Aug. 9, 1938. R. W. ATKINSON 2,125,869

ELECTRICAL CONDUCTOR

Filed July 18, 1933 2 Sheets-Sheet 1

Fig. 1.

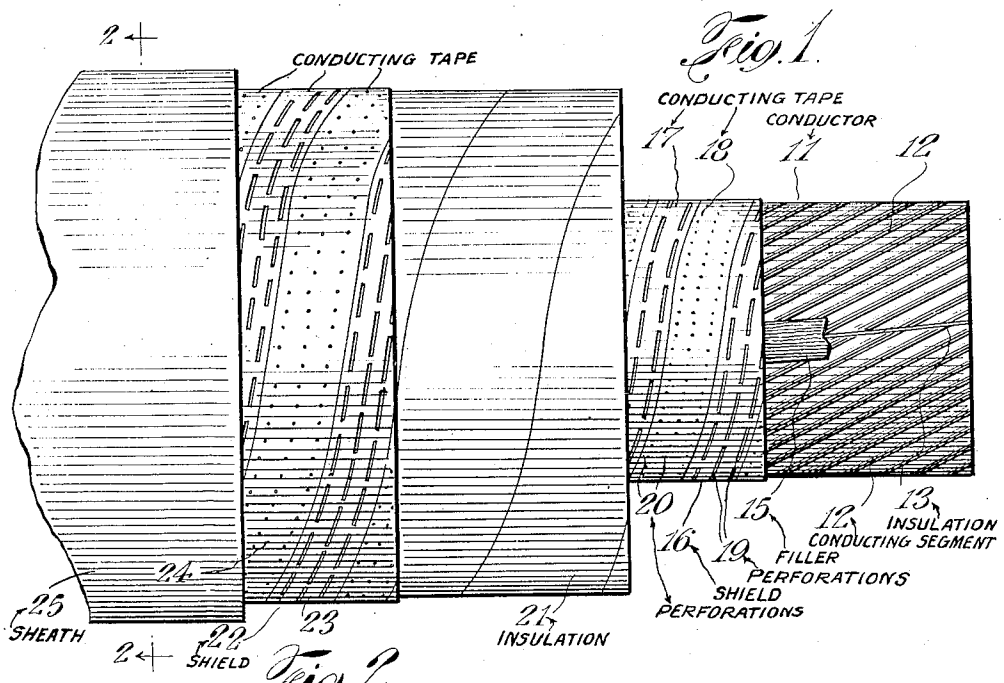

Fig. 2.

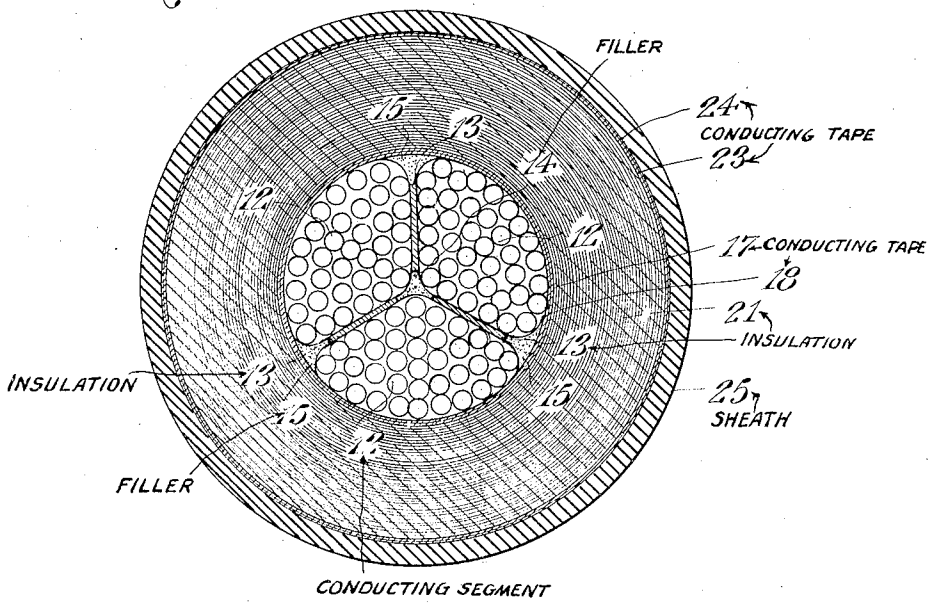

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Fig. 3.

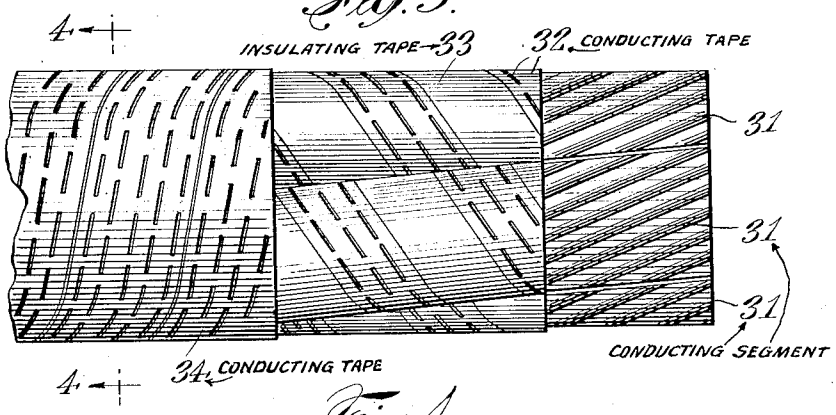


Fig. 4.

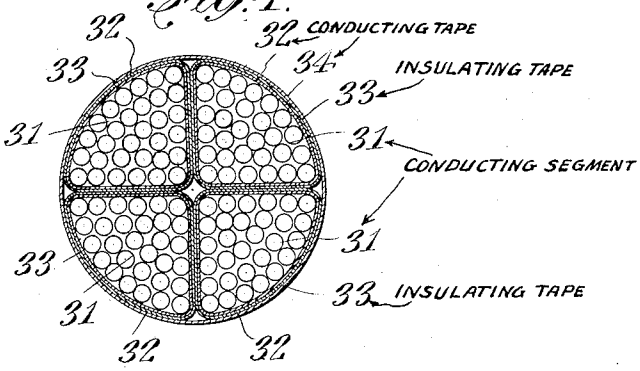


Fig. 5.

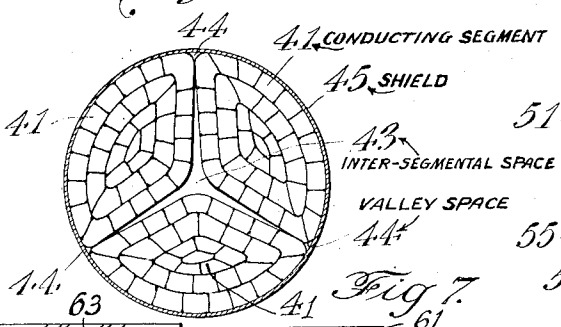


Fig. 6.

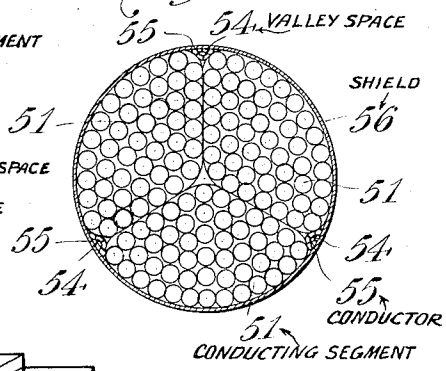
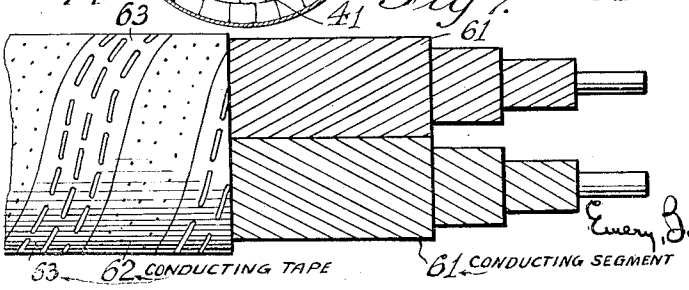


Fig. 7.



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UNITED STATES PATENT OFFICE

2,125,869

ELECTRICAL CONDUCTOR

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Application July 18, 1933, Serial No. 681,022

15 Claims. (Cl. 173—266)

This invention relates generally to electric conductors and cables, and more particularly to large conductors designed to have a reduced skin effect and otherwise improved electrical characteristics. It is an object of the invention to provide an improved conductor having a reduced skin effect. It is a further object of the invention to provide an improved electric cable. Other objects and advantages of the invention will appear hereinafter.

The invention will be best understood from the following description when read in the light of the accompanying drawings of certain specific embodiments of the invention, the scope of which latter will be more particularly pointed out in the appended claims.

In the drawings:

Fig. 1 is an elevation of a short length of insulated and sheathed single conductor cable, the parts being broken away progressively greater distances to disclose the construction more clearly;

Fig. 2 is a cross section through the cable of Fig. 1 substantially on the line 2—2;

Fig. 3 is an elevation of a conductor which differs slightly from the conductor of the cable of Figs. 1 and 2, the parts being broken away to disclose the construction;

Fig. 4 is a cross section through the conductor of Fig. 3 substantially on the line 4—4;

Fig. 5 is a cross section through another slightly different conductor;

Fig. 6 is a cross section through still another conductor; and

Fig. 7 is an elevation of a conductor illustrating another feature of the invention.

When an electric conductor is carrying alternating current there is a tendency for the current to concentrate in the outer portion of the conductor. This increase in current density near the surface of the conductor may be considered to be a result of the fact that that portion of the flux generated by the current and lying within the conductor itself generates counter-electromotive forces in the conductor which are greater in the center of the conductor than adjacent the surface thereof. This concentration of current near the outer surface of the conductor, commonly known as skin effect, results in an increase in the effective resistance of a conductor to the flow of alternating currents.

This increase in effective resistance of conductors is small for currents of the usual power frequencies in conductors of small cross section. However, as the size of the conductor increases, the increase in the effective resistance of the conductor due to skin effect rises rapidly. According to this invention an improved conductor is provided which has a greatly reduced skin effect, particularly in large size conductors, and which may be used economically for high voltages without substantial increase in the overall size of the conductor, and with a minimum danger of failure in the cable insulation adjacent the surface of the conductor.

Referring first to Figs. 1 and 2, there is shown by way of example a single conductor power cable in which the conductor 11 comprises a plurality of conducting segments 12, there being three of these segments in the illustrative embodiment. Desirably the segments 12 are sector-shaped, so that when they are cabled together they form a substantially round conductor. Each of these conducting segments comprises a plurality of conducting wires stranded together, and preferably the segments 12 are built up in a plurality of overlying layers with the wires stranded helically so that each wire follows a sinuous course longitudinally of the conductor, first approaching the center of the conductor 11 and then approaching the surface of the conductor 11.

If the contact resistance between the individual wires forming the conductor 11 is sufficient substantially to prevent passage of current from one wire to the adjacent wires of the conductor, the effects of the counter-electromotive forces will approach equality in all of the wires because of their transposition within the conductor. Therefore, the resistance of each wire of the conductor to the flow of alternating current longitudinally of the conductor will be approximately equal to the resistance of every other wire of the conductor, and the current flowing through the conductor will divide substantially equally between all of the wires. The resistance of the wires will not be exactly equal because the transposition of the individual wires between the center of the conductor and the surface of the conductor is not complete.

Heretofore in stranded conductors in which the wires have been transposed to reduce skin effect it has been considered necessary to insulate each wire individually, for example with enamel. I have found that the voltage between two adjacent wires in a stranded conductor carrying alternating current is in the order of a few microvolts, or less, and that the oxide coatings which form naturally on copper or aluminum wires when exposed to air have a sufficiently high resistance substantially to prevent passage of current from

one wire of a conductor to another wire of the same conductor in contact therewith. This is particularly true if all of the wires in the conductor are stranded helically in the same general direction because the potentials between contacting wires in adjacent layers are lower under these conditions than when the wires are stranded helically in opposite directions in adjacent layers.

In cabling the segments 12 together it will be desirable ordinarily to insulate them from each other to eliminate any danger of short circuiting the adjacent wires in the outer layers of the segments. Conveniently, such insulation may take the form of thin paper tapes 13 extending longitudinally of the cable between adjacent segments 12.

Conveniently, fillers 14 and 15 may be inserted centrally of the conductor between the segments 12 and in the valleys at the outer surface of the conductor. These fillers may be either conducting or non-conducting, for example a solid wire or a stranded conductor, or crushed paper, jute, etc.

Around the assembled conductor desirably is placed a thin conducting layer 16 to shield the valley spaces and the fillers between the conductor segments and also the smaller valleys between the wires in each segment. These spaces, if not shielded before the conductor is enveloped in insulation, would constitute electrically weak regions in which there would be danger of ionization resulting eventually in breakdown of the cable during service.

In the illustrative embodiment the shielding layer 16 comprises a helical wrapping of overlapping tapes 17 and 18 applied directly around the conductor 11 and the fillers 15, and in contact with the segments 12 to insure complete shielding. The tapes 17 and 18 preferably both are conducting, for example the tape 17 may be a metallic ribbon such as copper or aluminum and the tape 18 may be a metallized paper tape, the metal coating being aluminum for example.

The tapes 17 and 18 may be perforated as at 19 and 20, respectively, to facilitate passage of impregnating oil or compound therethrough, and to reduce the eddy current losses in the shielding layer.

The shielded conductor is surrounded by a wall 21 of insulation, for example a plurality of overlying layers of helically wrapped insulating tapes. Ordinarily these insulating tapes will be paper or varnished cambric, and if they are paper or other porous material preferably they will be impregnated with an insulating material, conveniently an oil or oily compound.

Over the insulation 21 there desirably is another shielding layer 22 comprising, for example, a helical wrapping of overlapping tapes 23 and 24. In the illustrative embodiment the shielding layer 22 is similar to the shielding layer 16. The insulated and shielded conductor is enclosed within a sheath 25 of lead or other suitable material.

Figs. 3 and 4 show a modified form of conductor. Merely by way of example this conductor comprises four sector-shaped segments 31 which, when cabled together, from a substantially round conductor. Each of the segments 31 is individually wrapped, for example with a helical wrapping of overlapping tapes 32 and 33. Desirably one of these tapes in an insulating tape, for example the tape 33 may be paper. In order that the valleys between the conductor segments 31 may be shielded electrically, the tape 32 preferably is a conducting tape, for example a thin metal foil. The tapes 32 and 33 are applied so that the tape 32 makes contact with the wires comprising the segment 31, and so that a portion of the tape 32 is exposed on the outer surface of the wrapped segment. It will be seen that with a wrapping as described each segment is individually shielded.

The segments 31, after being cabled together, desirably are enclosed within a common shielding layer. By way of example this common shielding layer is shown as a helically wrapped metal tape 34, although it may take other forms similar to the shielding layers 16 and 32, 33.

By making the segments in the form of compressed stranded sectors, the sectors can be designed so that when they are cabled together the adjacent segments will be in contact with each other only adjacent their outer edges. Such a construction is illustrated in Fig. 5, in which there are three segments 41. Each segment comprises a plurality of wires stranded together, preferably with the wires in overlying layers, and with all wires in any one segment spiralled in the same general helical direction. Where the adjacent segments make only substantially line contacts there is no great tendency for the wires in one segment to provide a short circuit from wire to wire in an adjacent segment, and there is no great tendency for exchange of current between segments at this contact.

The space 43 between the segments 41, and the valley spaces 44 may or may not be filled with material, as desired. If these spaces are filled, the filling may take the form either of conducting material or insulating material, for example crushed paper or jute. After the segments 41 have been cabled together they may be enclosed, if desired, within a shielding layer 45 in a manner similar to that described for the conductors of the foregoing figures.

Although ordinarily it probably will be desirable either to insulate the segments of a conductor from each other, for example as shown in Figs. 1 to 4 inclusive, or to shape the segments so that they have only limited contact with each other, as illustrated in Fig. 5, in other cases it may be adequate to cable the segments of the conductor together without provision of any special means or construction to prevent transfer of current from one segment to an adjacent segment. The oxide coatings normally found on copper and aluminum conductors have a sufficiently high electrical resistance with a limited contact between segments to minimize passage of current between the wires of one conductor segment and the wires of another segment of the same conductor.

The tendency for the wires of one segment to short circuit the wires of an adjacent segment, and for exchange of current between adjacent segments may be further reduced by having the outer layer of wires in one segment extend in one helical direction, while in the segments on either side the outer layers of wires extend in the opposite helical direction, so that the contacting wires of two adjacent segments are generally parallel. Such an arrangement is illustrated in Fig. 7, in which, for example, all wires of any one segment extend in the same general helical direction, but the wires of one segment extend in the opposite helical direction to the wires of the adjacent contacting segments. The assembled segments 61 may be enclosed in a shielding layer comprising overlapping, helically wrapped conducting tapes 62 and 63.

Fig. 6 shows a cable in which the conducting segments are in direct contact with each other. In this embodiment the conductor comprises three segments **51**, each composed of a plurality of overlying layers of wires, the wires in any one segment preferably being all laid in the same general helical direction. The valleys **54** between the conductor segments preferably are filled with suitable material, for example conducting material. This conductor filler may take the form of a single wire or a stranded conductor, and if the segments **51** are shaped so as to leave relatively large valley spaces the filler members conveniently comprise compressed stranded conductors **55**. After the conductor segments **51** have been cabled together the valley fillers **55** are inserted and the conductor then may be enclosed, if desired, within a shielding layer **56** generally similar to that described for the embodiments of Figs. 1 to 4 inclusive.

If the several segments comprising a conductor are so shaped that when they are assembled the conductor has a smooth and uniformly round outer surface it may be practicable, at least in some instances, to dispense with the enclosing shielding layer. Such a conductor might comprise, for example, compressed and shaped segments as shown in Fig. 5, or the combination of sector-shaped segments and shaped conducting fillers as shown in Fig. 6.

By my invention I have provided improved conductor and cable constructions particularly adapted for the transmission of large currents with a greatly reduced skin effect loss and with a reduced danger of breakdown at the surface of the conductor.

It will be understood that the present invention may be variously modified and embodied within the scope of the subjoined claims.

I claim:

1. An electric conductor having reduced skin effect comprising a plurality of conducting segments cabled together, each segment comprising a stranded conductor, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

2. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together, each segment comprising a plurality of conducting wires laid up helically in layers, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

3. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

4. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers and being so shaped that it will have substantially line contacts with adjacent segments, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

5. An electric conductor comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers, the angle between the flat sides of each segment being slightly more than

$$\frac{360}{n} \text{ degrees}$$

where n represents the number of segments, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

6. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers, all of the wires of any segment extending in the same general helical direction, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

7. An electric conductor comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers and being so shaped that it will have substantially line contacts with adjacent segments only near the periphery of the conductor, insulating material separating the segments near the center of the conductor, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

8. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers, an electrostatic shield enclosing each segment and in contact therewith, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

9. An electric conductor comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers, the helical direction of the outer layer of wires of each segment being opposite to the helical direction of the outer layer of wires in an adjacent segment, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

10. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers, filler material in the spaces between the segments to round out the core, and an electrostatic shield enclosing the assembled segments and filler material and connected electrically to the segments adjacent the outer surface of the conductor.

11. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each

segment comprising a plurality of bare conducting wires laid up helically in layers, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

12. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together with adjacent segments in contact with each other, each segment comprising a plurality of conducting wires laid up helically in layers and enclosed in a helical wrapping comprising an aluminum surfaced tape, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

13. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together, each segment comprising a plurality of conducting wires laid up helically in layers, thin layers of insulating material separating the segments, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

14. An electric conductor having reduced skin effect comprising a plurality of sector-shaped conducting segments cabled together, each segment comprising a plurality of conducting wires laid up helically in layers, thin layers of insulating material separating the segments, all of the wires of any segment extending in the same general helical direction, and an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor.

15. An electric conductor having reduced skin effect comprising a plurality of conducting segments cabled together, each segment comprising a stranded conductor, an electrostatic shield enclosing the assembled segments and connected electrically thereto adjacent the outer surface of the conductor, a surrounding wall of insulating material, and a sheath enclosing the insulated conductor.

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