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ELECTRICAL CONDUCTORS HAVING TRANSPOSED CONDUCTING ELEMENTS

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This invention relates to electrical conductors and more particularly to electrical conductors each comprising a plurality of transposed conducting elements and to methods of making them.

The term "transposed conducting elements" is used to refer to a plurality of conducting elements whose positions are shifted relative to each other and to an axis of the conductor. The shifting may be continuous along the length of the conductor or it may occur at discrete intervals. Also the transpositions may take the form of frequent shifting of large numbers of conducting strands as in the case of Litzendraht wire, or it may be an orderly change of position of a few conductors such as, for example, the type shown and described in my copending United States patent application Serial No. 366,510 which was filed July 7, 1953.

It is an object of this invention to simplify the construction of electrical conductors having transpositions.

It is another object of this invention to provide an electrical conductor, the alternating current resistance of which is less dependent upon frequency changes than that of conventional conductors.

In the transmission of electromagnetic waves, the current distribution which is substantially uniform throughout the cross-sectional area of the conductor at very low frequencies becomes nonuniform as frequency is increased. Consider, for example, the case of a solid conductor to which are applied waves of increasing frequency. At direct current and at very low alternating current frequencies the current is substantially uniformly distributed throughout the cross-sectional area of the conductor and the resistance of the conductor and hence the conductor loss is at a minimum. As the frequency is increased, the current density becomes a maximum at that surface of the conductor which is exposed to the main field of the waves, which, in the present example, is the outer surface, and decreases as distance from the field increases, i. e., towards the center of the conductor. The rate at which the current density decreases is dependent upon the frequency and the material of the conductor and, for most conducting materials, at high frequency the current density at the center of the conductor becomes negligible while the current density at the conductor surface is a maximum. This phenomenon is commonly known as "skin effect" and a "skin depth" is defined as the distance measured inwardly from the surface of the conductor in which the current in the conductor will decrease by one neper, i. e., the current density becomes $1/e$ times the density at the surface of the conductor, where e is the natural logarithm base. Because of the skin effect phenomenon the alternating-current resistance of conductors increases as the frequency increases, becoming quite large at the higher frequencies, necessitating frequent amplification of the signal along the transmission path.

It has long been recognized that alternating-current resistance of the conductor to high frequencies can be

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substantially reduced if the conductor is formed of a number of conducting elements or members connected in parallel and transposed often so that each conductor receives its share of exposure to the main field. This amounts to forcing the current to distribute itself over the entire cross-sectional area of the composite of individual conducting elements, thereby increasing the total current carrying area. It follows then that the alternating-current resistance is decreased substantially, and the frequency dependency of the alternating-current resistance is likewise decreased.

One well known example of a composite conductor which utilizes the foregoing principles is Litzendraht wire which, while effective at lower frequencies, suffers from many disadvantages at the higher frequencies in that, first, each individual strand of wire must be insulated from all of the others, requiring great care in fabrication especially for operation at the higher frequencies; second, for effectiveness at the higher frequencies the diameters of the individual strands of wire become so small that of necessity there are great sacrifices in strength and ruggedness; third, with the large number of individual strands involved, proper transposition is exceedingly difficult to achieve especially when use at high frequencies is contemplated which requires numerous transpositions at very short intervals.

In accordance with the present invention, an electrical conductor having transposed conducting elements is provided which is a great improvement in many respects over other known transposed conductors. The conductor of the present invention is of particular value in applications where it is desired to accomplish transposition of the elements at the time of installation, when the frequency requirements of the conductor are known. In an illustrative embodiment of the invention, a solid elongated core member is surrounded by a plurality of hollow cylindrical members of conducting material disposed along its length. Each cylindrical member is in turn surrounded by a hollow cylindrical member of conducting material which is concentric therewith and of shorter length than the cylindrical member which it surrounds. A sheet of flexible insulating material having attached to its surface two strips of conducting material is wrapped around the conductor at the point where the ends of adjacent cylindrical members are in proximity in a manner such that the conducting strips contact the conducting members of the conductor. By properly offsetting the strips relative to each other and by covering each strip with insulation over a portion of its length, electrical conductivity is established between an outer cylindrical member and the next adjacent inner cylindrical member through one strip, and an inner cylindrical member and the next adjacent outer cylindrical member through the other strip, thereby effecting a transposition of the conducting elements.

The invention will be more readily understood by referring to the following description in conjunction with the accompanying drawings, in which:

Fig. 1 is a side elevation sectional view of a preferred embodiment of the invention showing an electrical conductor having transposed conducting elements;

Fig. 2 is a plan view of the insulating wrapping for effecting transpositions;

Fig. 3 is a cross-sectional view taken along the line 3-3 of Fig. 1; and

Fig. 4 is a cross-sectional view taken along the line 4-4 of Fig. 1.

Turning now to Fig. 1, there is shown, by way of example, a composite electrical conductor 11, which has a plurality of transpositions along its length. For purposes of clarity of illustration, only two of the transpositions have been shown however. Conductor 11 comprises

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a solid elongated core 12 of conducting material having a thin coating 13 of suitable insulating material on its surface. Disposed along the length of insulated core 12 and concentric therewith are a plurality of hollow cylindrical members 14, 14 of conducting material, the ends 15, 15 of which are in proximity to but do not contact each other. If desired, the space between the ends 15, 15 may be filled with insulation (not shown) to prevent the possibility of the ends touching as a result of shifting of the members 14, 14. Surrounding each of the members 14, 14 and insulated therefrom by an insulating layer 16 is a hollow cylindrical member 17 of conducting material. It is apparent from an examination of Fig. 1 that both the insulating layer 16 and the conducting member 17 are considerably shorter than member 14. The reason for this difference in length will be apparent hereinafter.

Transpositions of the conducting elements of conductor 11 are accomplished by means of a "bandage" or wrapping 18 of insulating material, the structure of which is best seen in Fig. 2. Wrapping 18 comprises a flat sheet of flexible insulating material such as polystyrene or polyethylene or the like which is of sufficient length to extend well along the surfaces of adjacent members 17, 17, as best seen in Fig. 1. On one side of the sheet 18 are disposed in staggered relationship two strips of conducting material 19 and 20. Each of the strips 19 and 20 is of a length sufficient to extend over a substantial portion of that part of member 14 which extends beyond the end of member 17, across the gap between the adjacent ends 15, 15 of successive members 14, and over a portion of the member 17 on the other side of the gap, as best seen in Fig. 1. The amount of offset or stagger of strip 20 relative to strip 19 is determined by the length of member 14 extending beyond the member 17. Thus, as best seen in Fig. 1, strip 20 is staggered relative to strip 19 by an amount which prevents strip 20 from touching member 17. Strips 19 and 20 have their central portions covered by insulating barriers 21 and 22 respectively. The purpose of barriers 21 and 22 is to prevent strips 19 and 20 from contacting corresponding conducting members on both sides of the gap. Thus, strip 19 contacts member 17 on the right side of the gap, but is prevented from contacting member 17 on the other side of the gap by barrier 21. Instead of strips 19 and 20 being staggered, the same desired offset of the contacting portions may be had by masking with insulating barriers those portions of the strips 19 and 20 which are not used for contacting. It is to be understood that hereafter the terms "stagger" and "offset" are intended to include this arrangement, or other similar arrangements, as well as the one herein shown. Strips 19 and 20 should be wide enough to insure good electrical contact over a substantial portion of the conducting members 14 and 17 which they touch, as seen in Fig. 3. In applications where conductor 11 is subjected to extreme pressures or frequent shifting, such as in undersea cable systems, it is essential that barriers 21 and 22 be long enough and wide enough to prevent any metal-to-metal contact due to distortion of the various elements. Thus, in such cases, the gap which is apparent in Fig. 1 between the ends of members 21 and 22 and the ends of members 14 and 16 would be filled by members 21 and 22.

In accomplishing the transposition, the "bandage" 18 is tightly wrapped around the conductor, as best seen in Figs. 3 and 4, care being taken to insure proper placing of strips 19 and 20. The width of wrapping 18 should be sufficient to permit several complete encirclements of the conductor, after which the wrapping may be clamped or held in place by any suitable means, not shown. Alternatively, wrapping 18 may first be coated with a suitable adhesive material such as polyisobutylene or the like and then wrapped around the conductor, or the adhesive material may be applied after wrapping.

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From an examination of Fig. 1 it can readily be seen that electrical energy carried by any conducting member 14 on one side of the transposition point is carried in the conducting member 17 on the other side thereof, thereby effecting an electrical transposition.

In the embodiment described, the core member 12 is of conducting material. If either or both members 14 and 17 have a thickness less than the depth of penetration, core 12 may be made to contribute to the conduction, and eddy current losses are decreased as a result of making members 14 and 17 thin. In certain applications however, it may be desirable to have core 12 made of insulating or dielectric material, in which case insulating layer 13 can be eliminated.

The effectiveness of transposition of conducting elements in a conductor depends to a considerable extent upon a judicious selection of the transposition interval, that is, the distance l between the points a and b in Fig. 1. It is desirable to transpose often enough to insure a substantial reduction in losses, yet, on the other hand, in the interests of ease and low cost of fabrication, it is desirable that the conducting elements be transposed no more frequently than is necessary. As long as the currents carried by the conducting elements are approximately equal, losses will be minimized, hence it is necessary to transpose only often enough to maintain this condition of approximate equality of currents in the conducting elements. In the drawings of the present invention, the particular embodiments shown are neither to scale nor proportion, inasmuch as the transposition interval may be quite long as compared to the length of the conductor over which the transposition is accomplished.

It is readily apparent that conductor 11 can be manufactured having core member 12, conducting members 14 and 17, and insulating members 13 and 16 continuous. At the time of installation, when the requirements of the conductor are known, the necessary interruptions in members 13, 14, 16, and 17 may be made at the desired intervals and the "bandage" 18 applied. The advantages of such an arrangement are obvious.

While in all the embodiments herein shown the conductors have been shown as having a circular cross-section, it is obvious that they may have any suitable shape, and applicant does not intend to limit himself to the particular configurations herein shown. In addition, in the embodiments herein shown, the use of insulating material around the conductors, or the use of metallic sheathing has not been shown for the sake of clarity of illustration. It is obvious that such practice is desirable and permissible in all the embodiments herein shown.

It is to be understood that the above-described arrangements are merely illustrative of the application of the principles of the invention, and applicant does not intend to limit his invention to the particular embodiments herein shown. 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 low loss electrical conductor comprising a first elongated member of conducting material, said member being periodically interrupted along its length, and a second elongated member of conducting material surrounding said first member and insulated therefrom, said second member being periodically interrupted along its length at points corresponding to the interruptions in said first member, and means for effecting electrical connections between said second member on one side of an interruption and said first member on the other side of the interruption, and between said first member on the said one side of the interruption and said second member on the said other side, said means comprising a member of insulating material having a plurality of conducting elements thereon, said insulating member surrounding said conductor and so positioned relative to the first and sec-

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ond members that at least one conducting element contacts said second member on one side of the interruption and said first member on the other side thereof, and at least one conducting element contacts said first member on the said one side of the interruption and said second member on the said other side.

2. A low loss electrical conductor as claimed in claim 1 wherein said member of insulating material comprises a flexible sheet of insulating material wrapped around said conductor.

3. A low loss electrical conductor as claimed in claim 1 wherein said conducting elements each comprise a thin flat strip of conducting material having one surface affixed to said member of insulating material, and having its opposite surface covered with insulating material over its central portion.

4. A low loss electrical conductor as claimed in claim 3 wherein the contacting portions of said conducting elements are in offset relation to each other.

5. A low loss electrical conductor comprising an elongated core member, a plurality of hollow members of conducting material disposed along said core member in spaced relation to each other, an outer hollow member of conducting material surrounding each of said hollow members and insulated therefrom, said outer members being shorter in length than said hollow members, and a plurality of thin sheets of insulating material each having a pair of conducting strips thereon, each of said strips being coated with insulation over a portion of its length and being uncovered over a portion of its length, the uncovered portions of one of said strips being offset from the uncovered portions of the other of said strips, said

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sheets of insulating material being wrapped around said conductor, the conducting strips thereon forming an electrical connection between each outer cylindrical member and the axially adjacent hollow member.

6. A low loss electrical conductor as claimed in claim 5 wherein said core member is of dielectric material.

7. A low loss electrical conductor as claimed in claim 5 wherein said core member is of conducting material, said core member being insulated from said hollow members.

8. A low loss electrical conductor as claimed in claim 5 wherein said hollow members have a wall thickness equal to or less than a skin depth at the highest frequency of operation of said conductor.

9. A low loss electrical conductor as claimed in claim 5 wherein said outer members have a wall thickness equal to or less than a skin depth at the highest frequency of operation of said conductor.

10. A low loss electrical conductor as claimed in claim 5 wherein said core member is of conducting material, said core member being insulated from said hollow members, and both said hollow members and said outer members having a wall thickness equal to or less than a skin depth at the highest frequency of operation of said conductor.

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