

Oct. 21, 1958

B. M. OLIVER
TRANPOSED CONDUCTOR

2,857,450

Filed April 5, 1952

2 Sheets-Sheet 1

FIG. 1



FIG. 2

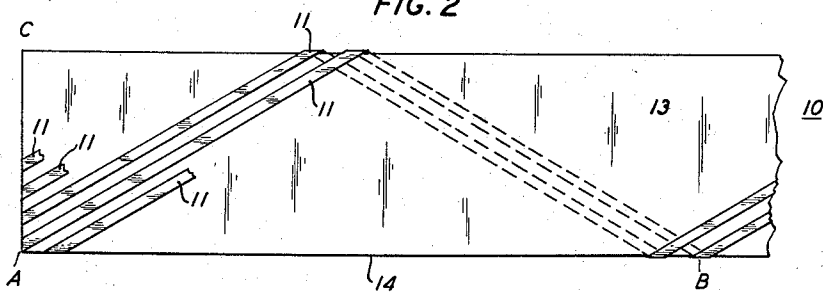


FIG. 3

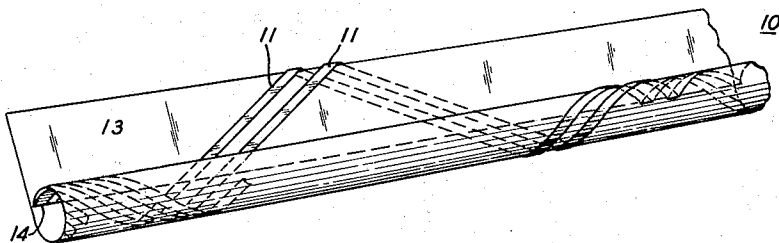
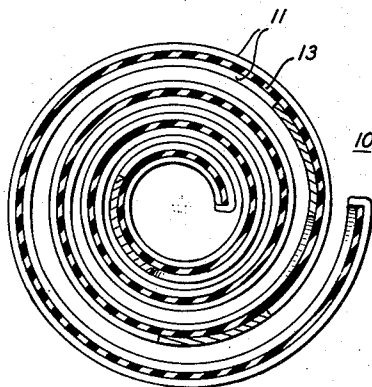


FIG. 4



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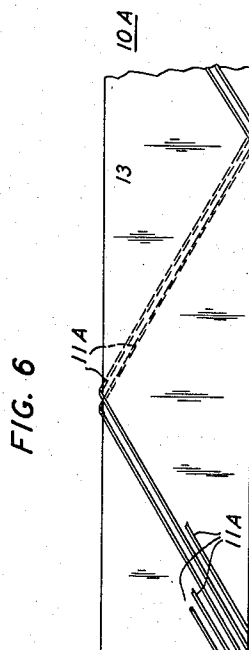
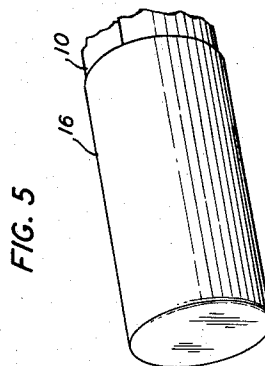
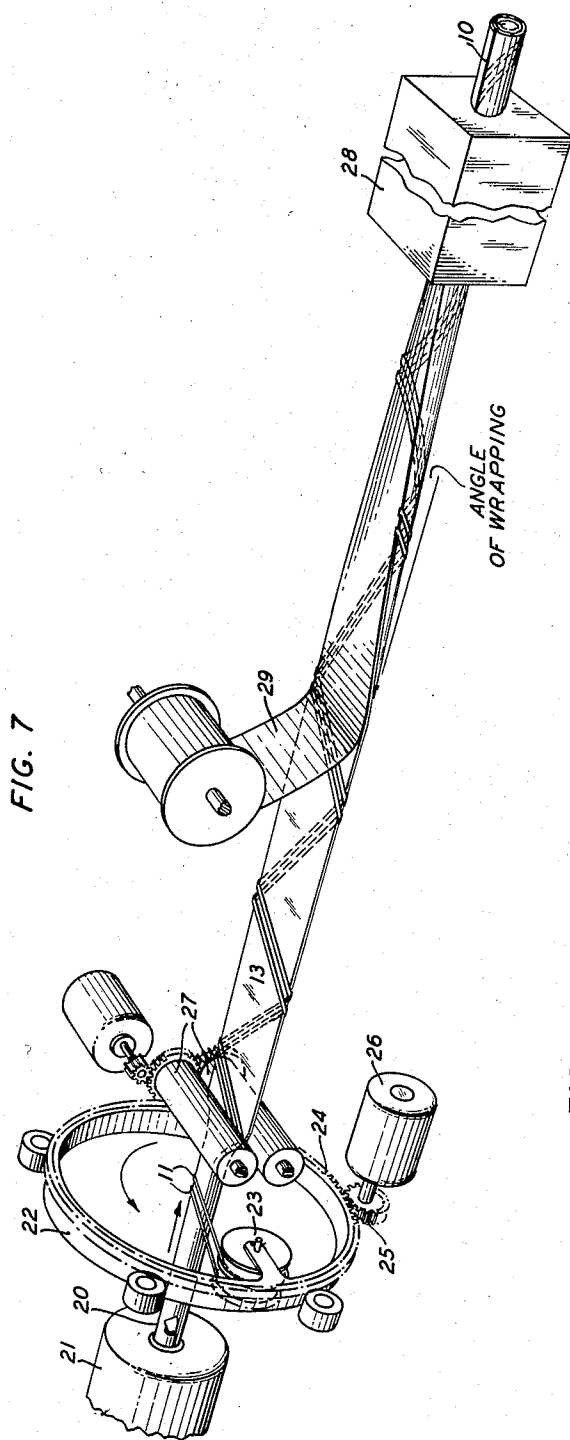
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2,857,450

TRANSPPOSED CONDUCTOR

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Application April 5, 1952, Serial No. 280,768

5 Claims. (Cl. 174—34)

This invention relates to composite electrical conductors and more specifically to transposed conductors and to methods of making them.

It is an object of this invention to simplify the construction of transposed conductors.

It is another object of this invention to provide an improved composite conductor formed of a multiplicity of wires or tapes transposed more or less continuously.

Due to the phenomenon known as "skin effect," at high frequencies the current distribution through a conductor is not uniform. Consider for example the case of a solid conductor to which are applied waves of increasing frequency. At zero and sufficiently low frequencies, the current in the conductor is substantially uniformly distributed throughout and the resistance of the conductor and hence the conductor loss in the line is at a minimum. With increasing frequency, the current distribution changes so that the current density is a maximum at the outer surface of the conductor and decreases into the material at a rate depending on the frequency and the material. In the example given, the current density may be negligible at the center of the conductor. In other words, the A.-C. resistance of the conductor at high frequencies, due to this uniform current distribution, is higher than the D.-C. resistance thereof.

It has been recognized that the A.-C. resistance at high frequencies can be greatly reduced if the conductor is formed of a number of insulated smaller conductors connected in parallel and these conductors are transposed often enough. This amounts to forcing the current to distribute itself over the entire cross-section allocated to the composite conductor and the purpose of doing this is to decrease the dependence of resistance and internal inductance upon frequency and also to decrease the effective resistance at high frequencies. For the method to succeed, transpositions at close intervals are required and over a particular transposition interval each conducting path in turn should occupy each radial position. One well-known example of such a transposed conductor is the Litz wire. The Litz wire has various disadvantages, however. First, it must be made of insulated wire so that the conductors do not come in contact with each other and, secondly, it is frequently difficult to transpose a large number of conductors at very short intervals (such as would be required for very high frequencies) with the process used for transposing the conductors in Litz wire. Moreover, it is frequently desirable to use flat tapes for the individual conductors rather than wires and the methods of making Litz wire do not lend themselves readily to the use of tape in the formation thereof.

In accordance with the present invention, a transposed conductor is provided which is a great improvement in many respects over other known transposed conductors. In an illustrative embodiment of the invention, a multiplicity of wires or tapes are wound in the form of a flattened helix around a thin sheet or strip of insulating material and all the conductors are connected in parallel.

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Insulation is placed on one or both sides of the insulating sheet and it is rolled up without short-circuiting the conductors. In this arrangement, any particular conducting member works its way into the center of the conductor and then back out again occupying all radial positions in a distance corresponding to one complete turn around the insulating sheet.

The invention will be more readily understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof, in which:

Fig. 1 is a schematic view in perspective of a transposed conductor in accordance with the invention, only a few of the elemental conductors forming a part thereof being shown for simplicity in the drawings;

Fig. 2 illustrates one step in a process of making the cable of Fig. 1;

Fig. 3 illustrates another step in this process;

Fig. 4 is a cross-sectional view of a cable somewhat like that of Fig. 1 drawn to greatly enlarged scale;

Fig. 5 shows one method of connecting in parallel the various conductors in the cable of Fig. 1;

Fig. 6 shows a step in the process of constructing a cable like that of Fig. 1 except that wires are used instead of tapes; and

Fig. 7 shows schematically apparatus suitable for constructing a cable of the type shown in Fig. 1.

Referring more particularly to the drawings, Fig. 1 shows, by way of example, and in perspective, a composite conductor or cable 10 in accordance with the invention. The conductor 10 comprises a multiplicity of tapes 11 connected in parallel by any suitable means such as a metal cap or disc 12 at the end of the cable. In order to understand more fully the construction of the cable member 10, reference is made to Figs. 2, 3 and 4. In Fig. 2, the conductors 11, which in this embodiment are in the form of tapes, are wrapped in the form of a flattened helix around a strip of insulating material 13. For simplicity in the drawing, only two tapes 11 have been shown developed while short sections of others have been indicated. In practice, substantially the whole distance between point A (where one tape 11 meets edge 14 of the strip 13) and point B (where the same tape 11 contacts the edge 14 again) is filled with tapes 11 spaced short distances apart. The pitch of each tape 11, that is the distance between points A and B, varies with the highest frequency for which the cable 10 is designed. In general, the necessary transposition interval (the distance AB) is shorter the higher the top frequency and, in fact, is inversely proportional to the highest transmitted frequency, other things being equal. As a practical matter, there should be several transpositions within a distance corresponding to a wavelength of the highest transmitted frequency. After the tapes 11 have been wound or otherwise applied to the insulating strip 13 (they may, for example, be coated on the strip 13 if desired), the strip 13 is then rolled up, starting from the lower edge 14 in Fig. 2, so that a cross-section of the rolled up conductor will be then as shown in Fig. 4. Fig. 3 illustrates the rolling step. In Fig. 4, for purposes of clarity of illustration, the sheet is shown loosely rolled. Actually it would be rolled as tightly as possible. Moreover, if the tapes 11 are uninsulated, insulation is added over one or both sides of the sheet 13 so that it can be rolled up without short-circuiting the conductors 11 (since each conductor 11 is on both sides of the sheet 13). For simplicity in the drawing, this additional insulation has not been shown in Figs. 2, 3 and 4 but it has been indicated in the equipment shown in Fig. 7 and which will be described below. Referring then to Figs. 1 through 4, it can be seen that any particular conducting strip 11 such as the strip starting at

the point A and touching the edge 14 again at the point B, works its way into the center of the conductor and then back out again, occupying all positions in a distance corresponding to the length on one side and back of the sheet 13, or in other words the distance AB. This transposition is effective for both skin effect and proximity effect. Another way of describing the physical path of each element 11 is to point out that it comprises a helix of continually increasing diameter up to a certain point at which point it reverses direction and becomes a helix of decreasing diameter to a second certain point where the diameter begins to increase again. Due to the periodic reversal of direction of turn, there is no longitudinal magnetic field set up by the transpositions.

For best results, it is necessary that the width and thickness of each conducting strip 11 be sufficiently small and the transposition interval sufficiently short. Assuming the absence of ferromagnetic materials, these factors depend on the over-all diameter of the cable 10, the diameter of the inside core or first wrapped, the highest transmitted frequency and the conductivity of the conducting strip. For stiffening purposes the cable 10 may have an inside core 15 as indicated in Fig. 1, or it may be omitted as shown in Fig. 4. Various means of terminating the cable can be used. One terminating arrangement has already been shown in Fig. 1 wherein the termination is made by a conducting ring 12 at the ends, that is, the points where all the strips 11 contact the edge AC of the sheet 13. Another way of connecting the conductors in parallel is shown in Fig. 5. This embodiment comprises a cap 16 which extends a distance along the surface of the cable 10 corresponding to the distance AB in Fig. 2.

While tapes have been shown in Figs. 1 through 5, it is obvious that wires 11A having a circular or other convenient cross section can be used instead. Such an arrangement is shown in Fig. 6.

It is obvious that there are many methods available for constructing composite cables of the type shown in the previously mentioned figures. One form of continuous process is represented by way of example in Fig. 7. Referring now to this figure, a core 20 of circular cross section and which may be either of solid or hollow construction is extruded from any suitable member 21 to which the insulating material of the core 20 is applied. The core 20 is passed through a tape or wire winding machine 22 which winds the tapes or wires 11 on the core 20. The machine 22 includes a plurality of wire or tape drums 23. These drums are mounted in a frame 24 which is rotated through suitable gearing 25 by a motor 26. While the tapes or wires 11 are being wrapped around the core 20, the latter is moved (from left to right in Fig. 7) by the extruding or feeding machine 21. After the conductors 11 are applied to the core 20, it is passed through rolls or other shaping members 27 which flatten the core 20 into a flat sheet 13. It is then moved through a shaping member 28 which causes the sheet 13, having the conductors 11 thereon, to be wrapped in a spiral and thus emerge as a completed conductor 10 at the right-hand end of the apparatus. Sheets of insulation 29 can be applied to the form 13 just prior to the wrapping process. Since it is generally desired that the pitch (that is the distance AB) remain substantially constant throughout the length of the cable 10, the shaping member 28

extends for a relatively great distance along the cable. The angle of wrapping shown in Fig. 7 is only for illustrative purposes and is actually greatly exaggerated. While in general a constant pitch is desirable, there are situations in which a varying pitch is useful.

It is to be understood that the above described arrangements are illustrative of the application of the principles of the invention. Numerous other embodiments may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A transposed conductor comprising a multiplicity of conducting elements connected in parallel at the ends of the conductor each being in the form of a helix which continually varies in diameter first in one direction and then in the other, the direction of winding reversing every time the change in diameter reverses its sign.
2. A transposed conductor comprising a multiplicity of conducting elements connected in parallel at the ends of the conductor each being in the form of a helix which continually varies in diameter and having a helix angle periodically varying in sign.
3. A transposed conductor comprising a multiplicity of conducting elements each being in the form of a helix which continually varies in diameter and having a helix angle periodically varying in sign, a thin supporting member of insulating material for supporting said helices, said member having a spiral cross section, insulating material between the turns of the spiralled support member, and means for connecting said helices together at the ends of said conductor.
4. In a transposed conductor a plurality of elemental conductors, each comprising a series of sections, each in the form of a frusto-conical helix, alternate junctions between said sections being larger base to larger base and smaller base to smaller base, means interconnecting said elemental conductors in parallel only at the ends of said transposed conductor, and means insulating said conductors from one another at all other points.
5. In a cable of generally circular cross section, a plurality of non-coincident insulated conductors each of which comprises a helix of conducting material, the helices being formed about the axis of said cable and having diameters which vary periodically between maximum and minimum limits, the order of variation reversing periodically along the length of said cable, and means for conductively interconnecting said elemental conductors at the ends of said cable.

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