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ELECTRICAL CONDUCTOR HAVING TRANSPOSED CONDUCTING ELEMENTS

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FIG. 1

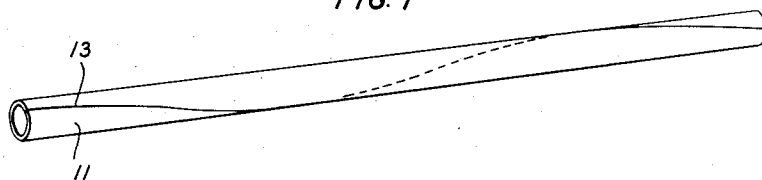


FIG. 3

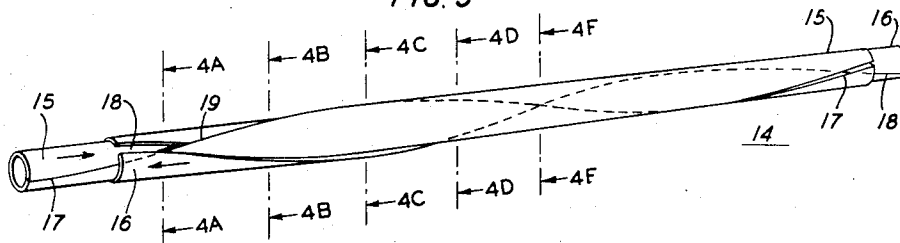


FIG. 4A

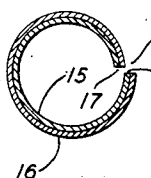


FIG. 4B

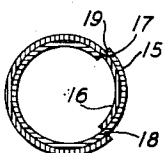


FIG.4C



FIG. 4D



FIG. 4F

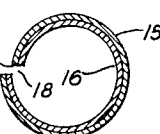


FIG. 6

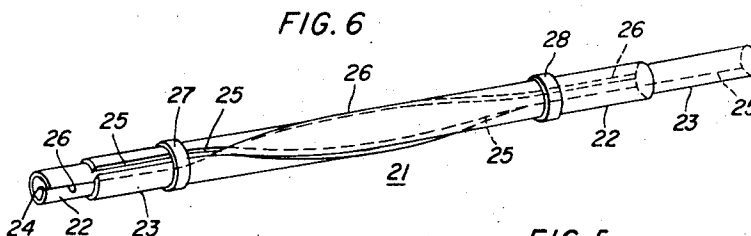


FIG. 5

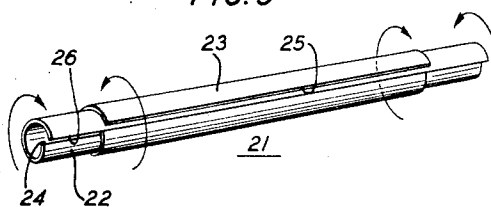
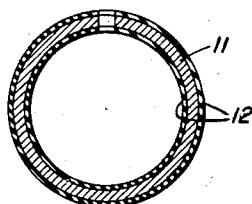


FIG. 2



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1

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ELECTRICAL CONDUCTOR HAVING TRANSPOSED CONDUCTING ELEMENTS

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Application June 30, 1955, Serial No. 519,023

4 Claims. (Cl. 174—34)

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 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, now Patent 2,812,502 issued on November 5, 1957.

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., toward 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

$$\frac{1}{e}$$

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 larger at the higher frequencies, necessitating

2

frequent amplification of the signal along the transmission path.

It has long been recognized that the alternating-current resistance of a conductor to high frequencies can be 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 diameter of the individual strands of wire must be made 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. In an illustrative embodiment of the invention, first and second hollow cylindrical members of conducting material, each having a coating of insulating material on both inner and outer surface, are spirally slit along their lengths. One member is inserted into the other member. The two members are threaded together lengthwise by pushing on one member and holding the other rigid so that the inner member slips through the slit in the other member until what was the inner member becomes the outer member, thereby effectively transposing the members.

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 perspective view of one of the members of the conductor of the present invention;

Fig. 2 is a cross-section view of the element of Fig. 1;

Fig. 3 is a perspective view of a portion of the conductor of the present invention, showing a transposition;

Figs. 4A through 4F are cross-sectional views of the conductor taken along the lines 4A through 4F, respectively, in Fig. 3;

Fig. 5 is a perspective view of an intermediate step in the production of another embodiment of the present invention; and

Fig. 6 is a perspective view of the embodiment in Fig. 5 showing a transposition.

Turning now to Figs. 1 and 2, there is shown an elongated cylindrical element 11 of any suitable conducting material having layers 12 of insulating material on both the inner and outer surfaces. In the illustrative embodiment of Fig. 1, element 11 has a spiral slit 13 extending longitudinally throughout the length of the element. As will be apparent hereinafter, the pitch angle of slit 13 is to an extent determinative of the length of conductor required to accomplish a complete transposition.

In Fig. 3 there is shown a conductor 14 which comprises

two conducting elements 15 and 16 which are identical to the element 11 shown in Figs. 1 and 2, conducting element 15 having a spiral slit 17 extending throughout its length and conducting element 16 having a spiral slit 18 extending throughout its length, the slit 18 being spiraled in opposite sense to slit 17. Elements 15 and 16 are threaded together lengthwise to form conductor 14 by pushing element 15 into the hollow cylinder of element 16, as best seen in Fig. 3, slit 17 in element 15 passing through slit 18 in element 16 to form edge 19. As elements 15 and 16 are assembled to form conductor 14, transpositions of the elements are periodically accomplished by elements 15 and 16 rotating relative to each other, as edge 19 moves along slit 18 in response to the pushing action exerted on element 15 while element 16 is held fixed, as best seen in Figs. 4A through 4F. In Fig. 4A elements 15 and 16 are shown in their position in conductor 14 just prior to a transposition. It can be seen that element 15 is substantially completely enclosed by element 16, and slits 17 and 18, at that point, intersect. As the elements 15 and 16 are moved relative to each other, edge 19 formed by slit 17 in element 15 is passed through slit 18 in element 16, as seen in Fig. 4B. Continued moving of elements 15 and 16 relative to each other results in element 15 passing through slit 18, or, depending upon the point of view, element 16 passing through slit 17 until a point is reached on conductor 14 where element 16 is substantially completely enclosed by element 15, as best seen in Fig. 4F. Thus a transposition of elements 15 and 16 is accomplished.

It is apparent that the foregoing technique is not the only method of threading together two tubular conductors. As an example, both tubes could be opened out where they are slit and threaded together by passing a free end of each through the slit of the other. Thus, it should be understood that applicant does not intend to be limited to the threading procedures herein described.

The effectiveness of transpositions of conducting elements in a conductor depends to a considerable extent upon a judicious selection of the transposition interval, that is, the distance between transpositions. 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 fabrications, 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 is preferably quite long as compared to the length of the conductor over which the transposition is accomplished.

In Fig. 5 there is shown another embodiment of the present invention. In the embodiment of Fig. 5, a conductor 21 is formed from two conducting elements 22 and 23. Elements 22 and 23 are similar to the conducting element 11 of Figs. 1 and 2, but, instead of a spiral slit, element 22 has a straight slit 24 extending throughout its length and element 23 has a straight slit 25 extending throughout its length. Conductor 21 is formed by insertion of one of the elements into the other which is held rigid. In the example shown in Fig. 5, element 22 is inserted into element 23 and substantially completely enclosed thereby except that the edge 26 formed by slot 24 in element 22 passes through slot 25 in element 23. During assembly of elements 22 and 23, transpositions are accomplished at the desired intervals by twisting the elements relative to each other so that edge 26 rotates with respect to element 23 as it passes through slot 25 in element 23. Continued application of torque at one end of the desired transposition length on member 23 and at the other end, in an opposite sense, on member 22 results in member 22 com-

pletely passing through slot 25 over the transposition length until it substantially completely encloses member 23. Thus members 22 and 23 are transposed. It is obvious from the foregoing that the length of conductor 21 over which a complete transposition occurs depends upon the amount of twist or torque applied to the elements 22 and 23. Thus, the greater the torque, the shorter the transposition length.

Unless members 22 and 23 are permanently deformable, it becomes necessary to tape or otherwise fix the members relative to each other at each side of the transposition after the transposition is made. Any suitable method or means for accomplishing this may be used. It is readily apparent from the foregoing, that although the slits in members 22 and 23 are straight over the major portion of the length of the conductor 21, for the length of the transpositions these slits will have a substantially spiral configuration since the generatrices of cylindrical members 22 and 23 are deformed in a spiral-like manner by the opposite turning moments applied to the members, as shown in Fig. 6. Tapes 27 and 28 shown on Fig. 6 fix the twisted members relative to each other. It should be noted in Fig. 6 that the element 22 is enclosed by element 23 to the left of tape 27 and that element 22 encloses element 23 to the right of tape 28, the transposition occurring between tapes 27 and 28.

In the embodiments herein shown, each conducting member has consisted of a single layer of conducting material. It is also quite feasible to make each of the conducting members in the form of a plurality of thin layers of conducting material separated by insulating material, and it is intended by applicant that such structures be included within the scope of his invention. In addition, in the embodiments herein shown, the particular uses to which applicant's invention may be put have not been shown for the sake of clarity of illustration. It will be obvious to one skilled in the art that the low loss electrical conductor of the invention is adaptable to a wide variety of uses, and is of value in any system calling for electrical conductors.

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 first and second conducting members, each of said conducting members having a layer of insulation on its surface and a slit extending throughout its length, said members alternately enclosing one another throughout the length of the conductor, the enclosed member periodically passing through the slit in the enclosing member to the outside thereof, whereby the enclosed member becomes the closing member.

2. A low loss electrical conductor as claimed in claim 1 wherein the slit in each of said conducting members is a spiral slit.

3. A low loss electrical conductor comprising a first hollow cylindrical member of conducting material having a thin layer of insulation on its inner and outer surfaces and a second hollow cylindrical member of conducting material having a thin layer of insulation on its inner and outer surfaces, each of said members having a slit extending throughout its length, said members alternately enclosing one another throughout the length of the conductor, the enclosed member periodically passing through the slit in the enclosing member to the outside thereof, whereby the enclosed member becomes the enclosing member.

4. A low loss electrical conductor comprising a first hollow cylindrical member of conducting material having a thin layer of insulation on its surfaces and a second

5

hollow cylindrical member of conducting material having a thin layer of insulation on its surfaces, each of said members having a spiral slit extending throughout its length, the slit in one of said members being spiraled in a sense opposite to the slit in the other of said members, said members alternately enclosing one another through-

6

out the length of the conductor, the enclosed member periodically passing through the slit in the enclosing member to the outside thereof, whereby the enclosed member becomes the enclosing member.

No references cited.