

March 30, 1937.

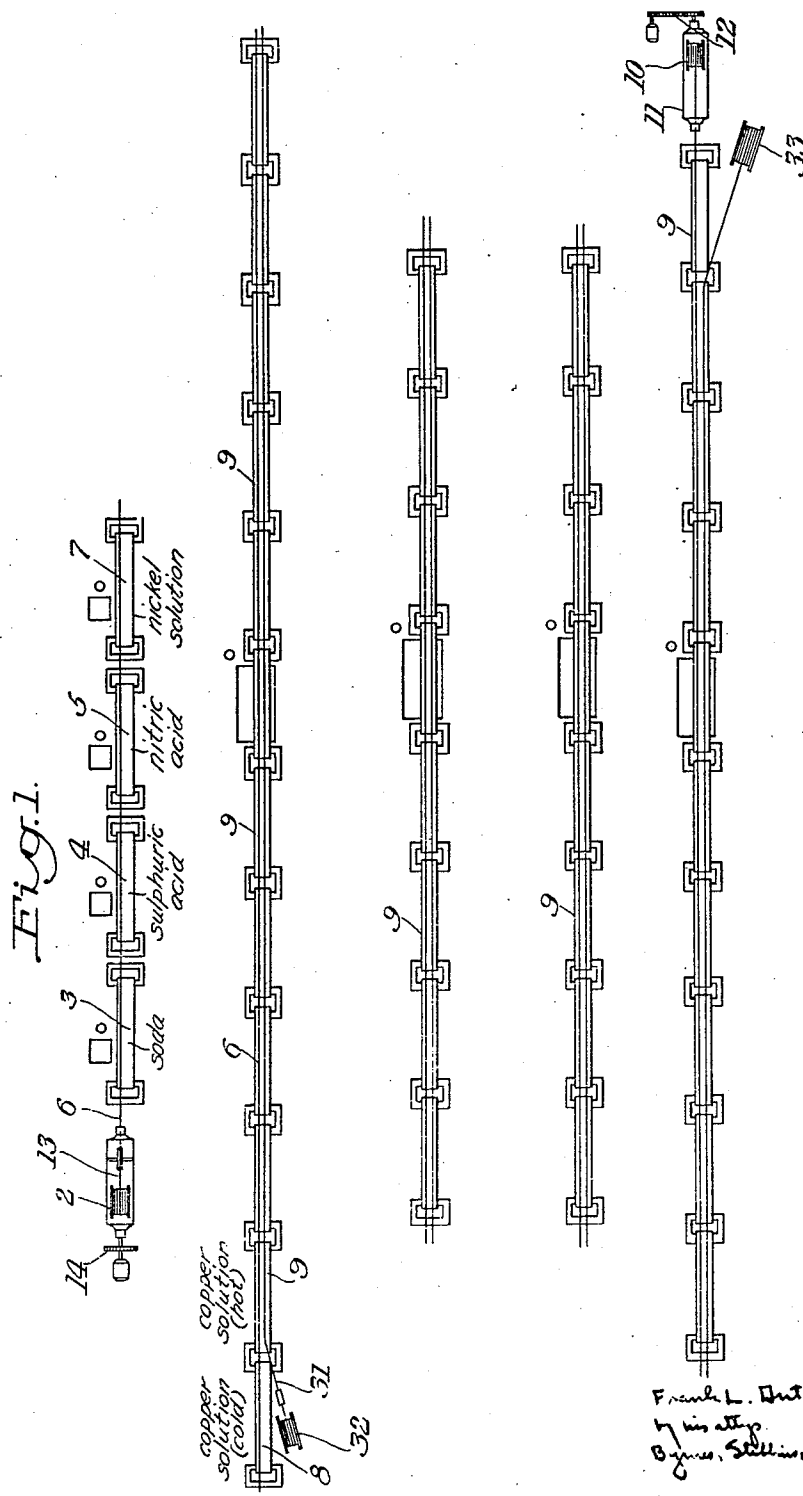
F. L. ANTISELL

2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

Filed Dec. 30, 1932

10 Sheets-Sheet 1



INVENTOR

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Ogden, Sedgwick, Paul & Blair

March 30, 1937.

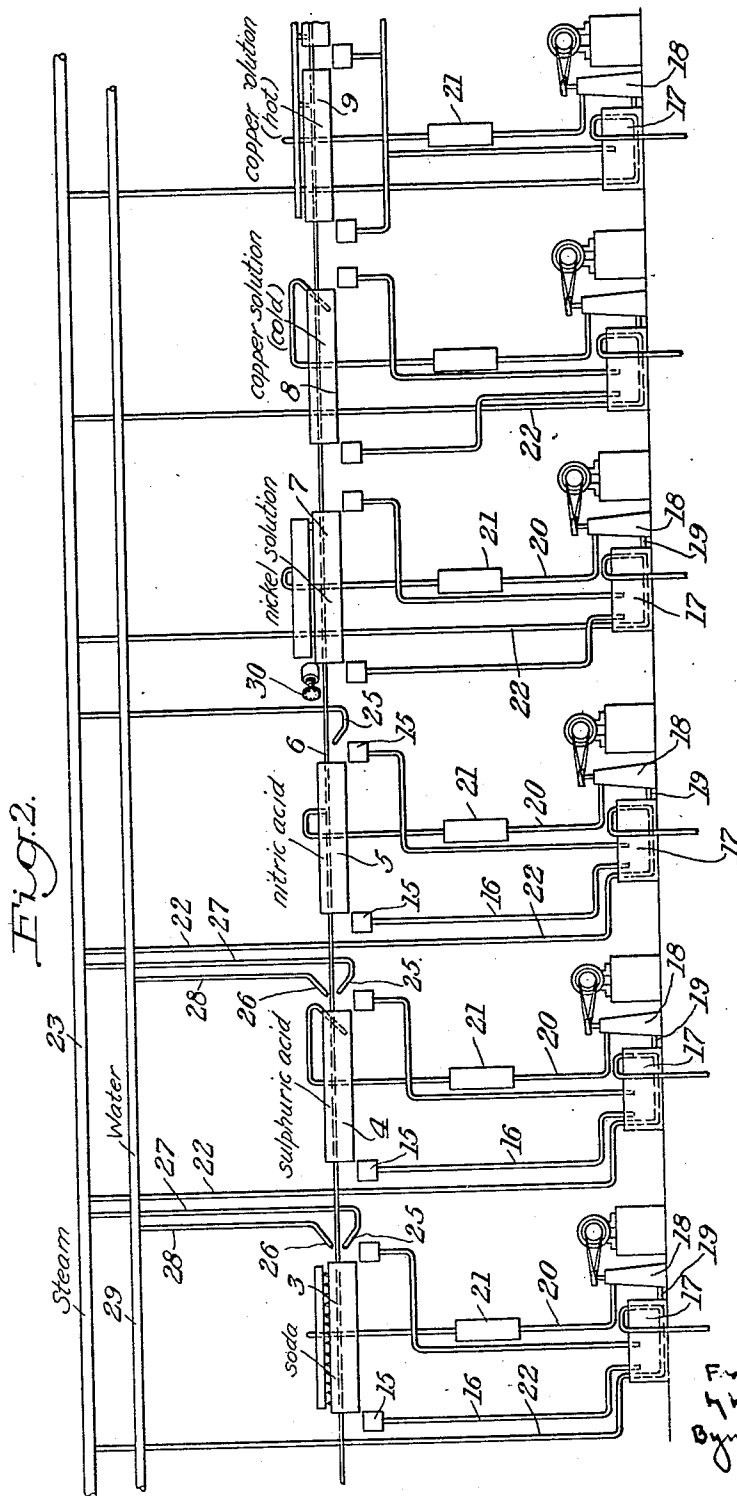
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2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

Filed Dec. 30, 1932

10 Sheets-Sheet 2



INVENTOR

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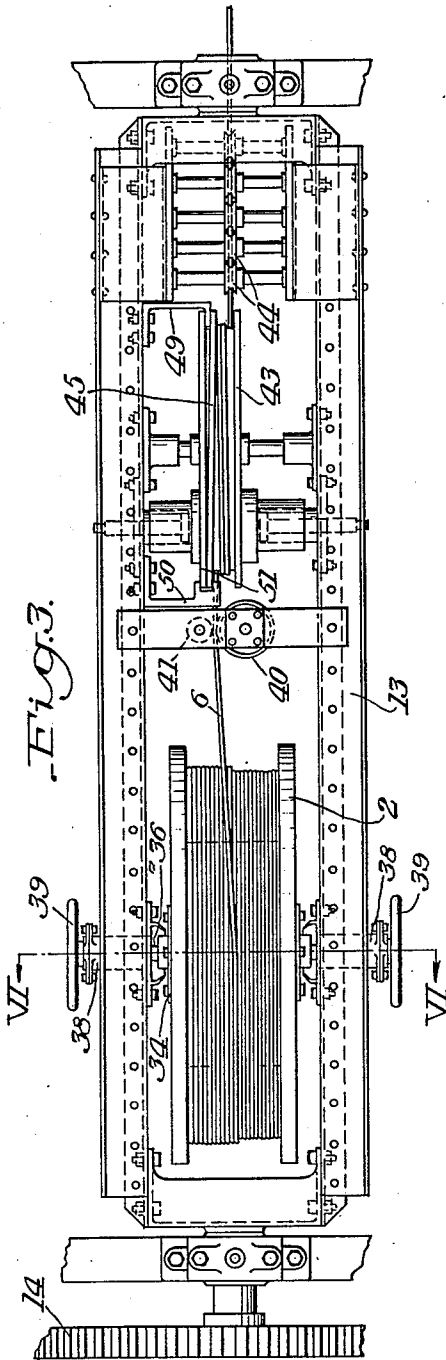
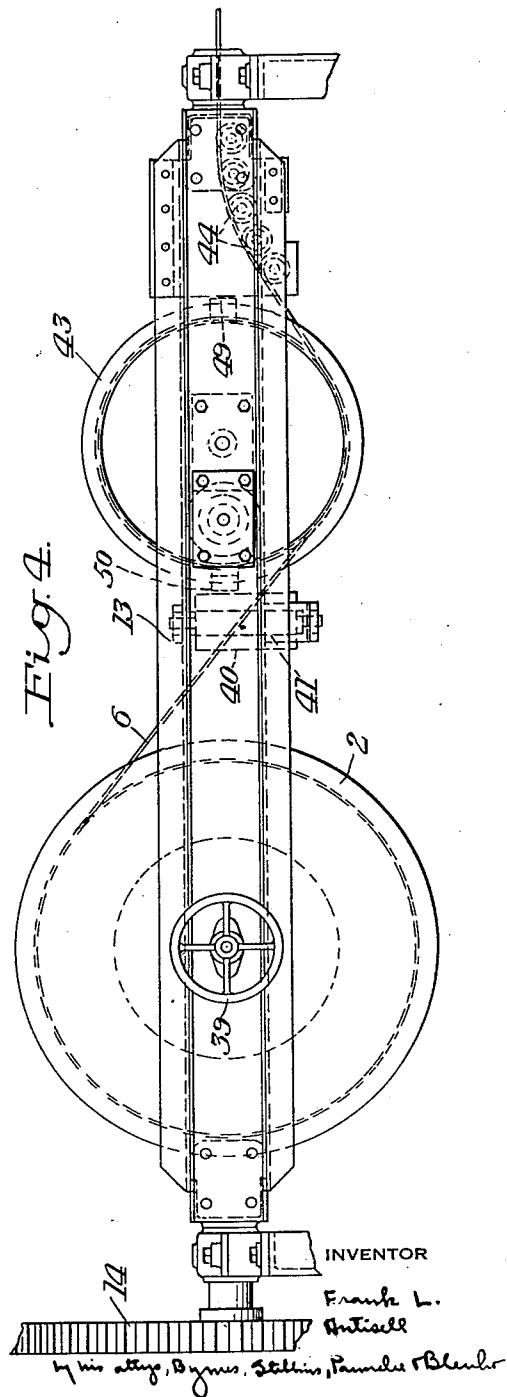
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METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

Filed Dec. 30, 1932

10 Sheets-Sheet 3



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2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

Filed Dec. 30, 1932

10 Sheets-Sheet 4

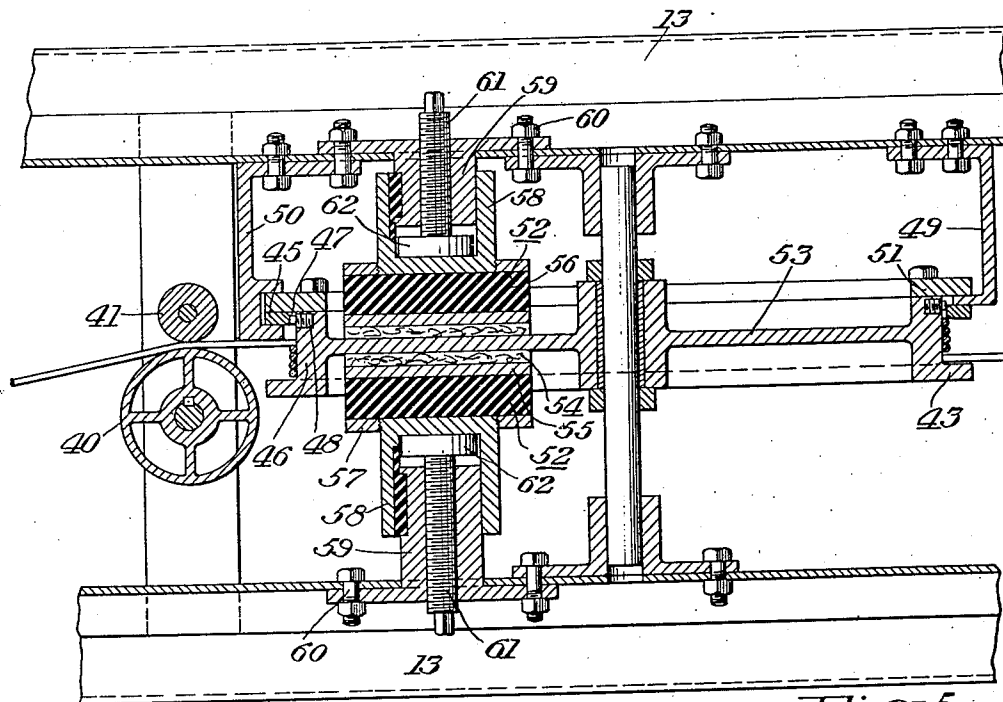


Fig. 5.

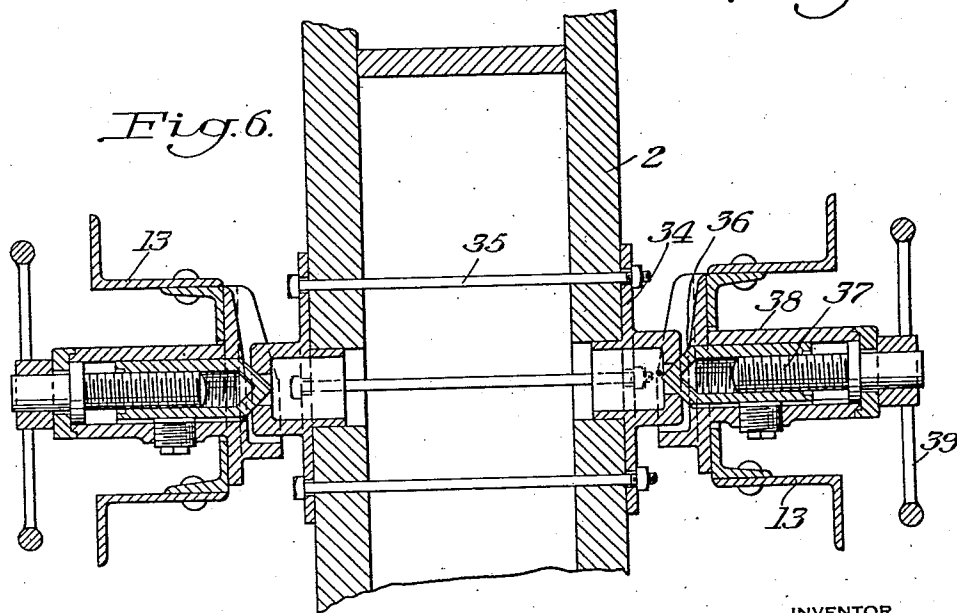


Fig. 6.

INVENTOR

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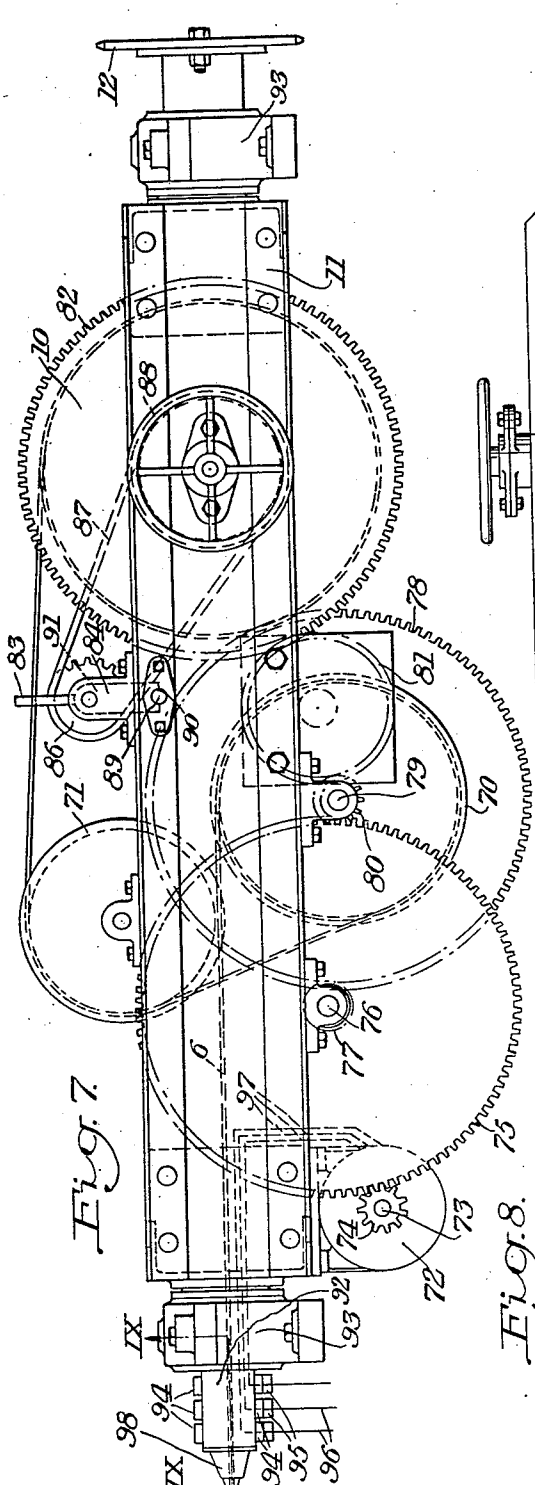
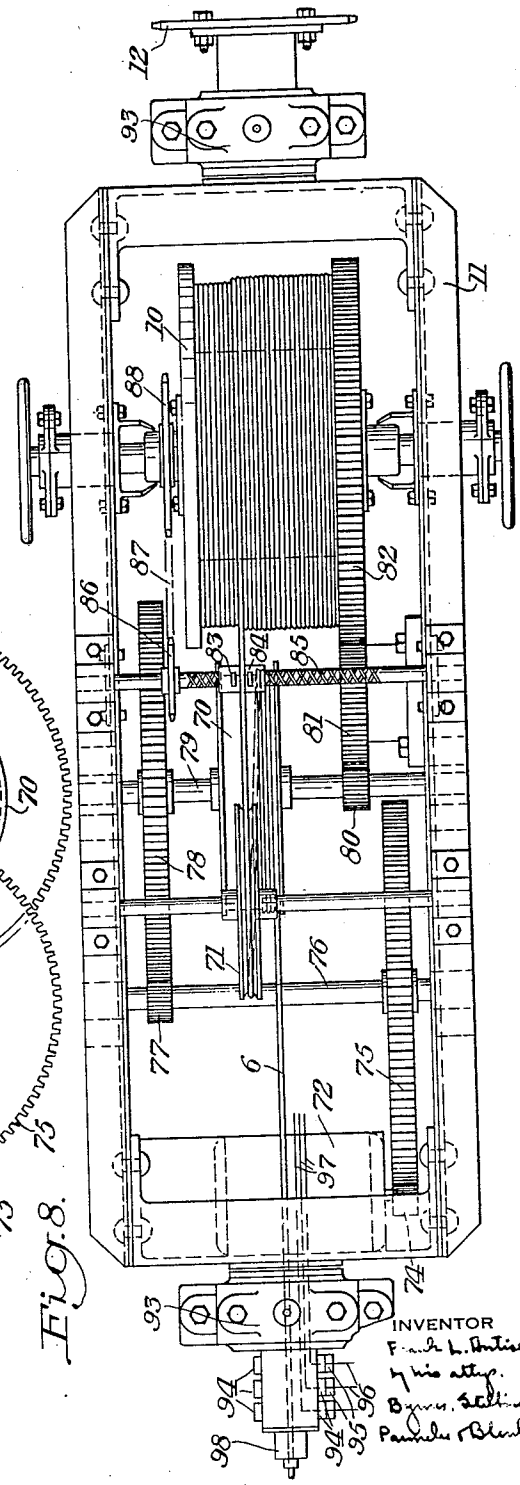
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2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

Filed Dec. 30, 1932

10 Sheets-Sheet 5



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2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

Filed Dec. 30, 1932

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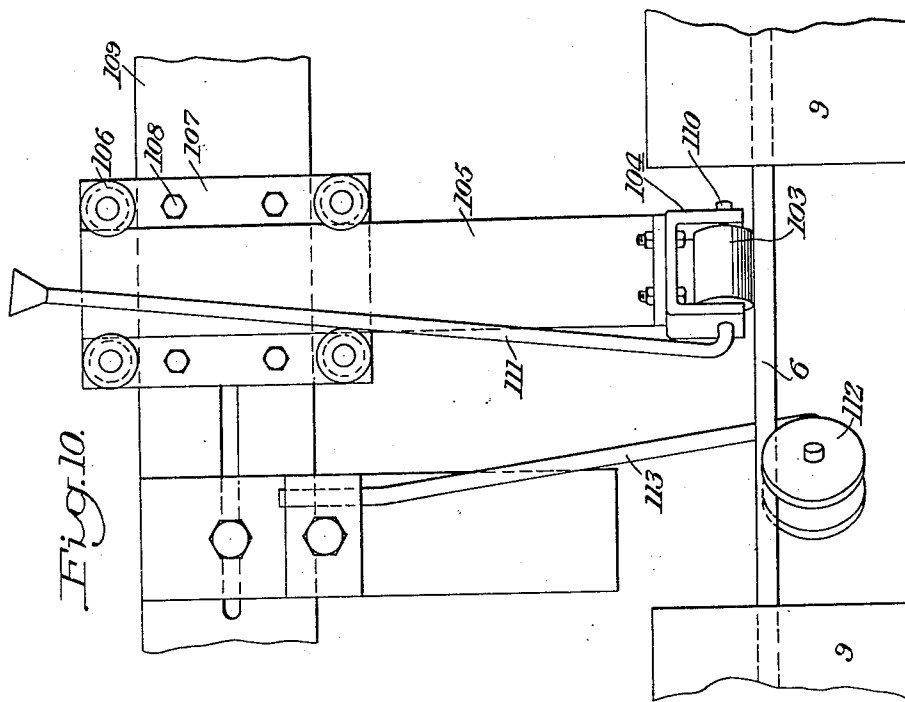


Fig. 10.

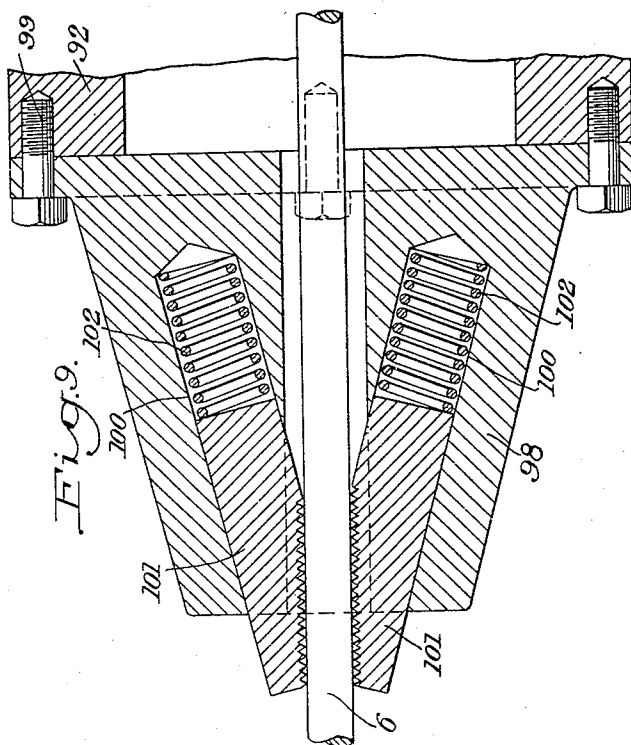


Fig. 9.

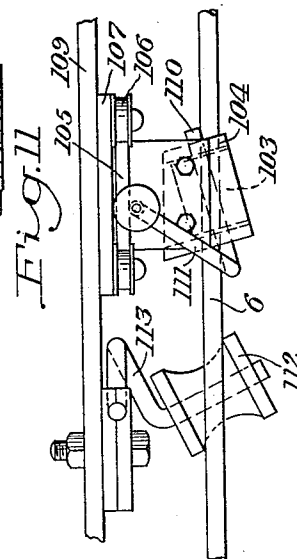


Fig. 11.

INVENTOR

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March 30, 1937.

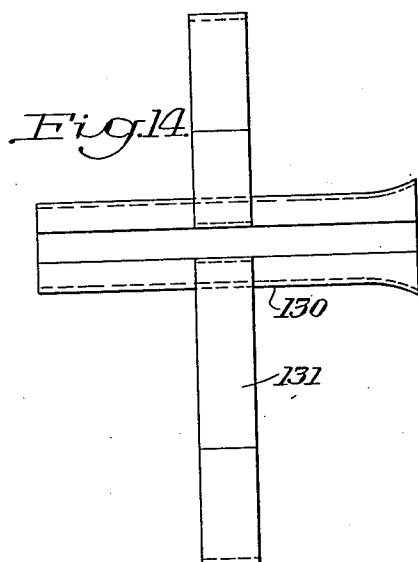
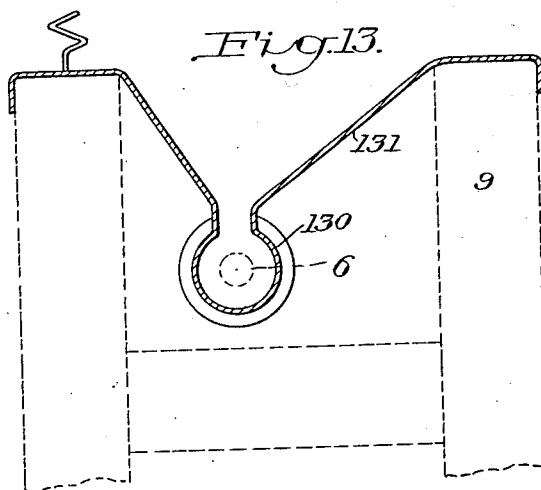
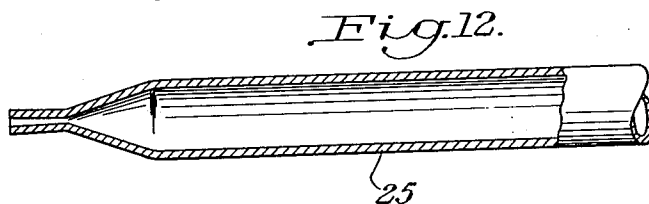
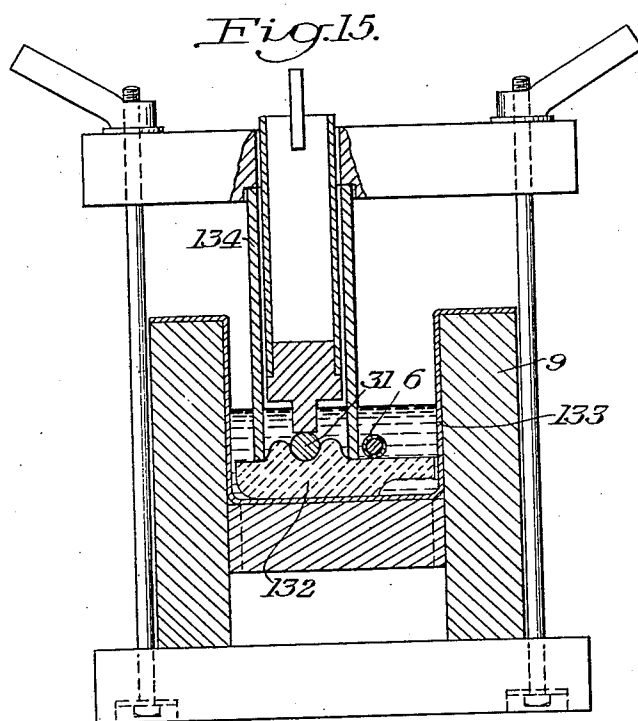
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METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

Filed Dec. 30, 1932

10 Sheets-Sheet 7



INVENTOR

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2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

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Fig. 16.

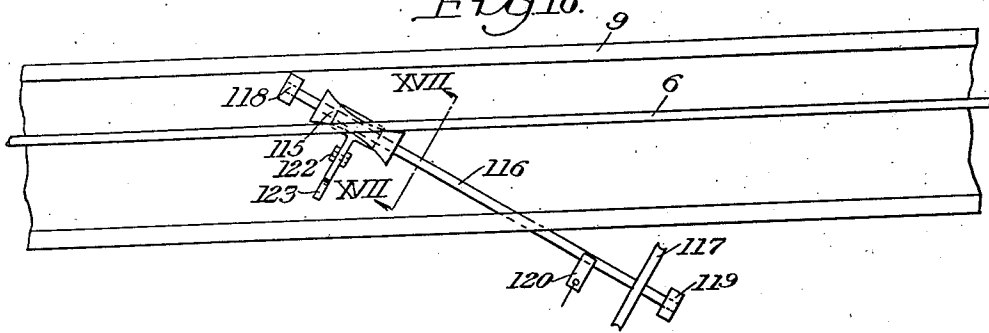


Fig. 17.

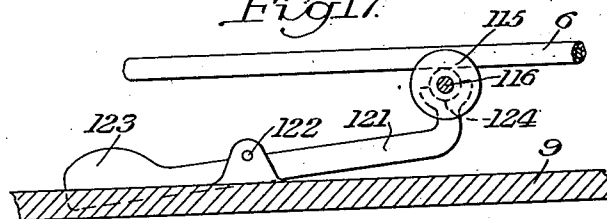


Fig. 19.

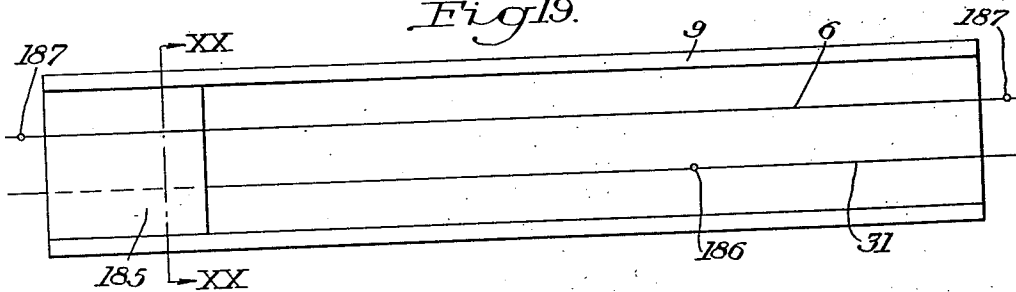
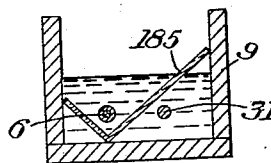


Fig. 20.



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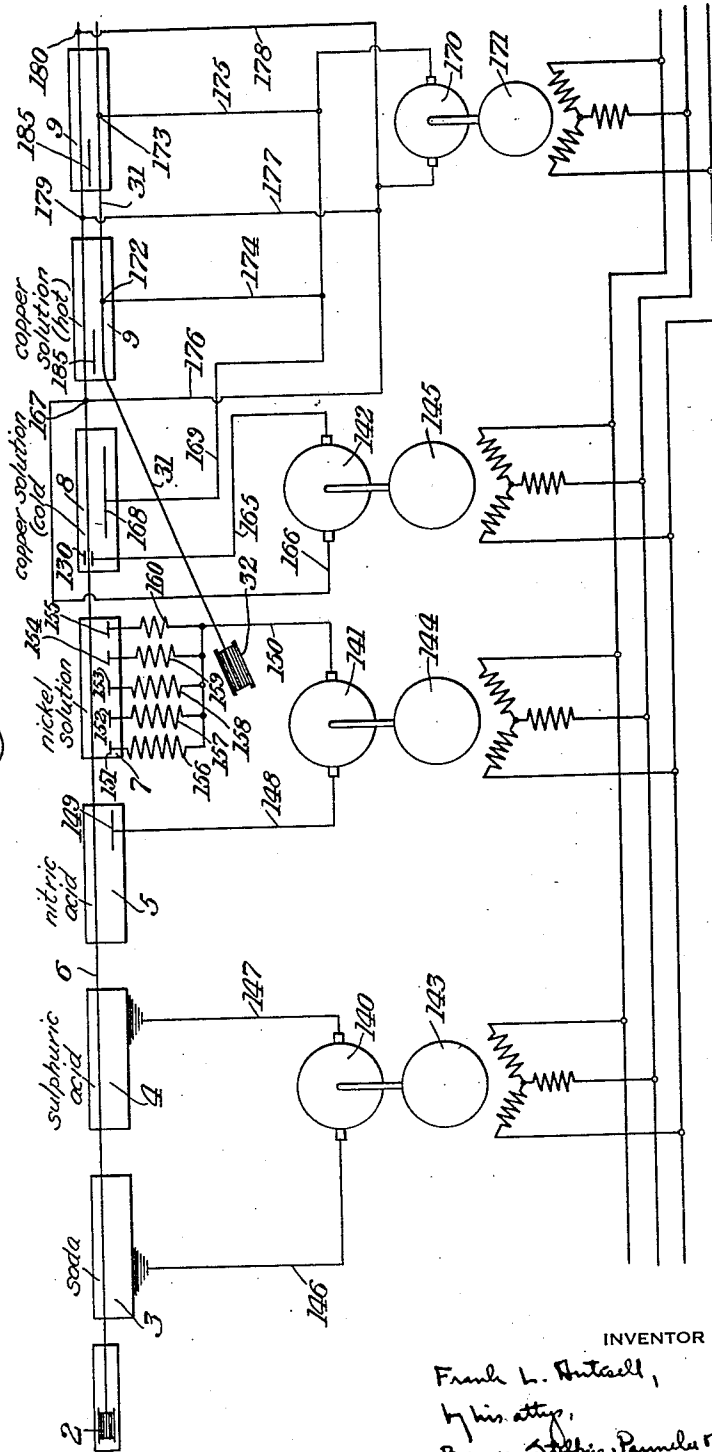
2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

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10 Sheets-Sheet 9

Fig. 18.



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March 30, 1937.

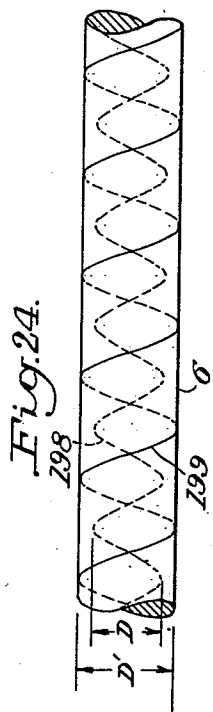
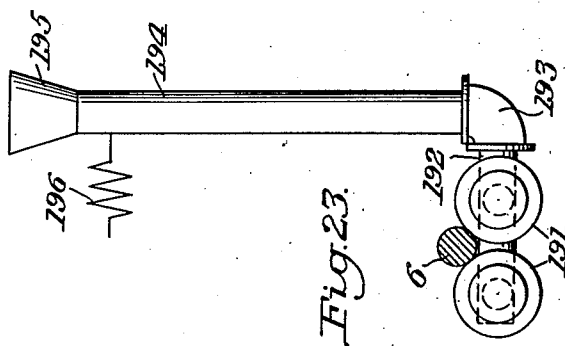
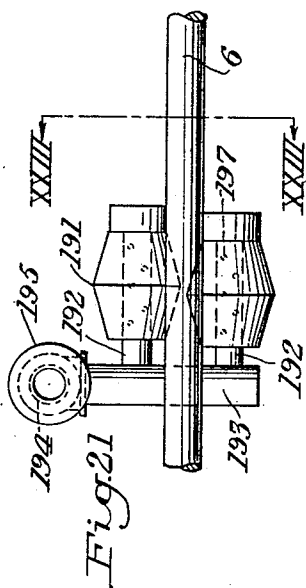
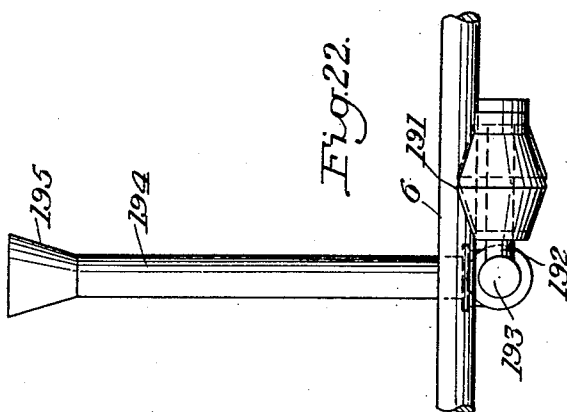
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2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

Filed Dec. 30, 1932

10 Sheets-Sheet 10



INVENTOR

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UNITED STATES PATENT OFFICE

2,075,331

METHOD AND APPARATUS FOR THE ELECTRODEPOSITION OF METAL

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Application December 30, 1932, Serial No. 649,532

20 Claims. (Cl. 204—11)

This invention relates generally to a method and apparatus for the electrodeposition of metal, and more particularly to such method and apparatus for electrodepositing metal on a core in order to produce a bimetallic article. The invention is particularly described herein as applied to the manufacture of bimetallic articles having a ferrous core or base and a copper coating. Such products supply a large demand in wire, cable, strips, tubes, and the like. They are of great value in that the ferrous core, such as steel, supplies strength and the copper provides electrical conductivity and resistance to corrosion. The invention is applicable, however, to the production of other combinations of metals. A non-ferrous base or core may be coated with copper, nickel or other metal. For trolley wires, a copper core may be coated with iron. Bimetallic articles may be made by depositing nickel or other metal on a core of copper or other metal. The present application is a continuation-in-part of my copending application Serial No. 359,624, filed May 1, 1929.

It has been proposed heretofore to make bimetallic articles in various ways. Attempts have been made to weld previously formed copper to a steel core, but these attempts have not been entirely successful. The most satisfactory method in use consists in applying the copper in a molten state to the core or base. The core is suitably cleaned and fluxed, and while centered in a heated mold, molten copper is poured around it. The ingot formed in this way is rolled to the desired shapes. The ratio of copper to steel in the ingot is governed by the relative size of the mold and steel core.

The requirements of the trade are such that in wire, for example, various ratios of cross-sectional area of copper to steel must be furnished. Some wires may have only 5% copper; others may have as high as 40% to 50%. Unfortunately, these requirements, as well as other requirements as to the purity of the copper and the concentricity of the steel core with the copper jacket, introduce a large number of manufacturing problems. Where the copper shell is thick, the difficulties of rolling are increased, because the copper, being softer and more easily deformed than the steel, tends to flow between the rolls more easily than the steel. It is therefore, difficult to maintain the concentricity of the steel and the copper. Another great difficulty arises in the pouring of the ingot. If the copper is too hot, a certain amount of steel dissolves into the copper and reduces its purity,

thus lowering the electrical properties of the product. If the pouring is carried out at too low a temperature, the permanent weld, which is the great virtue of the process, is not obtained.

In accordance with the preferred embodiment of this invention, a core is passed through a single electrolytic bath or a series of electrolytic baths and metal is deposited thereon. The core is passed through the baths under high tension and it is rotated about its axis as it is fed through the bath. The tension maintains the core straight, produces a better deposit than can be obtained otherwise, and the rotation of the core about its axis insures an even deposit of metal on all sides of it. The core is fed from a pay-reel and passes through a series of cleaning baths, after which it passes through a series of electrodepositing baths. It is then wound up on a take-up reel. Both the pay-reel and the take-up reel are mounted in frames which are rotatable at substantially a right angle to the axes of rotation of the reels, so that the core is rotated about its axis as it passes through the baths. The anode used in the principal electrodepositing solutions preferably is a moving wire, hereinafter termed a "drag wire". This drag wire is fed from a reel, and after passing through the electrodepositing solutions, is wound up on another reel. It moves through the baths alongside of the core which forms the cathode and the metal is deposited from the drag wire onto the core. Other types of anode may, however, be used instead of the moving drag wire. I may use stationary anodes such as slabs of the metal to be deposited, or metallic shot, or I may use an insoluble anode and add the metal to be deposited as a salt or as metal to the electrolyte.

In the accompanying drawings, which illustrate the present preferred embodiment of my invention and also certain modifications,

Figure 1 is a diagrammatic plan view of the whole apparatus, the view being shown in sections for convenience of illustration;

Figure 2 is a side elevation of a number of the containers or "tronnels" which contain the various solutions through which the core passes, and illustrates the means for filtering and recirculating the solutions. By "trunnel" I mean a trough-like structure with open ends in which the electrodeposition takes place, the electrolyte being supplied thereto at such rate as to maintain the desired quantity of electrolyte therein.

Figure 3 is a plan view of the mechanism at the entrance end of the apparatus for supplying the

core to the baths, and shows the pay-reel and the frame in which it is mounted;

Figure 4 is a side elevation of the mechanism shown in Figure 3;

- 5 Figure 5 is a sectional view of the snubber wheel and brake mechanism which is mounted in the same frame as the pay-reel located at the entrance end of the apparatus;

- 10 Figure 6 is a transverse section on the line VI—VI of Figure 3, illustrating the means for mounting the pay-reel and take-up reel in their frames;

Figure 7 is a side elevation of the take-up reel and its driving connections;

- 15 Figure 8 is a plan view of the apparatus shown in Figure 7;

Figure 9 is a section on the line IX—IX of Figure 7, illustrating a clamping means for preventing release of tension on the core;

- 20 Figures 10 and 11 are, respectively, a side elevation and a plan view of roller cathode contacts located between the tronnels which hold the electrodepositing solutions;

- 25 Figure 12 is a view, partly in section and partly in elevation, of one of the steam nozzles arranged between certain of the tronnels near the entrance end of the apparatus for cleaning the core;

- 30 Figures 13 and 14 are, respectively, a sectional view and an elevation of a high current density circular anode used to prevent re-solution of a previously deposited metal;

Figure 15 is a sectional view through one of the tronnels illustrating the contact for the anode or drag wire;

- 35 Figure 16 is a plan view of a driven roller cathode contact located within one of the tronnels;

Figure 17 is a sectional view on the line XVII—XVII of Figure 16;

- 40 Figure 18 is a wiring diagram showing the electrical connections for a number of the tronnels which contain the various baths;

- Figure 19 is a plan view, and Figure 20 is a section on the line XX—XX of Figure 19, of a means for shielding the cathode contacts in order to equalize the current density along the cathode;

- 45 Figures 21, 22 and 23 are, respectively, a plan view, a side elevation, and a section on the line XXIII—XXIII of Figure 21 illustrating a preferred type of rollers for supporting the core and compacting and refining the grain structure of the deposited metal, and

- 50 Figure 24 is an enlarged view of a portion of the core having deposited metal thereon and illustrating the manner in which the rollers shown in Figures 21, 22 and 23 compact and refine the deposited coating.

- Referring more particularly to the accompanying drawings, and for the present to Figure 1, the core or wire to be coated with metal is fed from
60 a pay-reel 2 through a series of cleaning baths 3, 4 and 5. The cleaning baths may be of different compositions, but I have found that in the coating of a steel core with copper, or first with nickel or tin and thereafter with copper,
65 effective cleaning can be accomplished when the bath 3 is a soda solution, the bath 4 is a sulphuric acid solution, and the bath 5 is a nitric acid solution. The core 6 then passes through a solution of a nickel salt, for example nickel sulphate, in the trunnel 7, and after that passes through a copper solution in the trunnel 8, and thereafter through a plurality of tronnels 9, each of which contains an acid solution of a copper salt such as copper sulphate. The character of
75 the grain structure of the electrolytic deposit of

copper is materially affected by the temperature of the electrolyte. It is particularly important that the initial deposit of copper be fine grained, as the succeeding grain structure built on the initial deposit cannot be good if the initial deposit was poor. In other words, poor grain structure in the initial deposit carries through the superposed deposit. Accordingly, the temperature of the solution in the trunnel 8 is lower than the temperature of the solutions in the tronnels 9, the temperature of the former being about 70° F., while that of the latter is about 140° F. After passing through the last of the tronnels 9, the core is wound up on a take-up reel 10 which is rotatably mounted in a frame 11 driven by a motor and gearing 12 so as to rotate the frame at substantially a right angle to the axis of rotation of the reel 10. The pay-reel 2 at the entrance end of the apparatus is mounted in a similar framework 13 driven by a motor and gearing 14. The construction is such that the core rotates about its axis as it is advanced through the various baths.

The tronnels which contain the various solutions are U-shaped in cross-section, being open at the top and ends. The tronnels do not form closed containers for the baths, but on the contrary are open at their ends so that it is necessary to continuously circulate the solution through the tronnels in order to maintain a desired level of the electrolyte therein. The solution in each trunnel flows out of the ends of the trunnel, is collected, filtered if necessary, and then returned to the trunnel. As shown in Figure 2, the solution flows from the ends of each trunnel into receivers 15 and is conducted by pipes 16 to a sump 17. It is then circulated by a pump 18 through pipes 19 and 20 through a filter 21, and then returned to the trunnel. The solution in the sump 17 is heated by a steam pipe 22 which is connected to a steam line 23. The use of such open end tronnels for the solutions eliminates the necessity of providing stuffing boxes, which would be required with electrodepositing tanks of the usual closed end construction. The stuffing boxes are objectionable for the reason that the packing scratches the surface of the deposited metal and may introduce foreign matter into the deposited metal. Also, by using a series of spaced tronnels instead of a single bath, different solutions can be used in the different tronnels, and these solutions can be filtered and recirculated back to the tronnels. It will be understood that when reference is made to "open end" tronnels, this does not mean that the ends are absolutely free of any structure impeding the flow of liquid. A weir or baffle may be employed, the essential thought being that the entrance and exit of the wire is effected without it passing through stuffing boxes or the like.

Located between the tronnels 3, 4 and 5, which contain different cleaning solutions, are steam nozzles 25 and water nozzles 26 connected by pipes 27 and 28, respectively, to a steam line 23 and a water line 29. The nozzles 25 and 26 subject the core between tronnels to jets of steam and water which, taken in conjunction with the various cleaning solutions, produce a very clean wire on which a good deposit of metal can be made. As shown in Figure 2, the steam jets 25 apply steam to the core wire 6 at an acute angle and in a direction opposite to the movement of the wire. It has been found that by so arranging the steam jets, the liquid on the wire is 71

forced backwardly so that the portion of the wire which passes the jet is substantially dry. Where a steam jet is applied at right angles to the direction of movement of the wire, it causes the liquid on the wire to splatter on both sides of the point of application of the jet and forms spots or stains on the wire. This objectionable spotting of the wire is overcome where the jets are applied as indicated so as to force back the liquid on the wire in the opposite direction to that in which the wire moves. Another steam jet 25 is also used between the tronnels 5 and 7 to further clean the core before it passes into the nickel solution in the tronnel 7. It is advantageous in some cases to coat the core first with a deposit of another metal such as nickel or tin before applying the copper coating. Nickel, which is preferred, readily forms an alloy both with the steel core and with the copper coating. The deposition of copper on the core which has previously been coated with nickel begins in tronnel 8 and is continued in tronnels 9. A copper drag wire 31 is unwound from a reel 32 and travels parallel to the core 6 through all of the tronnels 9 except the last one shown in Figure 1. The anodes in tronnel 8 and the last one of tronnels 9 are stationary, of any suitable type, as rods, casting, shot, etc. The drag wire 31 is wound on a reel 33 located adjacent the exit end of the apparatus. During the deposition process, the core 6 and the drag wire 31 both move through the depositing baths. In addition to this, the core which is maintained under great tension is also rotated about its own axis, so that the deposition will be uniform. The tension on the core is preferably from 20,000 to 50,000 pounds per sq. in., or approaching the yield point of the base material.

The means for supplying the core to the baths is illustrated in Figures 3 to 6. The reel 2 is rotatably mounted in a frame 13, so that as the reel is rotated about its axis, the core unwinds from the reel. The frame 13 is rotatable about its longitudinal axis, which axis is at substantially a right angle to the axis of the reel 2. The frame is rotated through a driving connection 14. The pay-reel 2 and the take-up reel 10 are similarly mounted for easy removal from the frames 13. As shown in Figure 6, the reel 2 is provided with hubs 34 which are secured in place by rods 35. The hubs are supported by cone-shaped bearing sleeves 36 which are internally threaded for reception of screws 37. The sleeves 36 are slidable within housings 38 secured to the frame and are adjusted by rotation of the hand wheels 39. With this construction, it is an easy matter to remove an empty reel from the frame and insert a full reel.

The core or wire 6, after leaving the pay-reel 2, passes between rollers 40 and 41 and is then wound around a snubbing wheel 43 in a direction the reverse of that in which it was wound around the reel 2. The reverse winding of the core around the pay-reel and snubbing wheel acts to straighten out the core before feeding it to the baths.

Means is provided for delivering the core from the snubbing wheel so that it will be in alignment with the guide rollers 44. For this purpose a wobbler ring 45 fits around the rim 46 of the snubbing wheel 43. The wobbler ring is provided with a notch 47, and into this notch fits a stud 48 which is screwed into the rim 46. There is a loose fit between the ring 45 and the rim 46 and between the notch 47 and the stud 48. As the wheel 43 rotates,

the wobbler ring 45 is carried with it due to the notch and stud connection 47, 48. The ring caused to wobble by a wedge 49 and a guide 50 is secured to the frame. The guide 50 holds the wobbler ring close to the flange 51 at one side of the snubbing wheel and the wedge 49 spreads the rim away from the flange 51 at the other side of the wheel. This arrangement delivers the core from the snubbing wheel in alignment with the guide rollers 44.

It has been stated that the core is fed through the baths under high tension. This tension is accomplished by using a pulling means at the exit end of the apparatus and providing the snubbing wheel with a brake. The brake comprises blocks 52 which press against the web 53 of the snubbing wheel. Each of the blocks is made up of a layer of brake lining, a layer 55 of wood, and a layer of rubber. The rubber layer is secured to a metal plate 57 into which is threaded a sleeve 58. Each of the sleeves 58 is supported by a bearing 59 secured by bolts 60 to the frame 13. The brake blocks are pressed against the web of the snubbing wheel by turning screws 61 having secured there heads 62 which fit into the sleeves 58. The brake provides any desired amount of back tension. The tension feature is highly important to the obtaining of a satisfactory and uniform deposit.

The take-up reel 10 and its driving connection are illustrated in Figures 7 and 8. The reel is rotatably mounted in the frame 11 in the same manner that the pay-reel 2 is mounted in frame 13. The frame 11 is rotated about its longitudinal axis by the driving motor and gearing illustrated in Figure 1. The motors and driving connections at the entrance and exit ends of the apparatus are synchronized by suitable electric controls so as to rotate the core about its axis at the same speed at both ends of the apparatus. The core 6, after passing through the last tronnel 9, passes around a drum 70, then around a wheel 71, and is then wound on the take-up reel 10. The take-up reel is driven from a motor 72 which is mounted on the frame 11 and rotates therewith. To the armature shaft 73 of the motor is secured a pinion 74 which meshes with a gear 75 secured to a shaft 76. The opposite end of the shaft 76 carries a pinion 77 which meshes with a gear 78 secured to a shaft 79. The opposite end of the shaft 79 carries a pinion 80 which meshes with gear 81 which, in turn, meshes with a gear ring 82 secured to the take-up reel 10.

Spacing means is provided for guiding the core wire as it is wound up on the reel 10. The core wire is guided between guide fingers 83 which form a part of a traveling guide 84 which moves back and forth across a screw 85 having a return thread therein. The screw 85 is rotated by means of a sprocket wheel 86 secured thereto and connected by a chain 87 to a sprocket 88 secured to the hub of the reel 10. A rod 89 fits into notches 90 formed in the lower ends of arms 91 of the guide so as to prevent the guide from rotating with the screw.

The axles 92 of the frame 11 are mounted in bearings 93. The left-hand axle, as viewed in Figure 7, extends beyond the bearing for some distance and is provided with contact rings 94. These rings make contact with brushes 95 which are connected by wires 96 to a source of electric current. The motor 72 is connected to the ring 94 by wires 97 which extend through the axle 92. In the construction just described, the frame is rotated about its longitudinal axis by the motor and driving connection 12, and the take-up reel is rotated

tated so as to wind up the core wire by the motor 72 which is mounted on the frame and which rotates therewith. The frame may be rotated about its longitudinal axis and the take-up reel rotated to wind up the wire by a single motor, but it is preferred to have separate motors and driving means for the frame and for the reel.

Figure 9 illustrates a device for preventing the release of tension on the coated core. It comprises a head 98 which, in the embodiment shown, is of truncated cone-shape secured to the axle 92 of the frame by screws 99. The head is provided with openings 100 arranged at an angle to each other and converging in a direction opposite to that in which the core travels. A clamping jaw 101 is arranged in each of the openings, and a spring 102 disposed within each opening abuts against the end of each jaw 101, tending to force them toward each other. When the core 6 moves to the right, as viewed in Figure 9, the springs are compressed and the jaws are forced into the openings and moved apart a distance sufficient to allow the core to move between the jaws. However, the core is prevented from moving to the left since in this direction the springs force the jaws together, so that they grip the core. This arrangement prevents loss of tension on the core when a full take-up reel is removed and is replaced by an empty reel. I have found that in certain cases it is possible to provide sufficient frictional resistance in the working parts of the take-up reel that this resistance alone is sufficient to keep the wire under tension when the motor is stopped.

Roller contacts arranged between the tronnels are employed for making the electrical contact with the core wire 6 which forms a cathode in the process. These rollers are shown in Figures 10 and 11. A copper roller 103 is mounted in a bearing 104, and the bearing is secured to a strap 105 which is adjustably guided by rollers 106 secured to a plate 107, the plate being secured by screws 108 to a support 109. This manner of mounting enables the roller to move slightly in order that it may provide good contact with the core wire 6. The roller 103 is rotatable on the lower end 110 of a pipe 111 which extends upwardly beyond the support 109. The upper end of the pipe 111 is funnel-shaped so that liquid may be easily introduced through the pipe and supplied to the roller. The lower end 110 of the pipe is perforated so that liquid supplied thereto leaks out and trickles down over the roller and onto the core wire 6. Slightly acidulated water is supplied through the pipe 111 to the roller. One part of sulphuric acid to one thousand parts of water may be used, and it has been found that in this manner the formation of a dark colored stain which otherwise would be formed on the core is prevented. The core is supported adjacent the roller 103 by a roller 112 supported by a pipe 113, through which acidulated water may be supplied to the roller in the manner just described. The axis of the roller 112 is arranged at an acute angle to the direction of travel of the core, thereby aiding in rotating the core as it is pulled over the roller.

Where the cathode contacts are immersed in the baths contained in the tronnels, there is a tendency for nodules of copper to form on the contacts. The nodules scratch the metal deposited on the cathode, which causes entrapment of the liquid in the scratches, and this, in turn, produces planes of weakness in the deposited metal. It is, therefore, of advantage to arrange

the cathode contacts between the tronnels so that they need not be immersed in the baths.

In Figures 16 and 17 there is shown a modified type of cathode contact in which the contact is a driven roller arranged within one of the tronnels. The tendency of the metal of the bath to form nodules on the roller contact is eliminated by using a scraper which prevents the metal from adhering to the contact. With this arrangement, the contact can be used in the bath instead of between baths without injuring the coating of the cathode. With this type of contact, a single long trunnel can be used in place of the plurality of spaced tronnels 9 shown in Figure 1. The employment of spaced baths has a tendency to form annular rings of deposited metal, the different rings having been formed while the core was passing through the different tronnels. Under conditions in which contacts can be immersed in the bath and the formation of nodules on the contacts and scratching of the cathode can be prevented, it is preferred to place the contacts in the baths so as to reduce the tendency to form the annular rings.

In the construction illustrated in Figures 16 and 17, a roller 115 is secured to a shaft 116 and the shaft is driven by a pulley 117 connected to any suitable source of power. The shaft is mounted in bearings 118 and 119 disposed, respectively, inside and outside of the trunnel. The roller 115 is disposed at an acute angle to the direction of travel of the core 6. Electrical connection is made with the shaft 116 by a brush 120. In order to prevent formation of nodules of copper on the contact, a scraper 121, which is pivoted as indicated by the reference numeral 122 and provided with a weight 123, is employed. The end 124 of the scraper opposite the weight contacts with the roller and removes any copper which might otherwise adhere to it.

A great deal of difficulty has been experienced in obtaining a good deposit of copper on the core which had previously been coated with nickel in the trunnel 7. It was found that copper displaced the nickel on the core when it passed through the copper solution in the trunnel 8. Spongy copper of poor bonding quality was thus formed. This difficulty was finally overcome by employing a circular anode of high current density concentrically placed around the cathode rod at the entrance end of the trunnel 8. This circular anode 130 is illustrated in Figures 13 and 14. It is an insoluble anode such as lead which extends only a small part of the length of the trunnel and partially surrounds the cathode 6. It is supported by straps 131 which fit over the sides of the trunnel. The use of the high current density anode counteracts the tendency of the previously deposited nickel to be displaced by copper when it is passed through the copper solution.

An anode contact is illustrated in Figure 15. The drag wire 31 which forms the anode is supported on a porcelain base 132 resting on the bottom of the trunnel which has a lead lining 133. A contact brush 134 contacts with the drag wire.

Current for carrying out the electrodeposition of the metals is supplied by a series of generators 140, 141 and 142 connected, respectively, to motors 143, 144 and 145, and a generator 170 connected to a motor 171. The tronnels 3 and 4 are connected in series with the generator 140 by conductors 146 and 147. The negative conductor 148 of the generator 141 is connected to an iron anode 149 in the trunnel 5. The posi-

tive conductor 150 of the generator 141 is connected in parallel to a plurality of nickel anodes 151, 152, 153, 154 and 155. The anodes 151 to 155 are connected to the conductor 150 through resistances 156, 157, 158, 159 and 160, respectively. The resistance 156 is the greatest and 160 is the least, the intermediate resistances decreasing from 156 to 160 as indicated on the drawings. This arrangement tends to produce a uniform current density throughout the length of the core wire within the trunnel 7. If varying resistances are not employed, the tendency is to have the greatest current density at the entrance end of the trunnel, which results in uneven deposition of the nickel. The varying resistances 156 to 160 counterbalance the resistance of the core wire, thereby equalizing the current densities along the whole length of the wire and causing deposition of metal throughout substantially the whole length of the trunnel.

The circular high current density anode 130 which is illustrated in detail in Figures 13 and 14 is connected by a positive conductor 165 to the generator 142. The negative conductor 166 is connected at the point 167 by a roller contact to the core wire 6. An anode 168 is connected by a positive conductor 169 to a generator 170 which is driven by a motor 171. The drag wire 31 is connected at points 172 and 173 within the trunnels 9 by positive conductors 174 and 175, respectively. Negative conductors 176, 177 and 178 connect the generator with points 167, 179 and 180, respectively, on the cathode wire.

In order to better equalize the current density along the length of the cathode wire in the trunnels 9, a shield is placed around the cathode near the entrance end of the trunnel, as illustrated in Figures 19 and 20. A shield 185 is placed in the trunnel near the entrance end between the drag wire 31 forming the anode and the process wire 6 forming the cathode. The drag wire has a very low electrical resistance compared to the process wire, since the former is of larger diameter than the latter and also because it is copper, whereas the process wire is steel, or steel on which copper has been deposited. If a shield is not used, the current takes the path of least resistance, and, instead of flowing uniformly from the anode to the cathode through the length of the trunnel, flows along the drag wire in both directions from the anode contact 186, rather than flowing through that portion of the bath near the anode contact. Under these conditions, a higher current density is obtained at the ends of the trunnels which are nearer to the cathode contacts 187 than is obtained at the middle of the trunnels. By interposing shields of non-conducting material between the anode and the cathode adjacent the cathode contacts, that is, between the wires 31 and 6 near the ends of the trunnels, the inequality in current density is minimized.

The greater the current density employed in the trunnels 9, the more rapid the deposition of copper will be and the less is the length of the apparatus required in order to deposit a given amount of copper. When the core wire enters the first of the trunnels in which copper is deposited thereon, it has a relatively low conductivity, the conductivity being about 7% where a steel core is employed. If it is attempted to apply too high a current density to the core wire in this trunnel, the deposit of copper is coarse and granular. I have found, however, that as the amount of copper is progressively built up

due to its passage through the various trunnels, a higher average current density can be employed in each succeeding trunnel and still produce a satisfactory deposit. In carrying out the process, I, therefore, prefer to progressively increase the current density as the exit end of the apparatus is reached. This enables me to form a satisfactory deposit and still keep the number of trunnels, or the length of a single trunnel if only one is used, within commercially practical limits. The proper spacing of the cathode contacts affects both the quality of the deposit and the cost of the process. High current densities decrease the total length of trunnels needed to produce a deposit of a certain thickness, but the current density cannot exceed a certain amount without injuring the quality of the deposit. In order to keep the current density within the limits which will give a good deposit, I preferably increase the distance between cathode contacts in the direction of travel of the core. If separate baths are employed, the length of the containers or trunnels 9, and the distance between cathode contacts likewise increases. The increased resistance due to the increased length of the coated core between cathode contacts compensates for the decreased resistance per unit of length resulting from the increased diameter of the coated core as the deposition continues. Important factors determining the proper spacing of cathode contacts are as follows:

- (1) The area of the process wire.
- (2) The conductivity of the process wire.
- (3) The average current density per square foot.
- (4) The electrical resistance of the solution, which resistance changes with the composition and temperature of the solution.

(5) The distance between anode and cathode. I have established a convenient rule for determining the distance between cathode contacts. Such distance for any part of the apparatus may be determined by multiplying the then area of the process wire (expressed in square inches) by the then conductivity of the process wire (expressed in percent of the conductivity of a wire of like size but all of one metal, e. g., copper) by a constant. I have found that the figure 100 is a good one to use as the constant in such formula and that the application of the formula gives the distance between cathode contacts in inches. 100 is, as stated, a good figure, but this may vary from 50 to 150. An example of the application of the formula is as follows:

Required, the distance between cathode contacts at the beginning of the coating operation, coating bare steel wire $\frac{3}{8}$ inch diameter. The area of the wire in square inches equals .11 approximately. The conductivity expressed as a percentage of a copper wire is 7. Therefore, the proper distance between cathode contacts equals $.11 \times 7 \times 100 = 77$ inches.

In Figures 21, 22 and 23 there is shown a preferred form of roller support for supporting the core either between trunnels or in a trunnel, the support being adapted to compact the deposited copper or other metal and refine its grain structure. In this device the core having a coating of metal thereon is supported by two rollers 190 having their axes extending in the direction of travel of the wire. Each of these rollers is of larger diameter at its center than at its end and is of a shape such as would be formed by placing the bases of two truncated cones on each other.

This type of roller provides a point contact for the core instead of a line contact such as would be provided by the usual cylindrical rollers. The core is supported by the large diameter portions 5 191 of the rollers. The rollers are preferably made of a hard corrosion resistant alloy, such as high chrome steel, or iron containing about 13% silicon, each roller being supported on a copper shaft 192. The shafts are connected to a coupling 193 which is connected at its upper end to a copper pipe 194 provided with a funnel 195. A cathode connection 196 is made with the pipe 194. Slightly acidulated water is supplied to the pipe 194, and after flowing through the 10 pipe, flows through the hollow shafts 192 of each of the rollers and is delivered through openings 197 in the pipe to the rollers and from the rollers to the core 6. The supply of acidulated water to the rollers prevents the formation of a dark colored stain in the same manner as described in connection with the embodiment shown in Figures 10 and 11.

There is a wedging action between the core and the rollers which compacts and refines the 25 grain of the deposited copper. This compacting action is many times as great as would be the case if ordinary cylindrical rollers were employed, since with the angular type rollers described, all of the weight of the core is concentrated at a single point on each roller. As the core revolves, the rollers form a helical path or slight groove in the copper, thereby compacting it and refining the grain structure by the mechanical work done thereon. In the illustrated embodiment, the two 35 rollers of each supporting and compacting device are so placed that their centers are slightly out of alignment. That is, the center of one of the rollers 190 is advanced slightly beyond the center of the other roller, the advance being equal to the pitch of the path made by the rollers, so that 40 when the core has passed over one set of rollers, only a single compacted path is formed on the copper.

A number of sets of rollers of the type described 45 may be used in carrying out the process. Figure 24 illustrates the paths made by two successive sets of rollers. Before the core having a coating of copper thereon has reached the first set of rollers, it has a diameter D, as shown in Figure 50 24. As the coated core passes over the first set of rollers, a path 198 is formed therein, in which path the grains of copper have been refined and compacted. As further copper is deposited the diameter increases as represented by D', and 55 when the core with the further amount of copper thereon reaches a second set of rollers, a second compacted path 199 is formed thereon. It will be seen that by increasing the number of sets of rollers, the compacting and refining action of the rollers may be exerted over substantially the 60 entire surface of the deposited metal. The great advantage of using angular rollers instead of cylindrical rollers is that the compacting and grain refining effect is enormously increased due to the point contact between the rollers and the deposited metal, and at the same time most of the crystal nuclei have been left undisturbed. The use of supports in a system of this kind is highly 65 advantageous as it permits of handling the wire expeditiously and without any deleterious effects upon the product. The guiding of the wire by means of the supports insures accurate positioning thereof at all times, thereby insuring that proper conditions will be maintained in the apparatus. 75

I prefer to use all of the different types of supports for the core which I have described, the different types of supports being used at different points in the process. Thus, in the tronnels, 3, 4, 5, 7 and 8, it is preferred to use solution contacts, that is, to avoid any mechanical contact with the core, as it has been found that minute scratches which are made by the use of mechanical contacts will be carried through the whole process and the defects may actually increase 10 as the process progresses. At the point 167 in Figure 18 between the tronnel 8 and the first tronnel 9, it is preferred to use a power driven roller contact of the type shown in Figures 16 and 17. It is necessary to supply current at this point, and yet the deposit is delicate. The use of power driven rollers reduces the friction which would be encountered with idler rollers and, therefore, reduces the tendency to scratch or mar the deposit. In passing through the first 20 tronnel 9 containing a hot copper solution, a relatively heavy deposit is made, so that a roller contact of the type shown in Figures 10 and 11 may be employed at the point 179. It is not necessary to use power driven rollers at this point, and yet the deposit at this point is not thick enough to advantageously use the compression rollers shown in Figures 21, 22 and 23. At point 180 and thereafter during the process, it is preferred to use the compression rollers shown 30 in Figures 21 to 23 to accomplish the compression and refinement in grain structure which has been described.

An advantage of the present process is that it gives a wide choice of combination of metals. 35 Certain of the high carbon steels cannot be successfully rolled at temperatures as low as 1900° F., yet in rolling bimetallic ingots, this temperature cannot be exceeded, because to do so would melt the copper. In consequence, it has not been possible to manufacture bimetallic 40 bodies by the molten process wherein the core steel had a high percentage of carbon.

Although it is preferred to use a steel core wire and to deposit a coating of nickel and then 45 a coating of copper thereon, the first coating may be eliminated and the copper may be deposited directly upon the core wire. Other metals than steel, copper and nickel may be employed, the compositions of the various cleaning solutions and electrolytic baths may be changed, and other shapes than wire may be produced. 50

I have illustrated and described the present preferred embodiment and manner of practicing my invention, but it should be understood that 55 the invention may be otherwise embodied or practiced within the scope of the following claims.

I claim:

1. In the method of electrodepositing metal on 60 a core, the steps comprising passing the core as a cathode through an electrolytic bath, rotating the core axially while passing through the bath, and forming compacted spaced paths in the form of helices on the deposited metal to refine 65 the grain structure.

2. In the method of electrodepositing metal on a core, the steps comprising passing the core as a cathode through an electrolytic bath, rotating the core axially while passing through the bath, 70 forming compacted helical paths on the deposited metal to refine the grain structure, and depositing additional metal on the compacted electrodeposited metal.

3. The method of compacting metal which has 75

been electrodeposited on a core, which comprises axially rotating the core having metal electrodeposited thereon, and while rotating it compacting helical grooves in the deposited metal to compact it and refine the grain structure.

4. In the method of electrodeposition of a metal on a base, the steps consisting in maintaining the base under a tension approaching its yield point and electrodepositing metal on the tensioned base.

5. In the method of electrodeposition of a metal on a ferrous base, the steps consisting in maintaining such base under a tension of 20,000-50,000 pounds per square inch, and electrodepositing metal on the tensioned base.

6. In the method of electrodepositing metal on a base, the steps consisting in passing the base as a cathode through an electrolytic bath to effect deposition of metal, compacting spaced zones on the deposited metal, and continuing the deposition.

7. A method of forming a wire of the type described which comprises passing a core wire as a cathode through a solution of the metal which is to form a sheath, plating metal from said solution onto said core wire, and rotating the wire about its axis while passing through said solution.

8. A method of forming a wire of the type described which comprises passing a core wire as a cathode through a solution of the metal which is to form a sheath, plating metal from said solution onto said core wire, rotating the wire about its axis while passing through said solution and burnishing said wire.

9. A method of forming a wire of the type described which comprises passing a core wire under tension as a cathode through an electrolytic bath to form a sheath, plating metal from said bath onto said core wire, rotating the wire about its axis while passing through said bath and burnishing said wire.

10. A method of forming a wire of the type described which comprises passing a core wire under tension as a cathode through an electrolytic bath to form a sheath, plating metal from said bath onto said core wire, rotating the wire about its axis while passing through said bath, burnishing said wire and passing said wire through a series of tanks and rotatably supporting said wire between said tanks.

11. The method of forming a multi-metallic article, which comprises pulling an elongate core, such as a wire, as a cathode through a solution of the metal which is to form a sheath, subjecting the core being fed to the solution to a force reacting against the pull in its direction of travel to maintain the core under tension, electrodepositing metal onto said core while under tension, and rotating the core about its axis while passing through said solution.

12. The method of forming a wire of the type described, which comprises advancing a core wire as a cathode through a series of electrolytic baths in a substantially straight path against a backward tensioning pull, electrodepositing metal on said core wire, rotating the wire about its axis while passing through said baths, and supporting said wire in its axial path while passing through said baths.

13. The method of electrodeposition, which comprises unreeling a core wire, advancing the core wire in a substantially straight path through an electrolytic bath, reeling up the coated product after passing through the bath,

relating the unreeling and reeling steps so as to highly tension the core wire, and electrodepositing metal onto the core wire in said bath while rotating the core wire about its axis.

14. The method of forming a multi-metallic article, which comprises pulling a core of unrestricted length, such as a wire, as a cathode through a solution of the metal which is to form a sheath, electrodepositing metal onto said core as a sheath, and rotating the core about its axis while pulling it through said solution.

15. The method of producing a multi-metallic article, which comprises advancing an elongate core in a single direction at a substantially constant rate as a cathode through a solution of the metal which is to form a sheath, electrodepositing metal onto said core as a permanent sheath, and rotating the core about its axis while advancing it through said solution.

16. The method of electrolytically forming successive deposits of different metals on a core, which comprises passing a core as a cathode through successive metallic baths of different metals, and substantially surrounding the core as it enters a bath of a different metal from the metal of the preceding bath with an anode of such potential as to effect a sufficiently high cathodic current density to produce a light flash coat of said different metal and subsequently depositing said different metal at ordinary current densities in the remainder of the bath.

17. The method of electrodepositing metal on a core, which comprises passing the core as a cathode through successive baths of nickel and copper, and acting upon the nickel coated core as it enters the copper bath by an anode of such potential as to effect a sufficiently high cathodic current density to produce a light flash coat of copper thereon and subsequently depositing copper thereon at ordinary current densities in the remainder of the copper bath.

18. The method of producing a multi-metallic article, which comprises electrodepositing metal as a permanent sheath on an elongate core advancing as a cathode through a solution of the metal which is to form the sheath, and simultaneously rotating the core about its axis and substantially continuously pulling the core through said solution.

19. The method of forming a multi-metallic article of the type described, which comprises pulling an elongate core, such as a wire, as a cathode through a solution of the metal which is to form a sheath, retarding the feed of said core into the solution so as to cooperate with the pull on the core in maintaining the core under tension while in the solution, electrodepositing metal from said solution on said tensioned core, rotating the core about its axis while passing through said solution, and supporting said core while passing through said solution.

20. The method of forming a multi-metallic article, which comprises substantially continuously advancing a core of unrestricted length such as a wire in a substantially straight path through a solution of the metal which is to form a sheath, rotating the core about its axis while passing through said solution, and electrodepositing a permanent sheath of metal on the core as a cathode as the latter advances through said solution.

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