Dec. 5, 1939. A. S. WINDELER 2,182,330

METHOD OF FABRICATING TUBULAR STRUCTURES

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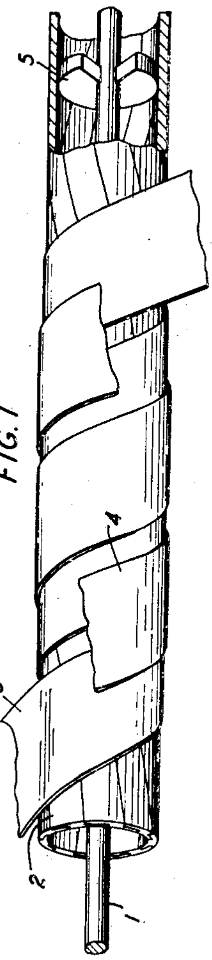
FIG. 1

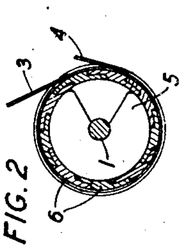
FIG. 2

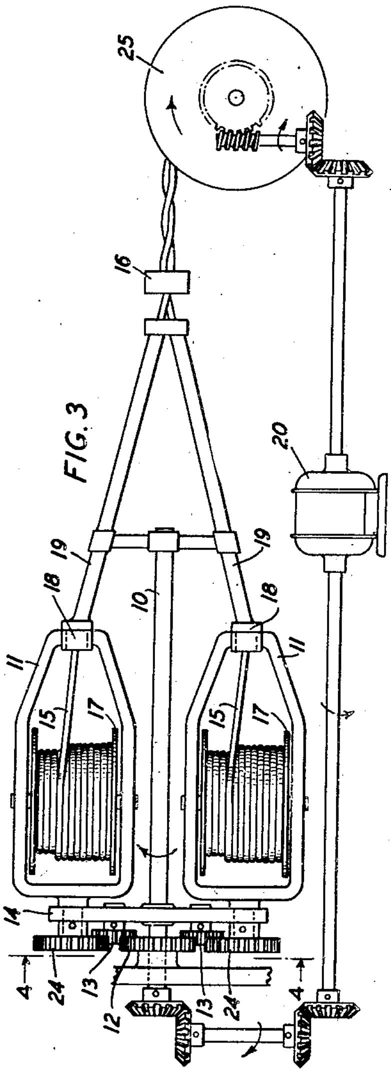
FIG. 3

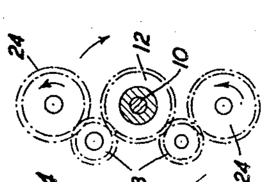
FIG. 4

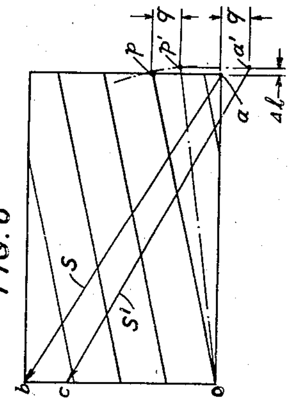
FIG. 6

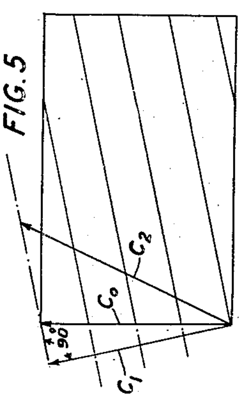
FIG. 5

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METHOD OF FABRICATING TUBULAR STRUCTURES

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6 Claims. (Cl. 153—78)

The present invention relates generally to the manufacture of composite tubular structures and more particularly to the manufacture of coaxial conductor transmission lines and cables adapted for high frequency electromagnetic waves in which the outer conductor of the coaxial pair comprises a plurality of interengaging profiled conducting strips.

A principal object of the invention is to improve the electrical properties of a composite tubular structure. More particular objects are to improve the electrical properties of a composite coaxial conductor of the kind described, to reduce the effective electrical resistance of the outer conductor and the attenuation of the coaxial pair and to increase the shielding effect of the outer conductor on the electromagnetic waves transmitted through the line. These and other objects will appear more fully in the description hereinafter of specific embodiments of the invention.

There has been described heretofore a structure for the transmission of electromagnetic waves at high frequencies comprising a pair of coaxial conductors, connected one as a return for the other, the inner conductor being a copper wire or tube and the outer conductor comprising a multiplicity of profiled copper strips disposed in laterally abutting and overlapping relation to form a tubular structure held together by a metallic tape applied helically and under tension around the composite tubular structure. Such a structure is shown in the United States patents of J. F. Wentz No. 2,018,477, October 22, 1935; A. Talmann No. 2,080,514, May 18, 1937, and C. Kreisher No. 2,080,491, May 18, 1937. The separator for holding the central conductor in position may comprise beads or washers of insulating material, a helical wrapping of partially acetylated cotton cord around the central conductor, or any other equivalent means such that the dielectric medium separating the two conductors is substantially gaseous. The separating means does not, or need not, contribute to the mechanical support of the outer conductor.

Preparatory to the manufacture of a coaxial conductor cable to provide carrier wave communication service between New York and Philadelphia, electrical tests showed that cables of the kind described, for example, in the Wentz patent supra, had greater attenuation than was anticipated, the effective resistance of the outer conductor ranging at 350 kilocycles per second from 26 per cent to 83 per cent higher than the effective resistance of an integral copper tube of the same dimensions. Various theories were advanced to account for the excess resistance and various refinements were incorporated in the strip profile and in the manufacturing method employed, but the effective resistance still remained high. At one stage of the experimental work, the binding tapes were applied under terrific tension and the conductor was drawn through a circular die that was so close-fitting that the conductor would be occasionally blocked and the machinery thrown out of commission.

Applicant's solution of the difficulty is a simple one but exceedingly effective. In its simplest terms it comprises twisting the conductor in one direction or the other, the proper direction of twist depending on various factors to be considered hereinafter. The twisting action is effective to increase the tension of the binding tape and to force the profiled copper strips into more intimate contact with each other and at the same time to displace or slide the strips slightly relative to each other thereby providing a better electrical and mechanical contact between them. The improvement in electrical characteristics obtained by use of the invention is indicated by the fact that the effective resistance of the outer conductor at 350 kilocycles per second may be reduced to as low as 112 per cent of the resistance of an integral copper tube. The shielding effect of the outer conductor is at the same time likewise substantially increased.

The nature of the present invention will appear more fully from the following detailed description, reference being made to the accompanying drawing, in which:

Figs. 1 and 2 show a coaxial conductor unit adapted for manufacture in accordance with the present invention;

Figs. 3 and 4 illustrate a specific embodiment of applicant's novel method of manufacturing coaxial conductor lines and cables; and

Figs. 5 and 6 are diagrams utilized in explaining the effects of twisting a cable of the kind illustrated in Figs. 1 and 2.

Referring now to Figs. 1 and 2 there is shown a coaxial conductor unit that has been selected as a basis for describing an illustrative embodiment of the present invention. The unit shown comprises a central copper wire 1, a tubular outer conductor 2 comprising profiled copper strips 6 of the specific kind shown in both Talmann and Kreisher, supra, and a pair of steel binding tapes 3, 4, applied helically over the tubular conductor. The inner conductor is held in its central position by means of slotted insulating washers 5 disposed at intervals on the central conductor.

In a particular embodiment which may be held in mind by way of example, the outer conductor comprises nine profiled strips disposed with a lay, direction left, of 3 inches to form a close-fitting structure having an inside diameter of 0.27 inch and a thickness of 20 mils. The steel binding tapes are each 6 mils thick and $\frac{5}{16}$ inch wide applied, direction right, with a gap of $\frac{1}{32}$ inch, the outer tape being centered over the gap formed by the inner tape. The unit is manufactured in suitable lengths, the ends of the steel tapes are brazed to the copper, and the lengths are reeled in preparation for the next stage in the manufacture of the cable.

Figs. 3 and 4 illustrate machinery and method for the fabrication of a twin coaxial cable comprising two units of the kind illustrated in Figs. 1 and 2 stranded together. Following the stranding operation, a lead sheath may be extruded over the assemblage. In the stranding operation the individual coaxial units are twisted in accordance with the invention at the same time they are stranded together, but before considering the details of machinery and method, attention is directed to Figs. 5 and 6 which illustrate qualitatively the effect of twisting the individual units.

Fig. 5 illustrates the effect twisting has on the diameter or circumference of the tubular copper structure, whereas Fig. 6 illustrates the effect it has on the diameter or circumference of the helical wrapping of steel tape. Each figure represents a development of a unit length of the structure, the unit length being the pitch of the steel tape before the structure is twisted and as illustrated in Fig. 1. The number of copper strips has been reduced in this showing for the sake of simplicity.

The outer circumference of the copper tube in its original condition is given directly by the dimension C_0 indicated in Fig. 5. If now the tubular structure is twisted in a right-hand sense, i. e., in such manner as to reduce the twist of the copper strips, the circumference decreases and approaches a minimum value C_1 which would be reached if the copper strips were completely untwisted so as to lie parallel to the axis of the tube. If, on the other hand, the structure is twisted in the opposite or left-hand sense to increase the twist of the copper strips then the circumference increases, a typical enlarged circumference being represented at C_2. Thus, twisting the copper structure in the one sense tends to decrease its over-all diameter and twisting it in the opposite sense tends to increase the diameter, and if the diameter of the helix formed by the steel tape did not change at the same time, these two directions of twist would result respectively in loosening and tightening the steel tape.

The twisting of the copper structure, however, causes a change in the diameter of the helix to which the steel binding tapes conform; and in the specific embodiment illustrated this change is in the same direction as the change in diameter of the copper structure. In the unit length of coaxial unit shown in development in Fig. 6, where S represents the steel tape, the distance *ob* represents the circumference of the helix to which the steel tape conforms before the structure is twisted. Supposing now that the unit is twisted in a right-hand sense, tending to straighten out the copper strips so that the strip edge *op* is moved to the position *op'*, the length of the unit is thereby increased by an amount Δl as the point *p* moves to its new position *p'*. The right-hand end *a* of the steel tape S has now moved circumferentially a distance *q* equal to the circumferential separation between the points *p* and *p'* so that its new position may be represented on the diagram as *a'*. The steel tape being of fixed length, it is evident that it will now extend along S' from *a'* to some point *c* on the left-hand end of the unit length, the distance *oc* representing the new circumference of the helix to which the steel tape tends to conform. In brief, the increase in length of the cable due to untwisting of the copper structure and the increase in the number of turns of the steel binding tape per unit length of cable both tend to force the steel tape to conform with a helix of lesser diameter. Conversely, reversing the helical sense in which the original structure is twisted will increase the diameter of the helix to which the steel tape conforms.

Whereas twisting the structure causes the diameter of the copper structure and of the binding helix to change in the same direction, applicant has discovered and demonstrated experimentally that one of these diameters, viz., that of the binding helix in the illustrative embodiment under consideration, changes at a slightly faster rate than the other one. The net result is that twisting the structure shown in Fig. 1 in a right-hand sense so as to untwist the copper strips causes the steel binding tape to be drawn tighter around the copper structure and to force the copper strips into more intimate contact with each other.

Figs. 3 and 4 show a typical stranding machine of the geared-carriage type, as distinguished from one of the free-floating carriage type, which can be used where a single coaxial unit is to be twisted or where two such units are to be individually twisted and stranded together to form a twin coaxial conductor cable. The same principles of manufacture can be used for cable comprising any number of coaxial units. The machine comprises the usual rotatable carriages **11** each of which carries a reel **17** on a transverse axis about which the reel is free to rotate as the coaxial unit it carries is drawn off. The carriages **11** are journaled at one end in a cross-bar **14** which is rigidly attached to the drive shaft **10**, the latter being driven from any suitable source such as the motor **20** illustrated. Shaft **10** is journaled at one end in a fixed gear **12** which meshes with intermediate gears **13** journaled in the cross-bar **14**. The gears **13** in turn mesh with gears **24** to rotate the carriages **11** as the latter revolve about the drive shaft. The coaxial units are taken off their respective reels **17** through hollow hubs **18** and hollow frame members **19** to a circular die **16** where the two units are stranded together to be taken off on a capstan or receiving reel **25**. With this form of machine the amount of twist imparted to the individual coaxial units may be controlled within wide limits by varying the relative sizes of gears **12** and **24**.

For the specific embodiment hereinbefore described and illustrated in Fig. 1 it is found that a favorable amount of twist is one turn in 32 inches length of coaxial unit, although this amount is not critical and twists ranging from one turn in 20 inches to one turn in 40 inches have been found to be entirely satisfactory.

In view of applicant's discoveries it has been concluded that the comparatively high resistance found in the Wentz type of coaxial unit as heretofore constructed and in twin cables comprising such units stranded together without distortion, that is, using the conventional free-floating carriage type of strander, is attributable in large part to interstrip resistance resulting from imperfect lateral contact of the profiled copper strips. As mentioned hereinbefore, applicant's method has made it possible to effect a substantial reduction in the excess of resistance over the theoretical ideal.

It may be added that the stresses incident to the twisting operation have not been found such as to cause collapse of the composite tubular structure even with a wall thickness of 20 mils. There is a strong tendency for the coaxial units to snarl, however, as they approach the die 16, but the tubular guides 19 have been found to suppress this tendency satisfactorily. No such tendency appears once the twisting and stranding operations have been completed, and it is supposed that the copper strips set themselves after distortion beyond the elastic limit.

What is claimed is:

1. In the manufacture of a flexible conductor for the transmission of high frequency electrical currents, said conductor comprising a multiplicity of strips disposed with a relatively long lay in one helical direction in laterally abutting, interengaging relation to form a tubular structure and metallic binding means wound helically about said structure with a relatively short lay in the opposite helical direction to render said structure self-supporting, the method step which comprises twisting said conductor about its axis in the helical sense of said binding means so as to tighten said binding means.

2. The method of fabricating a hollow conductor comprising copper strips disposed with a relatively long lay and in laterally overlapping relation with lateral abutment at least at the inner periphery of said conductor and a metallic tape wound helically with a relatively short lay around said strips to hold them in position, said lays being of mutually opposite helical senses, which comprises twisting said conductor about its axis in the helical direction of said metallic tape so that said strips are slightly displaced longitudinally with respect to each other and simultaneously forced laterally into more intimate contact with each other.

3. In the manufacture of a cable comprising a pair of coaxial conductor units, each of said units comprising a tubular outer conductor made up of a plurality of copper strips disposed in laterally overlapping, abutting relation with a relatively long lay in one helical direction and metallic binding means wound helically about said copper strips with a relatively short lay in the opposite helical direction to maintain said strips in position, the method step which comprises stranding said units together and simultaneously twisting each on its axis in the helical direction of said binding means.

4. In the fabrication of a cable for the transmission of high frequency electrical currents comprising a hollow conductor made up of a multiplicity of wide copper strips disposed with a relatively long lay of one helical sense and in laterally overlapping relation with lateral abutment at least at the inner periphery of said conductor and a metallic tape wound around said strips with a relatively short lay of the opposite helical sense to hold said strips in position, the method which comprises twisting said conductor in said opposite helical sense so that said strips are slightly displaced longitudinally with respect to each other and forced laterally into more intimate contact with each other.

5. In the manufacture of a cable comprising a plurality of shielded conductor units, each of said units comprising a tubular outer conductor made up of a plurality of metallic strips disposed in laterally engaging relation with a relatively long lay in one helical direction and metallic binding means wound about said strips with a relatively short lay in the opposite helical direction to maintain them in position, the method step which comprises stranding said units together and simultaneously twisting each in the helical direction of its respective binding means.

6. In the manufacture of a cylindrical structure comprising a multiplicity of strips disposed in laterally abutting relation with a relatively long lay in one helical direction and a binding member wound around said strips with a relatively short lay in the opposite helical direction for holding them in cylindrical assemblage, the method step which comprises twisting said structure about its axis in the helical direction of said binding member so that said binding member forces said strips into more intimate lateral contact with each other.

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