March 8, 1927. 1,620,552

E. H. JACOBS ET AL

ELECTRIC TRANSMISSION SYSTEM

Filed July 23. 1920 5 Sheets-Sheet 1

Fig. 1.

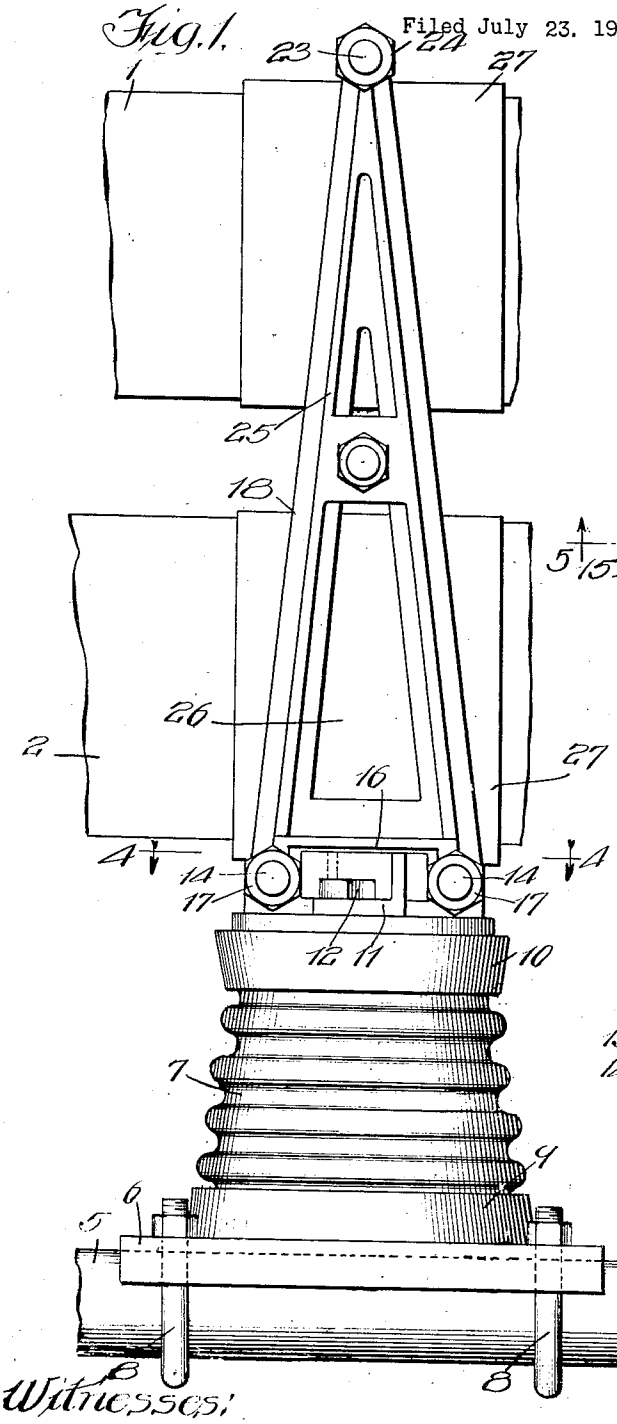


Fig. 4.

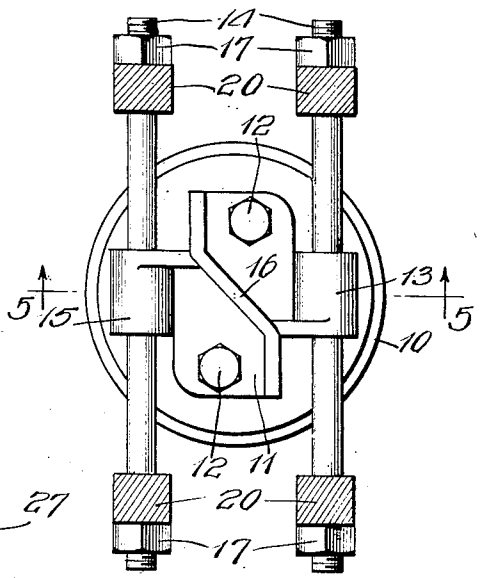
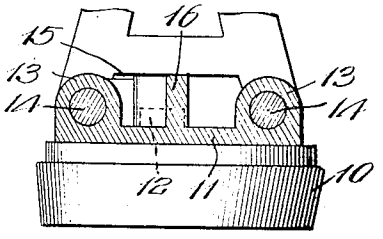


Fig. 5.



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ELECTRIC TRANSMISSION SYSTEM

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Fig. 2.

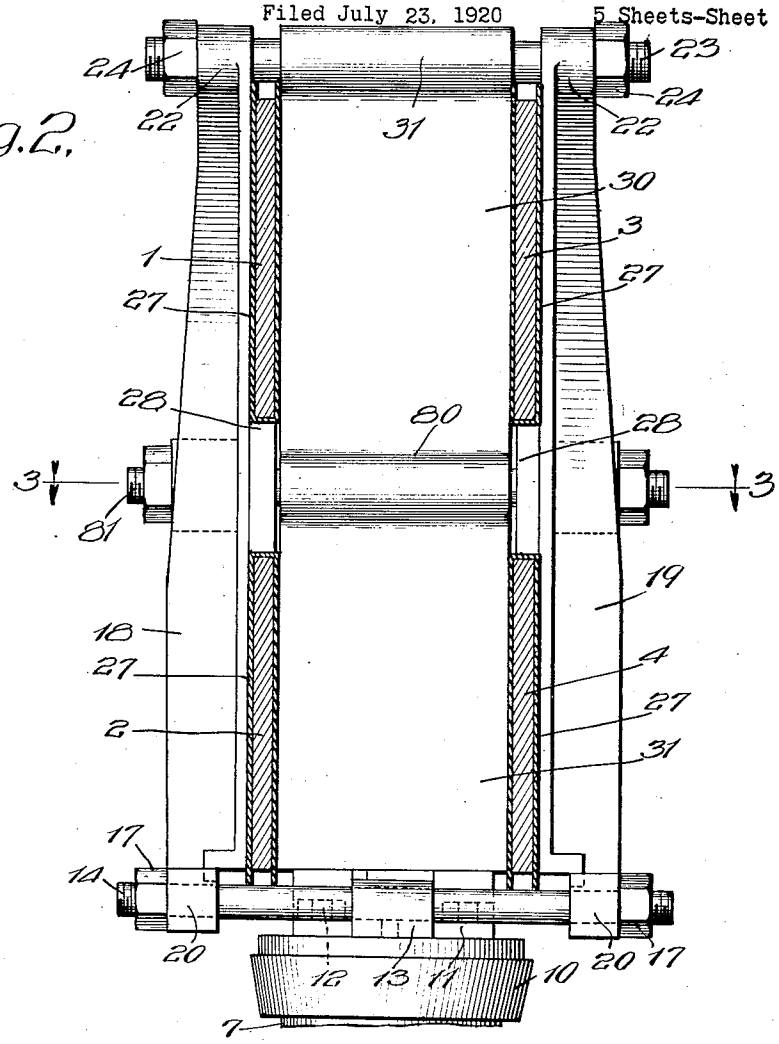
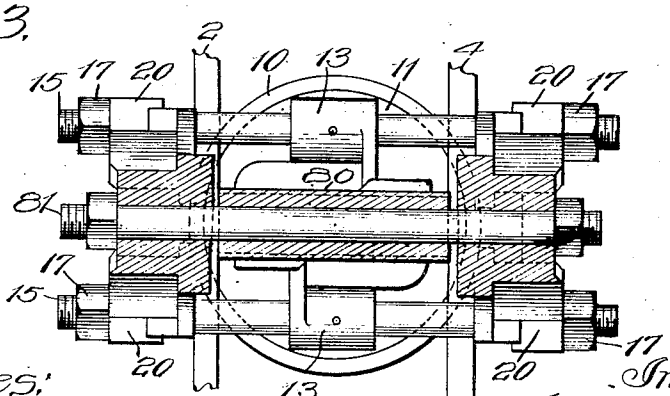


Fig. 3.



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ELECTRIC TRANSMISSION SYSTEM

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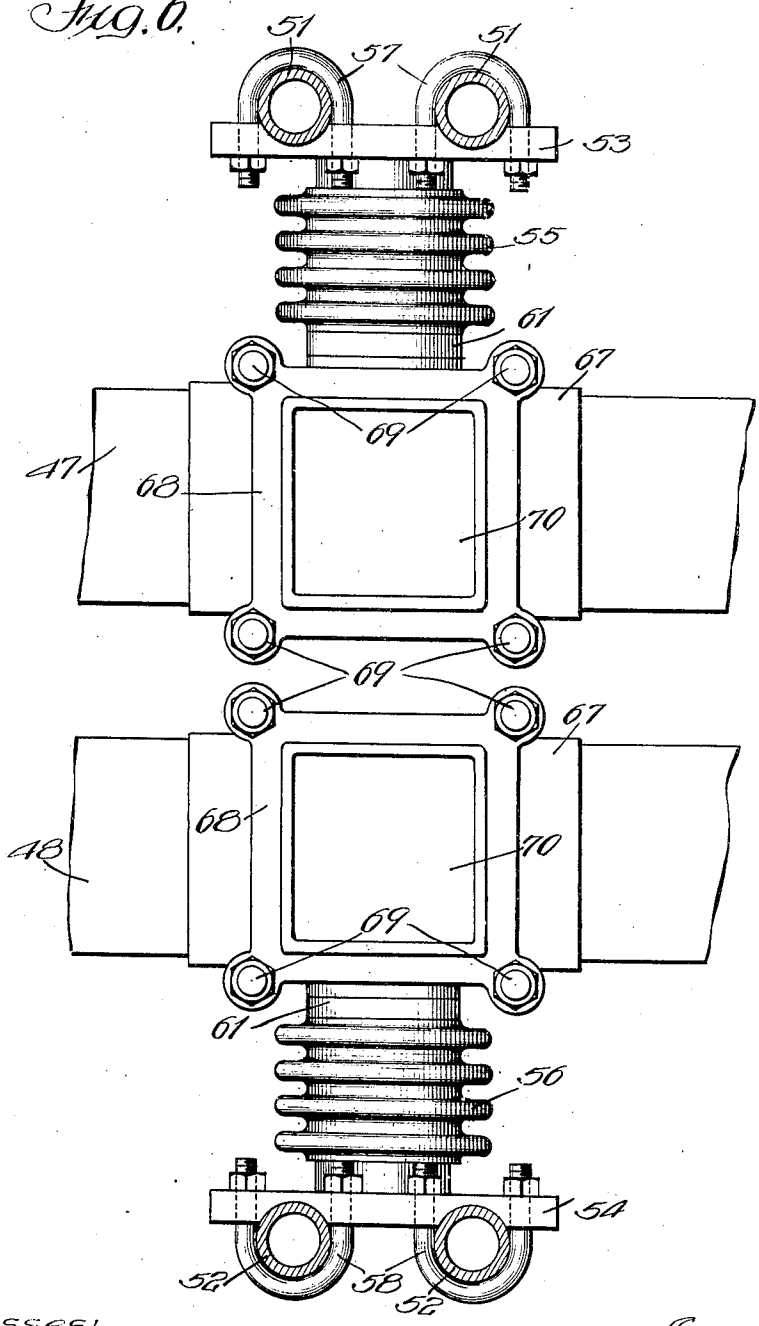
Fig. 6.



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E. H. JACOBS ET AL

ELECTRIC TRANSMISSION SYSTEM

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Fig. 7.

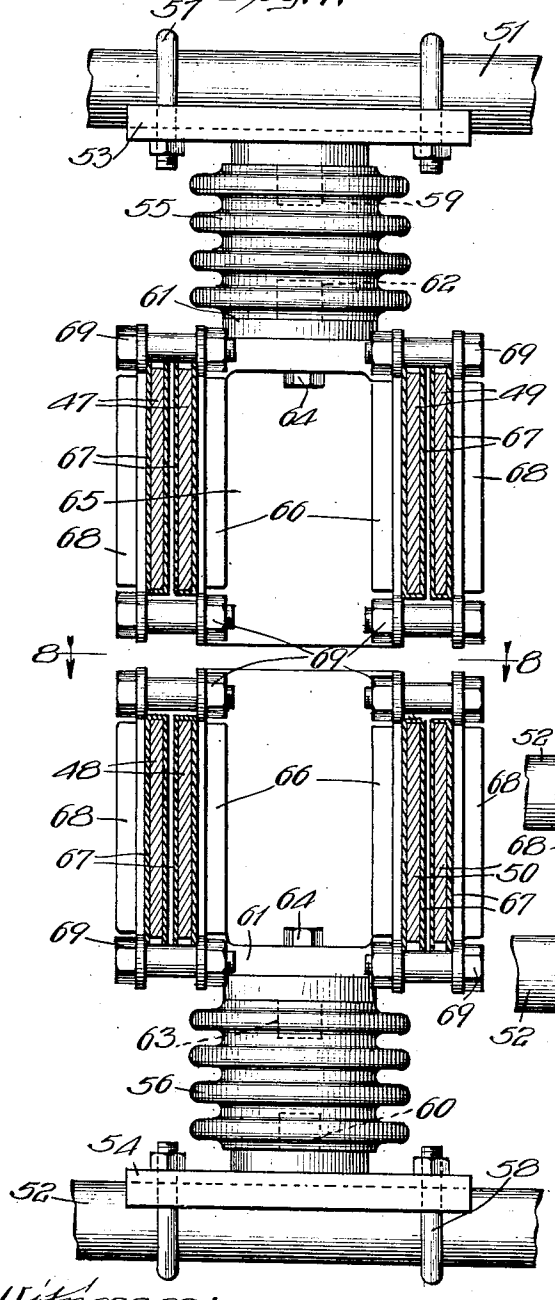
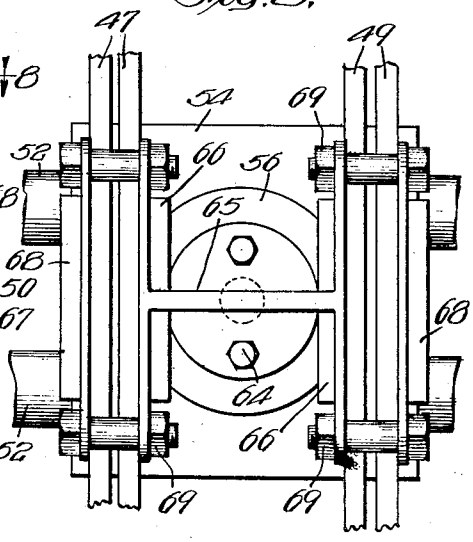


Fig. 8.



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March 8, 1927. 1,620,552

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ELECTRIC TRANSMISSION SYSTEM

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Fig. 9.

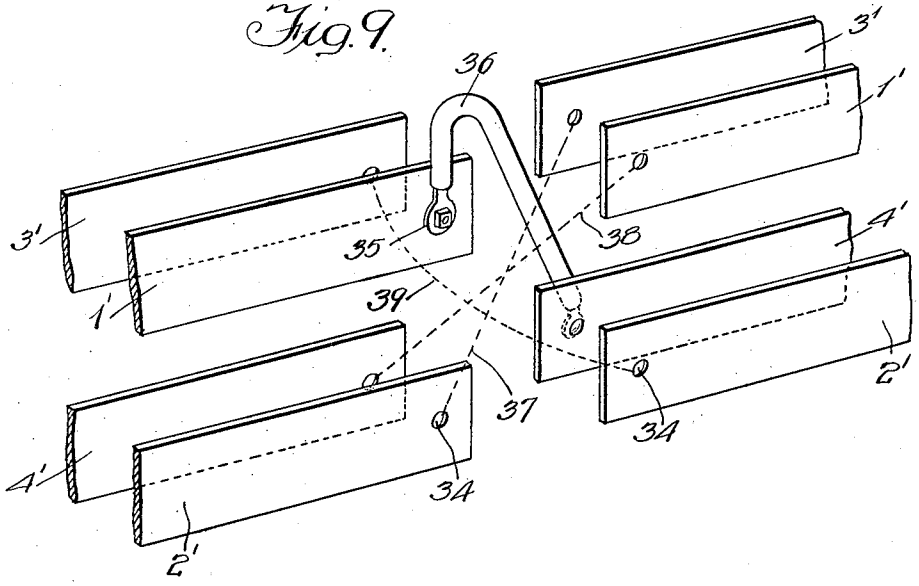


Fig. 10.

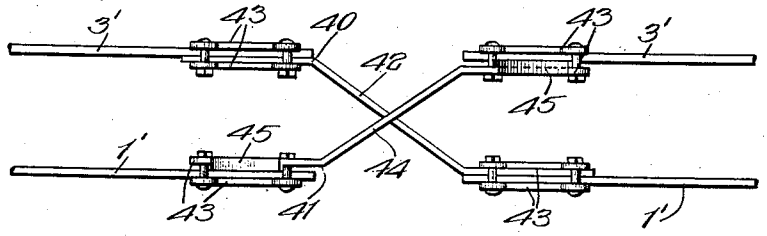
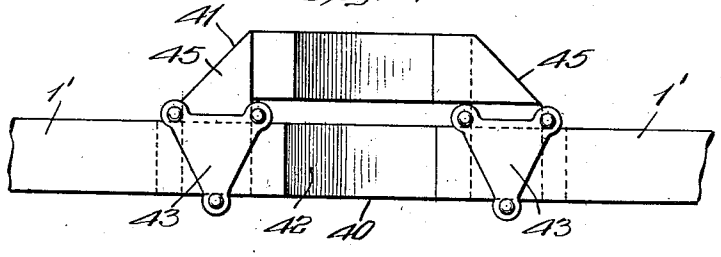


Fig. 11.



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Patented Mar. 8, 1927. 1,620,552

UNITED STATES PATENT OFFICE.

ERNEST H. JACOBS AND CHARLES FREDERIC SCHOONMAKER, OF CHICAGO, ILLINOIS.

ELECTRIC-TRANSMISSION SYSTEM.

Application filed July 23, 1920. Serial No. 398,532.

Our invention relates to systems of electrical transmissions and distribution, and particularly interior station systems and the like.

While our invention relates particularly to installations and systems requiring a large flow of current at relatively low voltage, we do not intend to limit the invention to the use of such voltage, but intend the invention to be applicable to all situations where the problem is chiefly one of current flow. The problem is, of course, complicated by higher voltages, but the principles of the invention are equally applicable to high voltages as well.

Heretofore, the transmission of relatively large current flow in a system such as the bus and feeder systems of an electric generating or distributing station has presented very considerable practical difficulties.

It is a well known fact that in direct current work for the conduction of a certain amount of current flow, a proportionate amount of copper is necessary to carry the current flow with a predetermined drop in voltage. This direct relation does not hold good for alternating current systems, because of the phenomenon of inductance. In systems employing a relatively high voltage, this drop of voltage (I R) is generally unimportant while in systems operated at a relatively low voltage, it may be quite important, but in each case, the most important factor is the matter of the heat or I^2 R loss which occurs due to the current flow. This loss appears as heat and it will be appreciated that the loss varies with the square of the current. Consequently where current flow of great magnitude is to be conducted, it is important that a minimum amount of resistance be encountered in order to make this loss as small as possible, and that the conductors be arranged to dissipate the heat that is unavoidably generated both for the purpose of safety and to keep the resistance of the copper as low as possible. Hence to avoid resistance the copper should be worked at low current density and should be well ventilated.

In alternating current work in addition to loss of energy due to I^2 R loss and in addition to drop of voltage caused by resistance encountered, the inductance of the conductors must be taken into account. The inductance causes undesirable results first in creating an additional drop in voltage at the point of consumption and second of reducing the efficiency of the system because of the less advantageous application of the electrical energy due to lowered power factor. The loss of energy due to resistance can be decreased by increasing the cross section of the copper, but this increases the cost of the installation.

It is advantageous to keep the cost of the installation as low as possible, first because of initial cost and second because of the interest on the investment and it will readily be apparent that if the interest on the investment is higher than the cost of the loss the investment in copper is too great. The economic balance prevails when the cost of the loss is equal to the interest on its investment in copper plus annual necessary allowance for depreciation.

But increase of the size of copper alone will not correct the inductive effect so long as the prior practice of arrangement of the conductors is adhered to. At present, it is customary to form the bus bar of strips of oblong cross sections, these strips or bars being set with the greatest length of the cross sectional dimension in a substantially vertical position. If one bar is insufficient, it is customary to clamp two or more of such bars side by side in order to increase the cross sectional area of the conductor.

We have found that such practice is not satisfactory, because the temperature rise increases more rapidly than the increase in cross sectional area. Among other reasons is the decreased effective area for radiation because of the arrangement of the bars and secondly and more important is the fact that the current does not distribute itself evenly throughout the cross section of such conductors.

Such increase in the size or cross section of the copper augments the "skin effect". Due to the fact that the alternating current is accompanied by an alternating magnetic flux, the innermost portions of the conductor are surrounded by a greater proportion of the flux than are its outer portions. The result is that a greater back E. M. F., due to induction, is encountered by the current flowing in the central port of the conductor. The result is that the current distributes itself mostly along the outer surfaces of the conductor and the central part of the con-

ductor carries a reduced proportion of its carrying capacity. This effect of back E. M. F. at the central part of the conductor is dependent upon the magnetic flux and since magnetic flux is a function of current flow it will be seen that the effect is intensified in conductors carrying relatively large currents.

Broadly the purpose of the present invention is to provide an improved arrangement of the conductors which will to as great a degree as possible avoid the above objectionable features.

According to the theory of our invention, we place all of the conductors relatively upon the outside around an air core and thus make all of the bars relatively outside bars where they are most effective to carry current and to radiate heat. It has been found that where a group of conductors are clamped side by side, the outside bars carry the most current and become most heavily heated. We preferably dispose the bars with the longer axis vertical, grouping them preferably in a closed figure as, for instance, at the corners of a polygon. In this manner, we secure a fairly even distribution of the current among all of the conductors of a bus or feeder and at the same time present a maximum of the lateral surfaces to the air for cooling with the result that we are able to carry a much greater volume of current per unit cross section than is possible as practiced in the prior art.

We are aware that it has been proposed heretofore to employ hollow conductors, but it will be apparent at once that a hollow conductor would not have the advantage in flexibility, cooling surface, ease of construction, and maintenance which is a property of the method and scheme of our invention.

We are aware that the prior art has subdivided the total cross section of a single high potential conductor into several finer wires in that a greater voltage is required to start corona (luminous spark discharge which surrounds a conductor when its potential is raised above a certain point) around such an arrangement than around a single conductor of cross section equal to the total cross section of the several finer wires. Such an arrangement increases the efficiency of the high tension system to a certain extent by increasing the voltage necessary to break down the air or other insulating medium surrounding the conductor. Such corona effect is not encountered in a low voltage system.

Our invention aims primarily to provide a method of employing the copper in such a manner that the non-utilized conducting areas of the prior art are reduced to a minimum and the heat radiating capacity of the surfaces is augmented by the chimney effect and by the presentation of greater area to cooler air. The efficiency of the conductor is thereby increased by reducing the amount of copper necessary for a given current flow, and the reactance to be overcome. The result is that the original cost of installation and the cost of operation are decreased.

As a further feature our invention provides an improved mounting for the conductors of great mechanical strength and admirably adapted for providing the proper ventilation of the conductors. To this end certain constructional features are novel and important and are made the subject matter of some of the appended claims. For example, we contemplate constructing one embodiment of our improved mounting so as to permit independent mounting of each of the various conductors, and maintain the desired copper arrangement. Initial installation as well as replacement is thus facilitated.

A still further aim of our invention is the provision of an effective system of insulation for the conductors whereby two or more phases can be carried on the same support if so desired, and at the same time the electrical or magnetic interaction is overcome or reduced.

A still further aim of our invention is the provision of a novel system of transposition which in conjunction with our novel arrangement or method of employing the conductors permits of a neutralization of the mutual inductive effect and equalizes the temperature distribution. The principle of our invention and a particular manner in which the desired result is secured will be understood from the following detailed description taken in connection with the accompanying drawings forming a part of this specification, it being understood that the specific disclosure is for exemplification only.

In the drawings,

Figure 1 is a side elevational view of a conductor constructed and mounted in accordance with the teachings of our invention;

Figure 2 is an end elevational view of the mounting showing the conductors in section;

Figure 3 is a horizontal cross section taken on the line 3—3 of Figure 2;

Figure 4 is a horizontal cross section taken on the line 4—4 of Figure 1;

Figure 5 is a fragmentary section taken on the line 5—5 of Figure 4;

Figure 6 is a view similar to Figure 1 of a modification;

Figure 7 is an end elevational view of the same;

Figure 8 is a plan view taken on the line 8—8 of Figure 7;

Figure 9 is an isometric view showing the

phases of a conductor arranged and transposed in accordance with my invention;

Figure 10 is a plan view of an alternative form of connection for transposing or crossing the conductors; and

Figure 11 is a side elevational view of the same.

Referring first to Figures 1, 2, 3, 4 and 5, we have provided the bars 1, 2, 3 and 4, which are preferably of copper, for carrying the current. In accordance with our invention the conductors 1, 2, 3 and 4 comprising a bus or lead, which are formed in the shape of flat bars of oblong cross section, are all spaced apart so that each conductor is an outside conductor and the entire conductor assumes the aspect of a thin walled cylinder or tube. These bars are of such proportion that a relatively large heat radiating area is provided for the cross section of the copper and the thickness of the conductor at any point is relatively small so that practically no particle of copper is very far from the surface. Heretofore it has been customary to build up a conductor of a number of such strips or bars clamped together, face to face, or arranged side by side in order to provide a conductor having sufficient cross section to carry the current under the proper temperature requirements.

We place all of the conductors upon the outside making all of the bars outside bars so that any skin effect will not interfere to any appreciable extent with the distribution of current through the copper and so that the free circulation of air strikes all of the surfaces of each bar, whereby the current density relative the amount of copper employed may be very greatly increased without exceeding the temperature rise requirements. Upon a flow of current the current density, as well as the temperature rise, will be substantially equalized in each of the conductors. As heretofore pointed out, in the side by side arrangement of the prior art, there is a tendency for the current to flow most densely along the outermost surface of the conductor, causing a temperature increase and an inefficient transmission relative the amount of copper employed.

Furthermore, in arranging busses or leads formed in the shape of flat bars of oblong cross section in accordance with the teachings of the present invention, not only will the current density, as well as the temperature rise be substantially equalized in each of the conductors, i. e., each of the conductors transmit a substantially equal amount of current and the capacity of the system relative the amount of copper employed be materially increased, but this uniform current density and temperature rise in each of the conductors will be more nearly equally distributed throughout the cross section of each thereof and the efficiency of the system thereby still further increased. If the bars 1, 2, 3 and 4 were of substantially equal width and thickness the current density and temperature rise would be greatest at the outermost corners of the open finger provided by their novel arrangement, whereas we have provided not only for equalizing the density and temperature rise in each of the conductors, but have provided for distributing this density and temperature rise more evenly along all of the conductors than heretofore.

The bars 1, 2, 3 and 4 are supported in the manner which we shall now describe, from the frame, which may be made of the well known pipe construction, or any other desired construction. In this particular instance the frame is shown as constructed of pipes 5 with the base 6 of the insulator 7 bolted thereto by suitable U-bolts or clamps 8. The insulator 7, which may be of any desired size or characteristic, is secured in a socket 9 in the base plate 6. The opposite end of the insulator 7 is secured in a suitable socket 10. The sockets 9 and 10 may be secured upon the ends of the insulator by cementing the same therein or in any other desired manner.

A clamping base 11 of the general character described in the co-pending application of Frank E. Getts, Serial No. 345,671, filed December 17, 1919, or any other suitable clamping base is secured upon the cap 10 by means of suitable cap screws 12. For this purpose the cap 10 is provided with suitable threaded holes into which the bolts or cap screws 12 are threaded. The clamping base 11 has a pair of central bosses 13 in which are mounted the threaded studs or rods 14. The bosses 13 are formed integral with the body of the clamping base 11 and strengthening ribs 15 extend from these bosses 13 to a central diagonal rib 16 which forms a strengthening flange for the clamping base. The studs 14 are provided at their outer ends with clamping nuts 17.

Clamping brackets 18 and 19 having suitable lugs 20 at their lower ends are mounted on the studs or bolts 14. These clamping brackets 18 and 19 also have connecting lugs 22 at their upper ends. A clamping bolt or stud 23 passes through the lugs 22. This stud or bolt 23 is provided with clamping nuts 24 at each end. The clamping brackets 18 and 19 are provided with stiffening ribs or flanges 25 at their outer sides for strengthening the same. The central part of each clamp is preferably open as indicated at 26 in Figure 1.

The conductors 1, 2, 3 and 4 preferably surrounded or embraced by suitable insulating sleeves 27 are clamped with their flat faces adjacent the inner sides of the clamping brackets 18 and 19. The insulating sleeves 27 which might be omitted in so far

as the essence of the present invention is concerned, are preferably formed of horn fibre. Suitable spacing lugs 28 hold the bars 1 and 2 spaced apart vertically and similar lugs on the bracket 19 space the bars 3 and 4 vertically. A spacing block 30 of substantially I vertical section is placed between the flat inner faces of the bars 1, 2, 3 and 4. This spacing block 30 is provided with a bored enlargement 31 along its upper edge thru which the clamping bolt or stud 23 passes and a similar bored enlargement 80 between its upper and lower edges thru which the clamping bolt or stud 81 is arranged.

Thus the conducting bars 1, 2, 3 and 4 are held out of contact with each other at such a distance as will permit the air to circulate freely around them to carry the heat away by conduction, thereby maintaining these conducting bars at or below a certain limiting temperature as may be required by the rules which govern the installation. At the same time the amount of copper is very materially reduced because of the greater current density at which it is possible to work the copper. We have found for instance that it is possible to operate the busses at a current density as high as 1000 amperes per square inch within the possible rise of temperature. Furthermore the bars are so spaced that the repulsion action of the high tension which causes the so called skin effect has a minimum effect on the distribution of current in the copper of the bars. Each of the bars carries a substantially equal portion of the current.

Theoretically the best disposition of the bars would be to have the copper distributed in the form of a tube or cylinder of thin walls. The disposition we have shown is a departure from the ideal conditions to meet actual working conditions and is not meant to limit us to the particular arrangement or dimensions shown. The bars might be arranged in various open figures. Furthermore, instead of depending merely upon natural air circulation, forced circulation may be employed. The bars 1, 2, 3 and 4 may be carried suspended instead of supported from below.

In Figure 9 we have shown a novel system of transposition whereby, in connection with our novel arrangement or method of employing the conductors, a coiled ring condition, which we find is the ideal shape for an alternating current conductor, or other suitable neutralizing condition may be approximated. In this case the bars 1′, 2′, 3′ and 4′ are made up in sections and the adjacent ends of these sections are apertured as shown at 34 or otherwise suitably adapted for connection with the terminals 35 of the transposing or cross connectors 36, 37, 38 and 39 respectively. Thus by connecting one end of a section 1′ with the adjacent end of a section 4′; one end of a section 2′ with the adjacent end of a section 3′, etc., a coiled ring condition is approximated which, as hereinbefore pointed out, we find is the ideal shape for an alternating current conductor.

In Figures 10 and 11 we have shown an alternative form of connection for transposing or crossing the conductors 1′, 2′, 3′ and 4′. This connection comprises a pair of connecting links 40 and 41. The link 40 comprises a diagonal portion 42 having ends extending in parallel engagement with the ends of the bars 3′ and 1′ for example, to be connected and securely clamped in engagement therewith as through suitable clamping plates 43. The link 41 comprises a diagonal portion 44 superimposed above the diagonal portion 42 of the link 40, and provided with a pair of substantially parallel extending ends. These parallel ends are bent down as shown at 45 and securely clamped in engagement with the conductors as through suitable clamping plates 43.

In Figures 6, 7 and 8 we have illustrated an alternative form of mounting for the conductors, which in this case are shown mounted in pairs 47, 48, 49 and 50, that is the conductors bearing current of independent phases are arranged side by side and clamped between the same clamping or mounting plates. In this particular instance the frame is shown as constructed of pipes 51—51 arranged above the pipes 52—52 arranged below with the bases 53 and 54 of the insulators 55 and 56 bolted respectively thereto by suitable U-bolts or clamps 57 and 58. The insulators 55 and 56, which may be of any desired size or characteristics, are cemented or otherwise suitably secured at their outer ends upon the bases 53 and 54 respectively. To this end the bases 53 and 54 are provided with integral studs 59 and 60 projecting into co-operating recesses in the insulators.

Cap members or mounting bases 61—61 are cemented or otherwise suitably mounted upon the opposite ends of the insulators 55 and 56, as through the studs 62 and 63 for example, projecting into co-operating recesses in the insulators and between these cap members or mounting bases are mounted, as by means of suitable bolts 64, the mounting brackets 65. These mounting brackets 65 and the cap members 61—61 could be formed in one piece if so desired. The mounting brackets 65 carry integral clamping plates 66. The conductors 47, 48, 49 and 50 surrounded or embraced by suitable insulating sleeves or spacers 67 are clamped between the outer faces or sides of the clamping plates 66 and suitable removable clamping plates 68 bolted or clamped to the relatively fixed plates 66 as through

suitable bolts or studs 69. The central part of each of the clamping plates 68 is preferably open, as indicated at 70.

Obviously the particular mounting shown in Figures 6, 7, and 8 permits independent mounting of each of the various conductors or sets of conductors 47, 48, 49 and 50, as the case may be, so that the mounting of neither conductor or set of conductors, is dependent upon the proper arrangement of the others. Initial installation, as well as replacement, is thus facilitated.

We do not intend to be limited to the proportions nor the specific details shown, as our invention goes broadly to the matter of the efficient disposition of the copper in a conductor whereby an even distribution of the current along all of the conductors of a bus or feeder is secured. The matter of grouping the strands in the form of a tube or cylinder so that a free circulation of air may obtain about the surfaces of the same to carry off the heat so that a permissible rise in temperature will not be exceeded, as well as the improved mounting and the provision for transposing the strands to approximate a coiled ring or other neutralizing condition, are further highly important aspects of our invention. The particular arrangement of the bars may be varied without departing from the spirit and scope of the invention.

We claim:

1. In combination an alternating current conductor of high current carrying capacity, comprising a plurality of air cooled, flat, copper bars disposed in parallel relation, the bars being placed at the corners of a polygon with their flat sides vertical, said bars being of the same phase and being arranged in sections, and transposing connections for connecting the sections.

2. In combination a pair of sectionalized conductors comprising flat bars, a cross connection comprising a diagonal portion formed of a piece of flat bar and having flat projecting ends for connection with the adjacent ends of one pair of said conductors, to transpose the same, and a second cross connection comprising a piece of flat bar formed into a diagonal portion superposed above the diagonal portion of said first cross connection, said latter diagonal portion having integral downwardly bent projecting ends for connection with the adjacent ends of the other pair of said conductors to transpose them.

3. A cross connection for transposing parallel flat conductors, said cross connection comprising a flat diagonal portion having integral flat ends lying at right angles thereto and projecting in parallel engagement with said conductors.

4. A clamping bracket of generally triangular contour having lugs at the angles thereof, said lugs being apertured to receive clamping bolts, and a spacing lug extending from the inner face of said clamping bracket for spacing conducting bars at different heights in a vertical direction.

5. In a multi-phase transmission line, a plurality of conductors comprising flat bars arranged at the corners of a rectangle, a clamping bracket for said conductors, and means for clamping any one of said conductors to said clamping bracket independently of any other one of said conductors.

6. A clamping bracket of generally polygonal contour having lugs at the upper, lower and intermediate portions thereof, said lugs being apertured to receive clamping bolts and removable clamping plates apertured to receive clamping bolts whereby said plates are associated independently with said clamping bracket.

7. In combination, a conductor for carrying a heavy current comprising a plurality of parallel bars of oblong cross section, means for spacing said bars apart to permit of free circulation of air about the same, and means for clamping said bars at different levels against said spacing means with their greater cross-sectional dimensions lying substantially vertically.

8. In combination, an insulator, a clamping base mounted on said insulator, said clamping base having adjustable clamping brackets secured thereto, said clamping brackets having spacing means along the inner sides of the same, for spacing the bars, flat bars lying against said spacing means, bolts connecting said clamping brackets with said clamping base and bolts connecting the free ends of said clamping brackets to hold said bars with their greater dimension lying in a vertical plane, said bars being of oblong cross section.

9. The combination of a pair of sectionalized conductors, comprising a portion formed of a piece of flat bar and having flat projecting ends for connection with the adjacent ends of two diagonally opposed sectionalized conductors, to transpose the same, and a second cross connection comprising a piece of flat bar formed into a similar portion superposed above the portion of said first cross connection, said latter portion having integral downwardly bent projecting ends for connection with the adjacent ends of two other diagonally opposed sectionalized conductors to transpose them.

10. Means for conducting a large flow of alternating current at a voltage below the corona break down strength of air with minimum energy loss, comprising a plurality of parallel flat bus bars arranged on a plurality of levels with their greater cross sectional dimension generally vertical to foster natural circulation of cooling air

along the side surfaces outside and inside of the bars, said bars being disposed with their centers substantially equidistant radially from a common center so as to equalize substantially the current flow and minimize the skin effect upon the copper in the bars, and to present as little depth of copper as possible to the alternating magnetic flux created by the current flow.

In witness whereof, we hereunto subscribe our names this 20th day of July, A. D. 1920.

ERNEST H. JACOBS.
CHARLES FREDERIC SCHOONMAKER.