

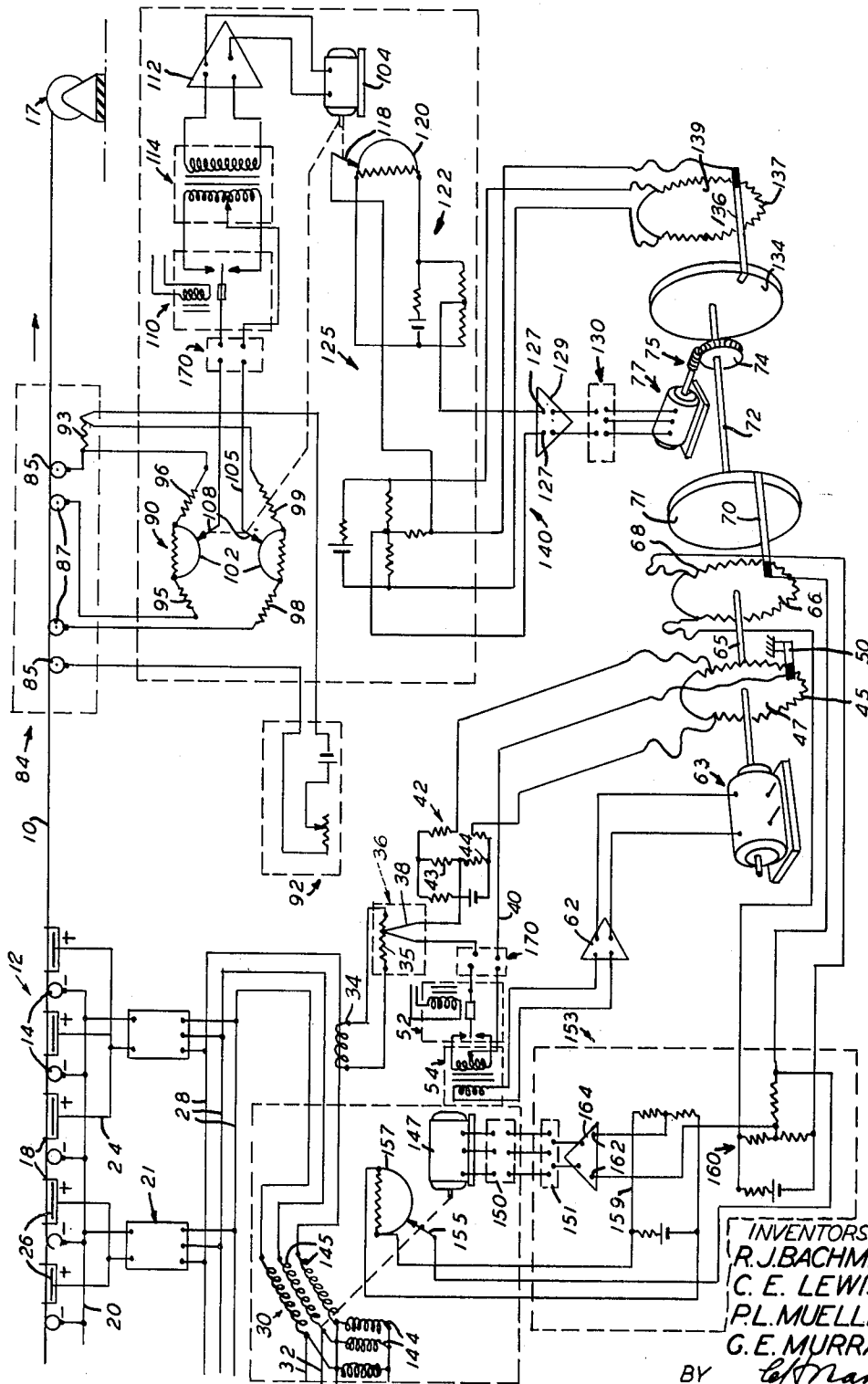
Feb. 14, 1956

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2,734,858

ELECTROPLATING APPARATUS WITH CURRENT CONTROL MEANS

Filed Sept. 30, 1952



1

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## ELECTROPLATING APPARATUS WITH CURRENT CONTROL MEANS

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Application September 30, 1952, Serial No. 312,326

2 Claims. (Cl. 204—211)

This invention relates to electroplating apparatus, and more particularly to apparatus for controlling the resistance of electroplated filamentary conductors.

In the manufacture of electrical conductors by an electroplating process, wherein a relatively heavy coating of a high conductivity metal, such as copper, is deposited upon a continuously advancing low conductivity core, such as steel, it is highly desirable that the resistance per unit length of the finished, electroplated conductor be maintained at a predetermined value. Manifestly, the resistance per unit length of the finished conductor is a function of the thickness of the coating of metal deposited upon the core.

Assuming that a cathodic steel core is advanced as a cathode at a substantially constant linear speed through a fixed number of electroplating cells, each containing a copper plating electrolyte and a copper anode, the thickness of the resulting copper coating plated on the steel core is dependent primarily upon the copper plating rate. Important factors which affect the copper plating rate are the cathode current density, the composition and temperature of the electrolyte, the spacing between the anodes and cathodic steel core, the spacing between cathodic contactors, the lengths of the individual cells, and the condition of the steel core. It has been found virtually impossible to maintain the aforementioned variable factors constant due to practical considerations, such as power line voltage fluctuations, failure of a rectifier, evaporation and contamination of the electrolyte, changes in temperature, disintegration of the anode materials, etc.

The resistance per unit length of the finished conductor is also a function of another variable factor, namely the resistance per unit length of the steel core. It is common to utilize steel wire for the core, the wire being normally produced in a standard wire drawing operation wherein there is no precise control of the resistance per unit length of the finished wire which may vary appreciably even along the relatively short length of wire included in a particular coil thereof.

With the exception of power line voltage fluctuations and rectifier failures, the variable factors which affect the resistance per unit length of the finished electroformed conductor are usually not subject to sudden variations, but instead vary normally at imperceptible rates over relatively long periods of time. Hence, it has been found desirable to compensate for the effects of these variable factors by controlling the plating current density in accordance with changes in the resistance per unit length of the finished conductor. However, due to the suddenness of changes in the system due to line voltage fluctuations and the considerable time lag between a control point on the finished conductor and the points at which current is supplied to the advancing core, it has been found necessary to compensate for the line voltage fluctuations independently of the resistance per unit length of the finished conductor.

2

It is an object of this invention to provide new and improved electroplating apparatus.

It is another object of this invention to provide new and improved apparatus for controlling the resistance of electroplated filamentary conductors.

An apparatus illustrating certain features of the invention may include means for supplying a plating current to an electroplating cell, means for continuously comparing the resistance of a predetermined length of a finished electroplated conductor with a standard resistance, and means actuated by difference between the measured resistance and the standard resistance for controlling the plating current supplying means to so change the plating current applied to subsequent portions of the core being plated as to cause the resistance of such portions to fall within predetermined limits.

A complete understanding of the invention may be had from the following detailed description of a specific method and a specific apparatus embodying the invention, when read in conjunction with the appended drawing, in which the single figure is a schematic representation of a control system designed to control the resistance per unit length of a finished copper coated, steel core conductor produced by an electroplating process.

Referring now to the drawing, a conductor 10 is advanced continuously through an electroplating apparatus, a portion of which is shown schematically at 12, by suitable drive means including driven contact rolls 14—14 and takeup apparatus, shown generally at 17. The linear speed of the conductor 10 is maintained substantially constant at a predetermined value by speed governing means (not shown) operatively associated with the drive means. The electroplating apparatus 12 includes a series of tanks 18—18 containing solutions of an electrolyte in which the advancing conductor 10 is immersed during the electroplating process wherein a coating of copper is electrolytically deposited upon its steel core.

The contact rolls 14—14 are electrically connected to a bus 20, which in turn is connected to the negative D. C. output terminal of a rectifier 21. The positive D. C. output terminal of the rectifier is electrically connected to a positive bus 24, which applies a positive potential to copper anodes 26—26 submerged in the electrolyte in each of the tanks 18—18. The anodes 26—26 are preferably formed in part of finely divided particles of copper. The rectifier 21 is connected at its input terminals to 3 phase 60 cycle A. C. supply lines 28—28, which are supplied by the output of an induction voltage regulator, shown generally at 30. The input to the induction voltage regulator 30 is supplied by lines 32—32 from a substation transformer (not shown).

One of the lines 28—28, between the rectifier unit 21 and the induction voltage regulator 30, is provided with a current transformer 34 which supplies a current proportional to the current existing in the line 28 to a resistor heater element 35 of a thermal converter unit designated 36. A thermocouple element 38, positioned in the thermal converter unit adjacent to the heater element, generates a D. C. voltage signal proportional to the square of the current in the lines 28—28.

The thermal E. M. F. generated by the thermocouple is inserted into the detector arm 40 of a potentiometer circuit, shown generally at 42. The potentiometer circuit 42 is provided with suitably proportioned resistances 43, 44 and 45, a suitable proportion of 45 being a slide wire resistance which is fixedly mounted on the periphery of a rotatable disk 47. The detector arm 40 is connected at one end to a stationary brush contact 50, which is positioned for sliding contact with the slide wire resistance 45 mounted on the rotatable disk 47, and at the other end to a junction intermediate of the resistances 43 and 44,

The detector arm 40 also includes a converter 52 connected in series with the thermocouple unit 38 for converting any D. C. voltage signal, produced in the detector arm due to an unbalance of the potentiometer circuit 42, into an alternating signal in order to facilitate a subsequent amplification thereof. The converter 52 is of a well-known type, having a metal reed which is made to move up and down 60 times per second, being driven by a 60 cycle coil, between a pair of contacts connected electrically to the opposite ends of the primary coil of a center tapped input transformer 54. During one-half of a cycle the current flows in one direction in the upper half of the primary coil of transformer 54 and during the remaining half cycle it flows in the opposite direction in the lower half of the primary coil. Hence, a 60 cycle A. C. signal voltage proportional to the D. C. unbalance voltage in the detector arm 40 is induced in the secondary coil of transformer 54.

The secondary coil of the transformer 54 feeds the A. C. signal voltage proportional to the D. C. unbalance voltage from the potentiometer detector arm 40 to an electronic amplifier, shown schematically at 62, wherein the A. C. signal voltage becomes strong enough to operate a two-phase balancing motor 63 in accordance therewith. The motor 63 is a two-phase induction motor having two separate windings and will not turn unless properly phased A. C. flows in both of its windings, one of which is connected to an A. C. supply, whereas the other winding is connected to the output terminals of the amplifier 62. Hence, when the latter is energized by a signal voltage from the potentiometer detector arm 40, the motor will turn in a direction determined by the polarity of the signal voltage. The balancing motor 63 is geared to rotate a shaft 65 upon which the disk 47 and a disk 66 are spacedly and fixedly mounted. The disk 66 is similar to the disk 47 and is likewise provided with a slide wire resistance 68 secured to its periphery.

A sliding contact 70 is fixedly and rigidly secured to the periphery of a disk 71 mounted on a second shaft 72 which is mounted for rotation about an axis aligned with the axis of rotation of the shaft 65. The contact 70 is arranged to slide along and in electrical contact with the slide wire resistance 68 whenever there is relative rotational movement between the disks 66 and 71.

When the motor 63 is operated, it rotates the shaft 65 to change the relative position of the stationary contact 50 with respect to the slide wire resistance 45, in such a manner as to reduce the signal voltage from the output terminals of the amplifier 62 to zero. Since the disk 66 is keyed to the shaft 65, a proportional change is made in the relative position of the sliding contact 70 with respect to the slide wire resistance 68.

The shaft 72 is provided with a worm gear 74 keyed thereto and designed for selective engagement with a worm 75 operatively connected for rotation by a balancing motor 77.

Positioned at the exit end of the electroforming machine is a conductor contacting device, shown generally at 84, which is similar to a device disclosed in a copending application Serial No. 312,209, filed September 30, 1952, by P. L. Mueller. The contacting device 84 includes a pair of spaced, freely rotatable, grooved current contact rollers 85—85 and a pair of freely rotatable grooved potential contact rollers 87—87 spacedly positioned between the current contact rollers. The contact rollers 85—85 and 87—87 are aligned in tandem on a suitable support structure which resiliently holds all four contact rollers in pressing electrical contact with the finished electroplated conductor 10.

The contact rollers 85—85 and 87—87 are electrically connected into a well-known Kelvin bridge circuit, shown generally at 90, which is well suited for the measurement or comparison of relatively small resistances. The potential contact rollers 87—87 make electrical contact with the advancing conductor at points spaced apart a pre-

termined distance so that the resistance between the ends of a predetermined length of the advancing conductor 10 is constantly being measured. D. C. current from a D. C. power source designated 92 flows continuously in a length of the conductor 10 between the current contact rollers 85—85 and also through a standard resistance 93. The potential drops across the predetermined length of the advancing conductor 10 and the standard resistance 93 are inserted into adjacent arms 98 and 99 of the Kelvin bridge circuit 90 containing suitably proportioned resistances.

The bridge arms 95 and 96 and bridge arms 98 and 99 likewise containing suitably proportioned resistances are connected by slide wire resistances 102—102, rotated by a two-phase balancing motor 104. A detector arm 105 is electrically connected at opposite ends to movable contacts, shown schematically at 108—108 operatively connected to a two-phase balancing motor 104, which are designed to make sliding electrical contacts with the slide wire resistances 102—102 respectively. The bridge circuit 90 is in balance as long as the resistance of the predetermined length of the advancing conductor 10 is equal to that of the standard resistance 93. Whenever the resistance of the predetermined conductor length varies from the standard resistance, the bridge circuit 90 is unbalanced momentarily and an unbalance signal current flows in the detector arm 105.

The current flowing in the detector arm 105 is converted to an A. C. signal by a converter 110, similar to the previously described converter 52, and fed into an amplifier 112 by means of an input transformer 114. The amplified A. C. signal proportional to the unbalance in the bridge circuit 90 is fed into one coil of the balancing motor 104, which causes the motor to move the contacts 108—108 to change their positions relative to the slide wires 102—102 simultaneously and equally, in such a manner as to restore the balance of the bridge circuit 90 and reduce the current in the detector arm 125 to zero.

Operatively connected to the shaft of the balancing motor 104 for movement therewith is a sliding contact 118. The contact 118 is designed to slide in electrical contact with a slide wire resistance 120, which forms a portion of a bridge circuit 122 of a standard L & N Series 50 control unit, shown schematically at 125. The sliding contact 118 is moved along the slide wire resistance 120 by the balancing motor 104 an amount proportional to the movement of the slide wire resistances 102—102 relative to the contacts 108—108.

A change in the position of the contact 118 and the slide wire resistance 120 results momentarily in an unbalance voltage between input terminals 127—127 of an amplifier-detector unit, shown schematically at 129, which in turn operates the two-phase balancing motor 77 through a well-known reversing relay 130 in accordance with the polarity of the unbalance voltage. The balancing motor 77, as previously, described, rotates the shaft 72 by means of a worm gear 75 and the spool gear 74, mounted on the end of the shaft 72 opposite the end supporting the disk 71.

A disk 134 is fixedly mounted for rotation with the shaft 72. The disk 134 supports a sliding contact 136 fixedly secured thereto, which is designed for sliding contact with a slide wire resistance 137 mounted on the periphery of a stationary disk 137 supported by a suitable means (not shown). The slide wire resistance 137 is inserted in a bridge circuit 140 which is a part of the control unit 125. The sliding contact 136 likewise is connected to the bridge circuit 140, in the manner shown in the schematic circuit for the control unit 125. The balancing motor 77 is energized whenever a voltage exists between the input terminals 127—127 of the amplifier-detector unit to rotate the shaft 72 in a direction determined by the polarity of the voltage, thereby changing the position of the sliding contact 136 so as to reduce the voltage between input terminals 127—127 to zero.

The induction voltage regulator 30 is provided with primary coils 144—144 forming a stator and secondary coils 145—145 forming a movable rotor. The rotor is operatively connected through suitable gearing to a reversible capacitor-type two-phase motor 147. A motor-control relay 150, which requires a very low operating current, controls the operation of the motor 147 in accordance with a directionalized signal voltage from an auxiliary reversing relay 151 actuated by an L & N Series 50 control unit, shown schematically at 153, similar to the control unit 125. When the secondary coils 145—145 of the rotor are moved relative to the primary coils 144—144 of the stator by the motor 147, the flux linkages between the rotor and stator are altered to vary the output voltage of the induction regulator unit.

Operatively connected to the drive shaft of the motor 147 for movement therewith is a sliding contact 155, which slides along a stationary slide wire resistance 157 which forms an integral part of a bridge circuit 159 in the control unit 153. Likewise, the slide wire resistance 68 is connected into a second bridge circuit 160 in the control unit 153. The sliding contact 70 associated with the slide wire resistance 68 is connected so that any change in its position results momentarily in D. C. unbalance voltage between input terminals 162—162 of an amplifier-detector unit, shown schematically at 164. The amplifier detector unit 164 operates the motor 147, through a reversing relay 151 and the motor-control relay 150, in such a manner as to change the relative position of the sliding contact 155 with respect to the slide wire resistance 157 so as to reduce the D. C. unbalance voltage between the terminals 162—162 to zero. When the motor 147 is energized to restore the balance within the control unit 153, the angular position of the primary coils 144—144 with respect to secondary coils 145—145 is changed by an amount proportional to the relative movement of the sliding contact 70 with respect to the slide wire resistance 68, thereby causing a change in the output voltage of the induction regulator unit 30.

The detector arms 40 and 105 associated with the potentiometer circuit 42 and Kelvin bridge circuit 90 are provided with damping and filtering networks shown generally at 170—170. The network 170—170 serve to reduce the time required to balance these circuits.

#### Operation

In order to facilitate the description of the operation of the control apparatus, it will be assumed that the electroplating apparatus 12 is in operation and the conductor 10 is being advanced continuously therethrough at a constant speed. Further, it will be assumed that a D. C. plating current is being supplied by means of the rectifier 21 to the individual plating cells via the contact rolls 14—14 engaged by the advancing conductor and the anodes 26—26 so that a uniform coating of copper is deposited upon the conductor. After the conductor 10 leaves the electroforming machine 12, it is engaged by the contact rollers 85—85 and 87—87, which are rotatably mounted on the conductor contacting device 84.

As previously described, the potential contact rollers 87—87 make electrical contact with the conductor at points spaced apart by a predetermined distance so as to pick off the potential drop along a predetermined length of the advancing conductor. This potential drop along the conductor is inserted into the Kelvin bridge circuit 90 and compared with the potential drop between the potential terminals of the standard shunt 93. If any difference exists between the resistance of the predetermined length of conductor 10 and the resistance of the standard shunt, an unbalanced voltage will occur momentarily between the contacts 108—108, causing a current flow in the detector arm 105 of the Kelvin bridge circuit. In the manner heretofore described, the unbalanced current in the detector arm 105 is converted to an A. C. signal voltage proportional thereto which is amplified and fed into one

of the coils of the two-phase balancing motor 104, which in turn is operated by the signal voltage in such a manner as to vary the relative positions of the contacts 108—108 with respect to the slide wire resistances 102—102 and reduce the unbalance current in the detector arm 105 to zero.

Simultaneously, with the balancing of the Kelvin bridge circuit, the balancing motor 104 moves the sliding contact 118 an amount proportional to the movement of the slide wire resistances 102—102 relative to the contacts 108—108. The movement of the contact 118 upsets the balance of the bridge circuit 122 within the electrical control unit 125, thereby initiating the operation of the balancing motor 77 which turns the shaft 72 to change the relative position of the sliding contact 139 with respect to the slide wire resistance 137 so as to reduce the unbalanced voltage at the input terminals 127—127 of the amplifier detector 129 to zero. Since the sliding contact 70 associated with the slide wire resistance 68 is keyed to the shaft 72, the relative position of the contact 70 with respect to the slide wire resistance is changed by an amount proportional to the unbalanced voltage which momentarily occurred in the control unit 125, which in turn was proportional to the original degree of unbalance in the Kelvin bridge circuit 90.

Simultaneously, with the change in the relative position of the contact 70 with respect to the slide wire resistance 68, an unbalanced condition is produced momentarily in the control unit 153, which results in the operation of the motor 147 to move the sliding contact 155 to change its position with respect to the slide wire resistance 157 by an amount proportional to the initial movement of the contact 70 with respect to its associated slide wire resistance 68. In operating to restore a new balanced condition within the control unit 153, the induction voltage regulator rotor positioning motor 157 moves the secondary coils 145—145 of the rotor relative to the primary coils 144—144 of the stator, thereby varying the output voltage of the induction regulator unit 30, by an amount proportional to the original unbalance in the Kelvin bridge circuit 90 due to the variance between the resistance of the predetermined length of conductor 10 and the resistance of the shunt 93.

The direction of the change in the output voltage of the induction regulator unit 30 is determined by the direction of the unbalance in the Kelvin bridge circuit 90. Hence, if the resistance per unit length of the conductor should decrease the output voltage of the induction regulator unit 30, the output voltage would be reduced thereby reducing the plating current and the rate of plating and tending to restore the resistance per unit length of the finished conductor to within the predetermined limits.

Immediately after the output voltage of the induction regulator unit 30 is changed, the resultant change in current in the lines 28—28 is sensed by the current transformer 34, thereupon causing a change in the thermal E. M. F. generated by the thermocouple 38 and momentarily creating an unbalanced condition in the potentiometer circuit 42. The D. C. unbalance current flowing in the detector arm 40 is converted into an A. C. signal voltage which is amplified and fed to one coil of the two-phase balancing motor 63, thereby causing the motor to turn the shaft so as to vary the position of the sliding contact 50 with respect to the slide wire resistance 45 in such a direction as to tend to restore the potentiometer circuit 42 to its balanced condition.

When the shaft 65 turns, it carries with it the disk 66 and its associated slide wire resistance 68 and again causes an unbalance in the control unit 153. However, these unbalanced conditions in the potentiometer circuit 42 and the control unit 153 are merely transient and the system finally arrives at a balanced condition with a new value of plating current being supplied to the plating cells.

To illustrate the operation of the system to compensate for line voltage fluctuations, let us assume that the input

voltage to the induction regulator unit 30 suddenly drops due to an increased load on the input or output side of the substation transformer. This reduction in the voltage across the input terminals of the induction regulator unit 30 would momentarily cause a proportional reduction in the output current and output voltage of the unit. The current transformer 34 would immediately sense the reduction in the output current and cause a change in the thermal E. M. F. generated by the thermocouple 32 which in turn would cause a flow of current in the detector arm 40 of the potentiometer circuit 42.

In a manner previously described, the unbalance current in the detector arm 40 initiates the operation of the balancing motor 63 to turn the shaft 65 so as to change the position of the contact 50 with respect to the slide wire resistance 45 and reduce the current in the detector arm to zero. The rotation of the shaft 65 likewise changes the position of the contact 70 with respect to the slide wire resistance 68 and in the manner previously described causes the operation of the induction voltage regulator positioning motor 147 to change the position of the rotor of the induction regulator unit in such a manner as to restore the value of the current in lines 28—28 to the value that existed prior to the drop in the voltage from the substation transformer.

It will be understood that this system may be utilized for controlling the production of any number of electroplated conductors. Where a plurality of spaced filamentary cores are advanced in parallel relation through an electroforming apparatus to simultaneously plate heavy conductive coatings thereon, continuous resistance measurements by means of the conductor contacting device may be made on a conductor representing the average conductor. The conductor contacting device may be shifted as desired to utilize another conductor as a control conductor.

Among the manifold advantages afforded by the aforementioned control system is its suitability for use in electroplating processes where a relatively large time lag occurs between the end of the plating section and the control point.

It will be understood that although the control system described is utilized for controlling the resistance per unit length of electroplated filamentary conductors, its use is not limited thereto. It is obvious that the system with certain modifications might be utilized to control the size of a finished article, e. g. the thickness of an electrolytically-deposited coating of copper, silver or the like upon a strip, a rod or a stranded filamentary material having a resistance higher than that of the metal plated thereon. It is manifest that numerous modifications of the heretofore described system may be made within the spirit and scope of the invention.

What is claimed is:

1. In electroplating apparatus wherein a filamentary conductive core is advanced continuously through an electroplating cell to produce a composite electroplated conductor, the improved electroplating control apparatus which comprises a source of E. M. F. having a variable voltage output for supplying plating current to the electroplating cell, resistance monitoring means for detecting

variations from a predetermined magnitude in the resistances of successive increments of the finished composite electroplated conductor of a predetermined length, primary means responsive to said resistance monitoring means whenever such a resistance variation is detected for demanding a new value of plating current such as would tend to restore the resistance of the finished conductor to the predetermined magnitude and for changing the output voltage of said source by an amount substantially proportional to the demanded change in the plating current, and secondary means responsive to the primary means and the plating current for continuously comparing the instantaneous plating current supplied to the cell with the value of plating current demanded by the primary means and for changing the output voltage of the source by an amount substantially proportional to a detected variation therebetween so as to maintain the actual plating current substantially constant at whatever magnitude is demanded by the primary means.

2. In electroplating apparatus wherein a filamentary conductive core is advanced continuously through a series of electroplating cells at a substantially constant linear speed to produce a composite electroplated conductor, the improved electroplating control apparatus which comprises a plurality of rectifiers for supplying plating current to the electroplating cells, a voltage regulator having a variable voltage output for energizing said rectifiers, a reversible electric motor operable for adjusting the output voltage of the voltage regulator, a bridge circuit for comparing the resistances of successive increments of the finished composite conductor of a predetermined length with a standard resistance of a predetermined magnitude, means for detecting differences between the compared resistances, primary means responsive to said detecting means for demanding whenever such a difference is detected a new magnitude of plating current to be supplied to the cells such as would tend to restore the resistance of the finished composite conductor to the predetermined magnitude, said primary means being designed to effect the operation of the reversible electric motor in such a manner as to change the output voltage of the voltage regulator by an amount substantially proportional to the demanded change in the plating current, means for continuously sensing the magnitude of the plating current supplied to the cells, and secondary means responsive to said primary means and to said current sensing means for continuously comparing the magnitude of the instantaneous plating current supplied to the cells with the magnitude of plating current demanded by the primary means and for operating the reversible electric motor in such a manner as to change the output voltage of the voltage regulator by an amount substantially proportional to a detected variation therebetween so as to maintain the actual plating current substantially constant at whatever magnitude is demanded by the primary means.

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