium under pressure between the core and the envelop, and recurring mechanical spacers between the core and envelop extended as to length and attenuated as to thickness so that for any line of electric flux the length thereof in spacer dielectric shall be but a small fraction of the total length from the core to the envelop, each spacer formed in parts circumferentially and adapted to be fitted together directly around the cable core, held against longitudinal movement by direct engagement with the core, and held together circumferentially by the enclosing envelop.

7. A cable adapted for high transmission voltage with large current density in the conductor and with low dielectric losses comprising a core, a surrounding envelop coextensive with said core, a fluid dielectric medium under pressure between the core and the envelop, and recurring mechanical spacers between the core and envelop of solid dielectric material having walls of substantially uniform thickness and shaped approximately like the walls of an hour glass with the central constricted portion engaging the core, and the outer extended portions engaging the envelop.

8. A cable adapted for high transmission voltages with large current density in the conductor and with low dielectric losses comprising a core, a surrounding envelop coextensive with said core, a fluid dielectric medium under pressure between the core and the envelop and recurring mechanical spacers between the core and envelop of solid dielectric material having walls of substantially uniform thickness and shaped approximately like the walls of an hour glass with the central constricted portion engaging the core, and the outer extended portions engaging the envelop, said walls being made sufficiently attenuated to make any path of the electric flux pass through them in a small fraction of the length of the spacer.

9. A cable adapted for high transmission voltages with large current density in the conductor and with low dielectric losses comprising a core, a surrounding envelop coextensive with said core, a fluid dielectric medium under pressure between the core and the envelop, and recurring mechanical spacers between the core and envelop of solid dielectric material having walls of substantially uniform thickness and shaped approximately like the walls of an hour glass with the central constricted portion engaging the core, and the outer extended portions engaging the envelop, said walls being made sufficiently attenuated to make any path of the electric flux pass through them in a small fraction of the length of the spacer, and the length and shape of the spacer being such that any flashover along its surface will occur at a higher voltage than through the fluid dielectric.

In testimony whereof I hereunto affix my signature.

THOMAS F. PETERSON.