Nov. 19, 1963 G. R. SCHAER 3,111,479

POWER SUPPLY FOR CHROMIUM PLATING

Filed Aug. 23, 1960 3 Sheets-Sheet 1

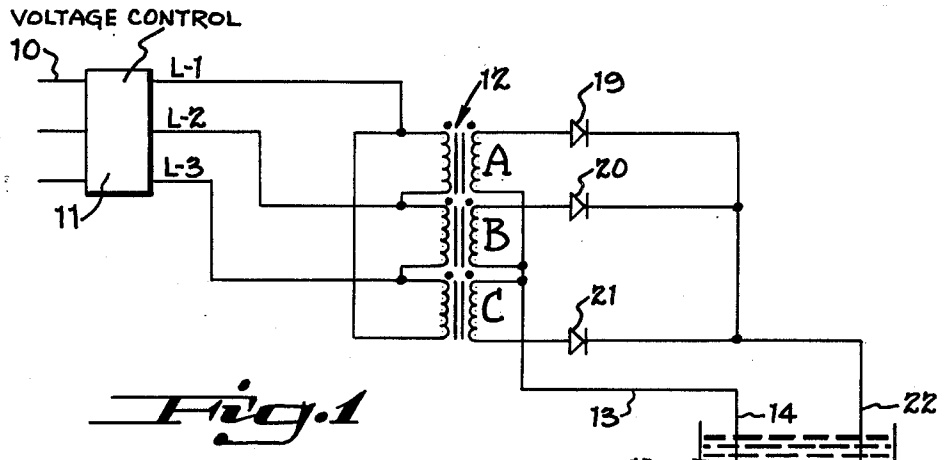


Fig. 1

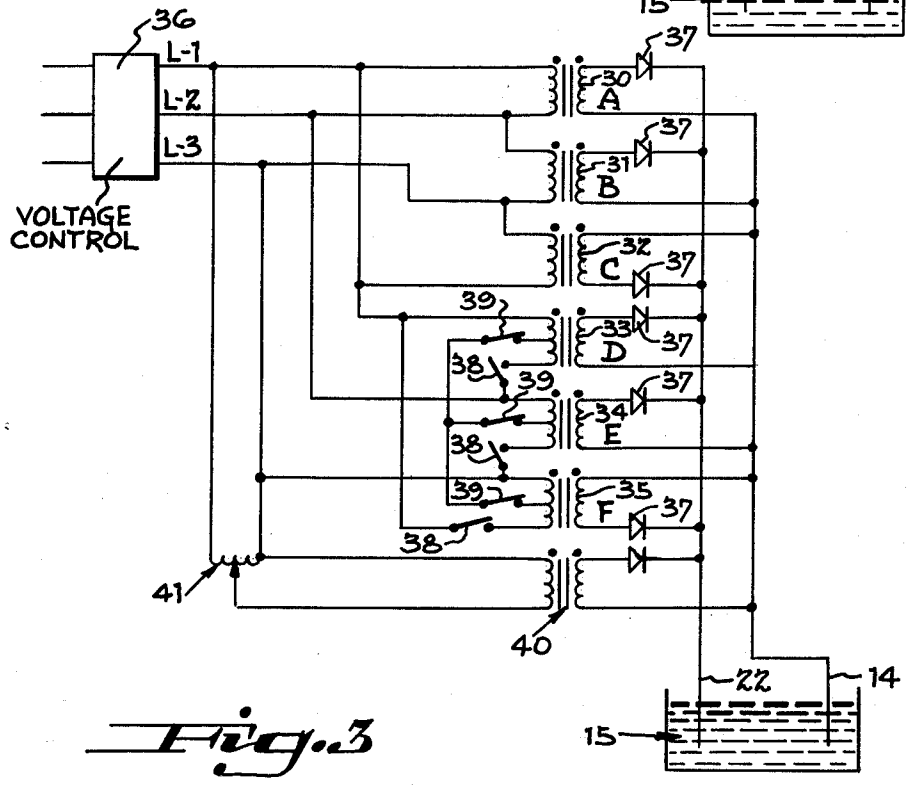


Fig. 3

INVENTOR.
Glenn R. Schaer.
BY
Wood, Herron & Evans.
ATTORNEYS.

Nov. 19, 1963 G. R. SCHAER 3,111,479

POWER SUPPLY FOR CHROMIUM PLATING

Filed Aug. 23, 1960 3 Sheets-Sheet 2

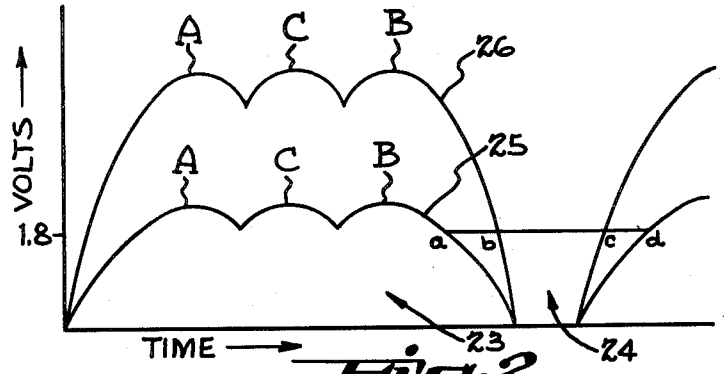


Fig. 2

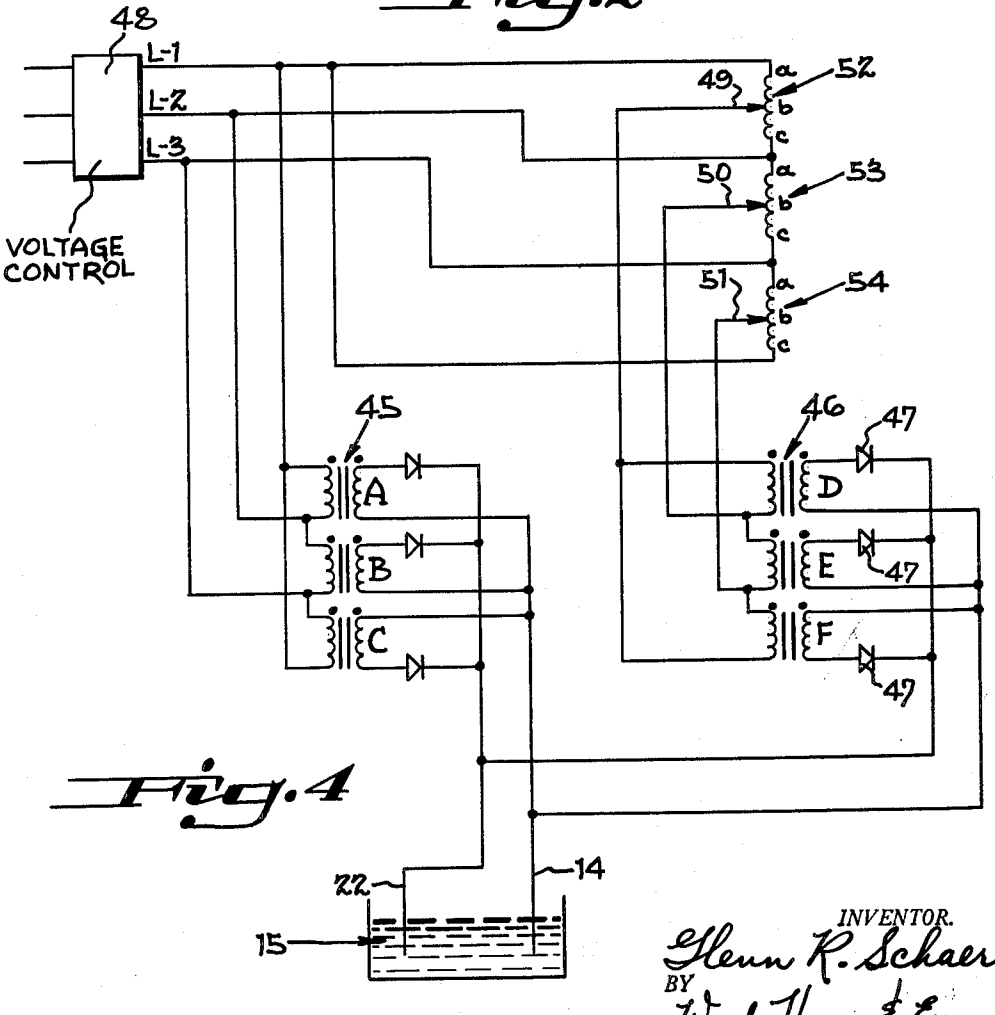


Fig. 4

INVENTOR.
Glenn R. Schaer.
BY
Wood, Herron & Evans.
ATTORNEYS.

Nov. 19, 1963 G. R. SCHAER 3,111,479

POWER SUPPLY FOR CHROMIUM PLATING

Filed Aug. 23, 1960 3 Sheets-Sheet 3

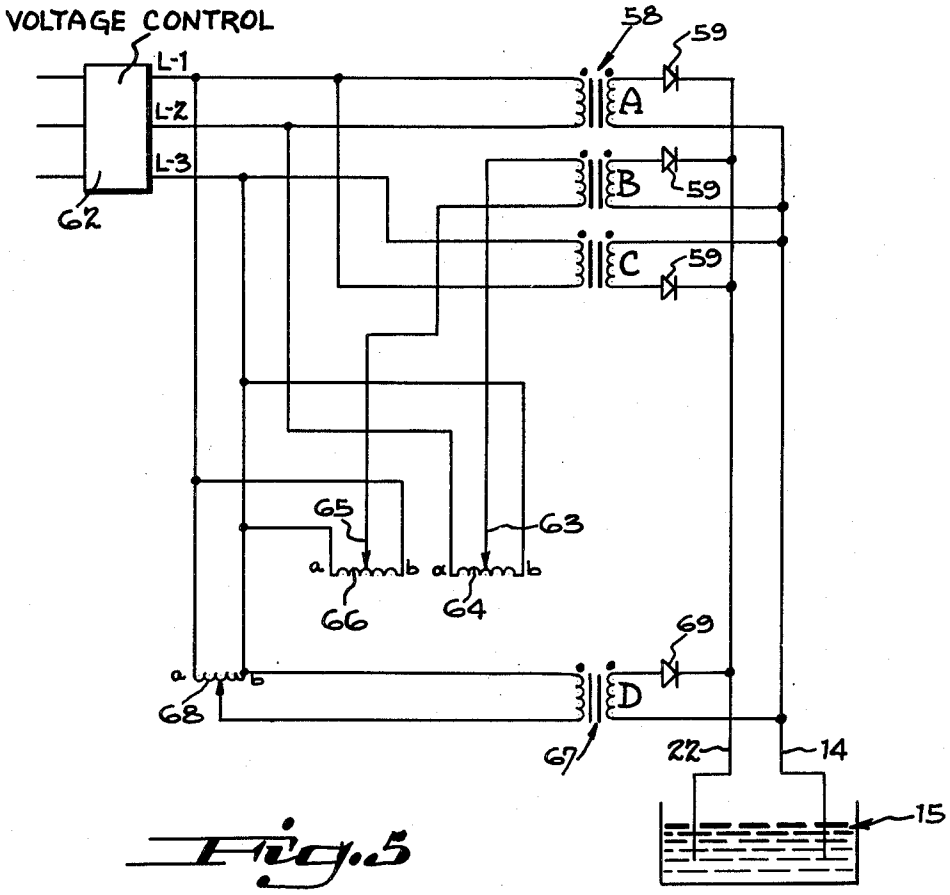


Fig. 5

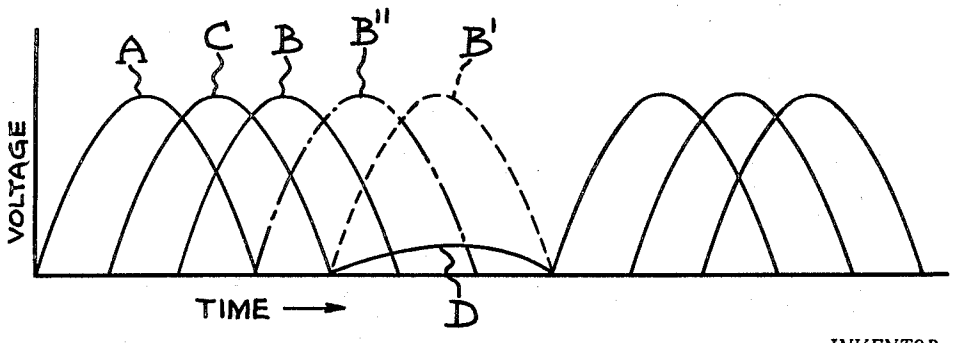


Fig. 6

INVENTOR.
Glenn R. Schaer.
BY
Wood, Herron & Evans.
ATTORNEYS.

United States Patent Office 3,111,479 Patented Nov. 19, 1963

3,111,479

POWER SUPPLY FOR CHROMIUM PLATING

Glenn R. Schaer, Columbus, Ohio, assignor, by mesne assignments, to General Development Corporation, Miami, Fla., a corporation of Delaware

Filed Aug. 23, 1960, Ser. No. 51,426
12 Claims. (Cl. 204—228)

This invention relates to the art of electrolytic processes and apparatus therefor and more particularly the invention is directed to an improvement in power supplies for plating certain metals which are difficult to plate such as chromium.

It has been an objective of the invention to provide an improved power supply for various electrolytic processes including electroplating, electrocleaning and electropolishing. The invention will be described with particular relation to chromium plating for it is in chromium plating that the most dramatic results have been observed.

Chromium plating is a comparatively new and somewhat inexact science. Early attempts to plate chromium on base metals were only sporadically successful. It was known that chromium could be plated on base metals but, until the 1920's it was impossible to enjoy any substantial reproducibility of good plating results. In the twenties it was discovered that reproducibility could be attained if the ratio of chromic acid to sulfate ion was maintained within a prescribed range.

Attention was given to the power supply for chromium plating. Since the beginning of successful chromium plating until quite recently, authorities in the art of chromium plating have insisted that the plating current be maintained as free from "ripple" as possible; for otherwise, the results of chromium plating will be at best erratic. Preferred forms of power supplies for attaining minimum ripple plating current are motor generator sets or more economical three-phase full wave rectified power supplies.

In my co-pending application Serial No. 818,302, filed June 5, 1959, now Patent No. 3,042,592, there is disclosed a new theory in the art of chromium plating, the new theory being directed to the mechanism by which the type of current wave form affects the deposition of chromium on base metal. It is stated that superior results can be attained not by maintaining a ripple free plating current but rather by introducing a controlled ripple, that is, by employing a current having a predetermined on-time and a predetermined off-time.

Throughout this specification, "on-time" is defined as that portion of each cycle of impressed plating voltage wherein the voltage is of a sufficient amplitude to plate chromium on the cathode of the plating bath. "Off-time" is defined as the remaining portion of each cycle of impressed plating voltage wherein the voltage is of insufficient amplitude—but not less than zero—to plate chromium on the cathode of the plating bath. Under certain load conditions the prescribed conditions of on-time and off-time can be attained by the use of a single phase full wave rectified current. In practice, the power supply will be 60 cycles for 60 cycle current is that which is normally supplied to industrial areas throughout the United States. It can be appreciated from the discussion in my earlier application that the frequency of the power supply is not a controlling consideration as long as the prescribed on-time off-time relationship is maintained.

In large industrial plating installations where the total amperage for any plating bath is substantially in excess of 2,000 amperes the prescribed relationship of on-time off-time is difficult if not impossible to attain when the single phase full wave rectified power supply is used.

In my co-pending application I proposed two alternative power supplies, the first being a half-wave rectified two-phase voltage the phases being 120° apart as for example in two phases of a three-phase system. The second form, which is preferred because it permits a better balance of the loading on a three-phase system, is a half-wave rectified three-phase voltage in which the one phase is inverted by reversing its normal connections. The current form resulting from these two power supplies has a theoretical on-time for 300° of each cycle and an off-time for 60° of each cycle. In practice, and as will be explained in detail below, under low load conditions the off-time might go as high as approximately 110° or 30% of each cycle. Such a high percentage off-time is undesirable and may lead to unsatisfactory deposits of chromium on a base metal.

An objective of the invention has been to provide a power supply which can be used in plating chromium through a wide range of loading. The power supply of the present invention can be used either at 10% of full load or at full load with equally satisfactory results. Broadly, this objective is realized in one of two ways. First, provision can be made for phase shifting at least one phase of a three-phase system with respect to the other two phases. Similarly, two sets of three-phase transformers can be employed with provision for shifting the phase of one set of transformers with respect to the phase of the other set of transformers.

The second method and apparatus for realizing the objective is to provide three-phase circuitry which provides an optimum median off-time, on-time relationship. With such a circuit design, whether the transformer is used under full load or at a small percentage of full load, the ratio of on-time to off-time will remain within a satisfactory range.

It has been found that when using inexpensive materials in the rectifiers for the power supply, there is an undesirable reverse flow of current, that is, a change of polarity during off-time. As explained in my earlier application, it is very important that reversal of polarity of the current be avoided. It is an objective of the invention to provide a circuit design in which reversal of polarity of the current is avoided by providing a low voltage booster current which will occur during the normal off-time, the voltage of the booster current being maintained at a low enough level that plating will not occur during the off-time.

These and other objectives of the invention will become more readily apparent in the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a circuit diagram of a three-phase system connected to provide an on-time and an off-time;

FIG. 2 is a circuit showing the voltage resulting from the circuit of FIG. 1;

FIG. 3 is a circuit diagram of a preferred form of my invention;

FIG. 4 is a circuit diagram of an alternative form of my invention;

FIG. 5 is a circuit form of still another alternative form of my invention; and

FIG. 6 is a curve showing the voltage resulting from the circuit of FIG. 5.

The simplest form of the three-phase power supply of my invention is shown in FIG. 1. There a three-phase voltage supply indicated at **10** is fed through a voltage control unit **11** of known design and is connected to a three-phase transformer **12** through lines L–**1**, L–**2** and L–**3**. The transformer **12** may be a single three-phase unit, that is, a transformer in which all windings are on a single core; or it may be comprised of three single phase transformers, each transformer being wound on a separate core. The primary of the transformer **12** is delta

connected and the secondary is wye connected. The neutral terminal of the secondary is connected by a lead 13 to the cathode 14 in a plating tank 15. The cathode 14 is formed by the articles to be plated which are racked in a known manner.

The secondary of the transformer 12 has three phases A, B and C. The free ends of each secondary winding are connected through half-wave rectifiers 19, 20 and 21 to an electrode 22 which forms the anode of the plating bath. It can be seen from FIG. 1 that the terminals of secondary phase C are reversed as compared to the terminals of phases A and B. The circuit of FIG. 1 results in a voltage at the plating bath electrodes whose form is illustrated in the curve of FIG. 2. The output from a symmetrically wound, half-wave rectified three-phase transformer would be a series of pulses each spaced 120° in time from the preceding half-wave pulse. However, because of the inversion or reversal of phase C in transformer 12, its half-wave pulse is not spaced 120° after the pulse of phase B but rather the pulse of phase C occurs between the half-wave pulses of phases A and B with an off-time period occurring at the end of the pulse of phase B. The on-time period is indicated at 23 and the off-time is indicated at 24.

In practice, because of the electrolytic or battery effect of the plating bath, a voltage of approximately 1.8 volts can be measured across the electrodes during the off period 24.

In FIG. 2, two conditions of loading are illustrated by curves 25 and 26 respectively. The curve 25 shows the voltage when the power supply is operating at low load. Since the flow of current ceases when the applied voltage, which is substantially in phase with the current, drops to approximately 1.8 volts, at low loads the current will have a comparatively short on-time and comparatively long off-time. The long off-time is indicated by the distance between points *a* and *d* on the curve. This condition in which the off-time is as high as about 30% of the total cycle tends to result in unsatisfactory plates.

Curve 26 illustrates a condition of high load on the power supply. The voltage required under high load conditions decays much more rapidly from maximum amplitude and, as can be seen, results in much shorter off-time as designated by the distance between points *b* and *c* of the curve.

The circuit of FIG. 3 represents an improvement in a three-phase power supply through which the variation of on-time off-time through a range of low load to full load is minimized. In the circuit of FIG. 3, six single phase transformers 30–35 are connected to a three-phase regulated voltage source indicated at 36. Transformers 30, 31 and 32 producing phases A, B and C have their primaries delta connected and their secondaries wye connected through rectifiers 37. The transformer 32 producing phase C has its terminal connections reversed as compared to transformers 30 and 31 so as to provide the phase relationship illustrated in FIG. 2.

Transformers 33, 34 and 35 producing phases D, E and F have their secondaries connected through rectifiers 37 identically to the secondary connection of transformers 30–32 so as to produce an inverted phase F. The primaries of transformers 33–35 however, are wye connected so as to shift the phase of the output of the transformers 33–35 by 30° with respect to transformers 30–32. Thus with the circuit of FIG. 3, the output of transformers 33–35 reduces the theoretical off-time by 30° and increases the theoretical on-time to 330°. While there will be some variation in the off-time under changing load conditions, at low load conditions that is about 10% of full load the off-time will be less than approximately 17.5%.

The primaries of transformers 33–35 are provided with three normally open switches 38 and three normally closed switches 39. When the switches are in their normal position as shown, the primary is wye connected as discussed above. The voltage impressed on each primary of the wye connected transformers will be the line voltage divided by $\sqrt{3}$. Since the line voltage is impressed on the primaries of the delta connected transformers, in order to maintain balanced outputs on transformers 30–32 and 33–35, the primaries of transformers 33–35 must be tapped at

$$\frac{n}{\sqrt{3}}$$

where n is the number of turns. Stated another way, if transformers 33–35 are to be connected to a 220 volt source, a 127 volt tap should be employed. The delta-wye circuit of FIG. 3 provides a theoretical intermediate off-time of 30° which has proved to be well suited for a wide range of operating conditions, and does not require an operator to manipulate tap changing switches with each change of operating conditions.

Under conditions of high loading the 30° phase shift may not be desirable for under high loads the off-time is sometimes reduced to an undesirable point. Under such conditions, the power supply can easily be converted to a theoretical 60° off-time by opening switches 39 and closing switches 38 to convert the 127 volt tapped wye connection to a 220 volt delta connection.

It should be appreciated that the particular values of voltage are set forth herein by way of example. The circuit for the power supply will be substantially the same when connected to a voltage source other than that described with different but proportionate values of voltages being used.

As discussed above, there is a tendency in rectifiers such as selenium rectifiers, for current to reverse during the off-time. Such current reversal has resulted in erratic plating results and is undesirable. To eliminate current reversal, a booster transformer 40 connected through an auto transformer 41 is connected across the inverted phase so that a low positive going voltage will be applied to the plating electrodes during the normal off-time. The voltage from transformer 40 will be high enough to block current reversal but will be of insufficient magnitude to cause plating.

An alternative power supply is illustrated in FIG. 4. The power supply of FIG. 4 has two sets of three-phase transformer systems indicated at 45 and 46. The secondaries of transformers 45 and 46 are connected to the plating electrodes as were the secondaries of the transformers of FIG. 3 with a third phase (C and F respectively) inverted to provide the 60° off-time. Rectifiers 47 are employed in the usual manner for half-wave rectification.

The transformers 46 are fed from a three-phase regulated voltage source 48 through the taps 49, 50 and 51 of auto transformers 52, 53 and 54. By moving the taps of the auto transformers from a position indicated at *a* to the position indicated at *c*, it is possible to shift the phase relationship of the transformers 46 through 120°. When the taps are at position *a*, the voltage of transformers 46 is exactly in phase with the voltage of transformers 45. As the taps are moved to position *b*, the phase of transformers 46 is shifted so that the on-time of transformers 46 overlaps the off-time of transformers 45 thereby reducing the off-time of the combined transformers below 60°.

Still another form of power supply permitting a foreshortening of the normal 60° off-time is illustrated in FIG. 5. In circuit of FIG. 5 only one three-phase transformer system 58 has its secondaries connected through half-wave rectifiers 59 to the electrodes 14 and 22 in a plating tank. The three-phases of the transformer 58 are designated by A, B and C. The primaries through the transformers are fed by a regulated voltage source 62. Phase A and the inverted phase C are connected directly to the voltage source 62. The primary of phase B is connected on one side to a tap 63 of an auto transformer 64. The other side of the primary of phase B is connected to

a tap 65 on an auto transformer 66. Auto transformer 64 is connected between lines L–2 and L–3 of the voltage source 62 and auto transformer 66 is connected across lines L–1 and L–3 of voltage source 62.

In operation phase A is connected between lines L–1 and L–2 phase C is connected between lines L–3 and L–1. For operation with a 60° off-time as illustrated in FIGS. 1 and 2, phase B should be connected between lines L–2 and L–3. As can be observed from the diagram, when the taps 63 and 65 of the auto transformer are positioned at *a*, the primary of phase B will be connected between lines L–2 and L–3. The output will appear as shown in FIG. 6 wherein the three phases A, B and C are shown in full lines.

If the taps are shifted to the position indicated at *b*, it can be observed that the primary of phase B will be connected across lines L–1 and L–3. When phase B is connected across line L–1 and line L–3, the voltage of the secondary will be in phase with the voltage of the secondary of phase C. Since the secondaries of phase B and C are rectified so as to be inverted with respect to each other. The resultant wave will be as illustrated in FIG. 6 wherein the voltage outputs from the three phases is represented by A, C and B′, B′ being shown in broken lines. In this condition of the transformer system the off-time will be substantially eliminated. However, when the taps 63 and 65 are shifted to an intermediate position between positions *a* and *b*, the resultant voltages from the three phases will appear as A, C and B″, B″ being shown in dot and dash lines in FIG. 6.

As explained before in connection with FIG. 3, a voltage booster may be employed to apply a low level voltage to the system during the off-time in order to block any current reversal. To this end, transformer 67 is connected across lines L–1 and L–3 through a regulating auto transformer 68 so that transformer 67 is in phase with phase C. However, the secondary of transformer 67 has a rectifier 69 connected to invert the output of transformer 67 with respect to transformer C so that the resultant output of transformer 67 will appear as a low level voltage indicated at D in FIG. 6.

The invention has been described in relation to the plating of chromium particularly because of the marked improvement obtainable with this metal which is notoriously difficult to plate. The invention has proved useful in other electrolytic processes such as copper plating, electrocleaning and electropolishing.

For example, an improved copper plate was obtained by applying the power supply of the present invention to an aged proprietary bright cyanide copper plating bath. The plate produced in 10 minutes of plating at 20 amperes per square foot was bright and free of haze caused by micronodules. Plating with conventional low ripple direct current gave a place which was dull and had many very small micronodules. Improved brightness was obtained using the known techniques of interrupting the low ripple current for one second after every ten seconds of plating. However, there were micronodules on this plate. Using periodic current reversal of sixty-second plating and twenty seconds deplating eliminated the small nodule formation but the plate was dull.

Thus it should be appreciated that the invention has provided improved results on such easy-to-plate metals as copper.

I claim:

1. Apparatus for converting a three-phase voltage to direct current voltage for electrodes in an electrolytic process comprising a first three-phase transformer having its primary delta connected and its secondary wye connected, a second three-phase transformer having its primary wye connected and its secondary wye connected, one phase of the secondary of each transformer having its connections reversed, each said secondary having a neutral terminal and three remaining terminals, said neutral terminals being connected together for connection to an electrode, the remaining terminals of said secondaries being connected together for connection to the other electrode and half-wave rectifiers connected between each remaining secondary terminal and said other electrode.

2. Apparatus for converting a three-phase voltage to direct current voltage for electrodes in an electrolytic process comprising a first three-phase transformer having its primary delta connected and its secondary wye connected, a second three-phase transformer identical to said first transformer having its primary wye connected and its secondary wye connected, each phase of said second transformer being connected across

$$\frac{n}{\sqrt{3}}$$

turns of said primary winding, where n is the total number of turns of each primary winding, one phase of the secondary of each transformer having its connections reversed, each said secondary having a neutral terminal and three remaining terminals, said neutral terminals being connected together for connection to an electrode, the remaining terminals of said secondaries being connected together for connection to the other electrode and half-wave rectifiers connected between each remaining secondary terminal and said other electrode.

3. Apparatus for converting a three-phase voltage to direct current voltage for electrodes in an electrolytic process comprising a first three-phase transformer having its primary delta connected and its secondary wye connected, a second three-phase transformer identical to said first transformer having its primary wye connected and its secondary wye connected, each phase of said second transformer being connected across

$$\frac{n}{\sqrt{3}}$$

turns of said primary winding, where n is the total number of turns of each primary winding, one phase of the secondary of each transformer having its connections reversed, each said secondary having a neutral terminal and three remaining terminals, said neutral terminals being connected together for connection to an electrode, the remaining terminals of said secondaries being connected together for connection to the other electrode and half-wave rectifiers connected between each remaining secondary terminal and said other electrode, and switch means connected to the primary of said second transformer for changing said wye connection to a delta connection across the full turns of each primary winding.

4. Apparatus for converting a three-phase voltage to a direct current voltage for electrodes in an electrolytic process comprising a first three-phase transformer having its primary delta connected and its secondary wye connected, a second three-phase transformer having its primary wye connected and its secondary wye connected, one phase of the secondary of each transformer having its connection reversed, each said secondary having a neutral terminal and three remaining terminals, said neutral terminals being connected together for connection to an electrode, the remaining terminals of said secondaries being connected together for connection to the other electrode, half-wave rectifiers connected between each remaining secondary terminal and said other electrode, a single phase booster transformer connected across the input of said reversed phase of said first transformer, a rectifier connecting said output of said booster transformer to said electrodes to provide a voltage pulse 180° out of phase with the output of said reversed phase, and means for maintaining the voltage output of said booster transformer below the level required for the electrolytic process.

5. Apparatus for supplying direct current voltage to electrodes for an electrolytic process comprising a three-phase transformer system, half-wave rectifiers in the secondaries of each phase of said transformer system with one phase being inverted to provide an on-time of three

voltage pulses spaced 60° apart and a 60° off-time, means for connecting the output of said secondaries to said electrodes, and means for increasing the ratio of on-time to off-time.

6. Apparatus for supplying direct current voltage to electrodes for an electrolytic process comprising a three-phase transformer system, half-wave rectifiers in the secondaries of each phase of said transformer system with one phase being inverted to provide an on-time of three voltage pulses spaced 60° apart and a 60° off-time, means for connecting the output of said secondaries to said electrodes, means for increasing the ratio of on-time to off-time, and means for applying a booster voltage of lesser amplitude than said three voltage pulses to said electrodes during said off-time, said booster voltage being of sufficient magnitude to prevent current reversal.

7. Apparatus for converting a three-phase voltage supply to a direct current voltage for electrodes in an electrolytic process comprising a three-phase transformer system, half-wave rectifiers in the secondaries of each phase of said transformer system with one phase being inverted to provide an on-time of three voltage pulses spaced 60° apart and a 60° off-time, means for connecting the output of said secondaries to said electrodes, a pair of auto transformers having variable taps, said transformer system having one primary other than the primary of said inverted phase connected to said taps, said auto transformers being connectable across two phases of said voltage supply whereby said one primary can be selectively phase shifted through 180° to increase the ratio of on-time to off-time.

8. A power supply for converting a three-phase alternating current voltage to a direct current voltage to be applied to the anode and cathode of a chromium plating bath comprising a first three-phase transformer having one phase reversed, means including half-wave rectifiers for connecting said transformer secondary windings to said anode and cathode, a second three-phase transformer having one phase reversed, means including half-wave rectifiers for connecting said second transformer secondary windings to said anode and cathode, and means for shifting the phase of said second transformer with respect to said first transformer.

9. A power supply for converting a three-phase alternating current voltage to a direct current voltage to be applied to the anode and cathode of a chromium plating bath comprising a first three-phase transformer having one phase reversed, means including half-wave rectifiers for connecting said transformer secondary windings to said anode and cathode, a second three-phase transformer having one phase reversed, means including half-wave rectifiers for connecting said second transformer secondary windings to said anode and cathode, three auto transformers connected across said alternating current voltage in parallel with said first transformer, said auto transformers having variable taps, and means connecting said variable taps to the primaries of said second transformer, whereby the phase of said second transformer can be shifted with respect to said first transformer by shifting said taps.

10. Apparatus for chromium plating a metal object wherein the object is constituted the cathode to be chromium plated in an electrolytic circuit with an anode and plating solution comprising an aqueous solution of chromic and sulfuric acids adapted for chromium plating, a power supply for said cathode and anode comprising a source of three-phase voltage, a voltage reducing transformer across each phase, half-wave rectifiers similarly oriented in the secondary outputs of two of said transformers, and a half-wave rectifier in the output of said third phase and oriented opposite to said first rectifiers, and means connecting positive terminals of all phases to said anode and connecting negative terminals of all phases to said cathode.

11. Apparatus for chromium plating a metal object wherein the object is constituted the cathode to be chromium plated in an electrolytic circuit wtih an anode and plating solution comprising an aqueous solution of chromic and sulfuric acids adapted for chromium plating, a power supply for said cathode and anode comprising a source of three-phase voltage, a voltage reducing transformer across each phase, half-wave rectifiers in the outputs of each said transformer, means connecting the outputs of said transformers through said rectifiers to said anode and cathode to provide conventional current flow from anode to cathode from two of said transformers during the positive portion of their cycles, and conventional current flow from anode to cathode from the third transformer during the negative portion of its cycle.

12. Apparatus for chromium plating a metal object wherein the object is constituted the cathode to be chromium plated in an electrolytic circuit with an anode and plating solution comprising an aqueous solution of chromic and sulfuric acids adapted for chromium plating, a power supply for said cathode and anode comprising a source of three-phase voltage, a voltage reducing transformer across each phase, said transformers having outputs A, B and C which are positive going in alphabetical sequence, half-wave rectifiers connecting outputs A and B to said anode and cathode to be positive going in alphabetical sequence, and connecting means including a half-wave rectifier inverting the phase of output C and connecting the resultant voltage to anode and cathode to provide a current form having an on time and an off time.

References Cited in the file of this patent

UNITED STATES PATENTS

2,521,522 Keitley ---------- Sept. 5, 1950

FOREIGN PATENTS

124,885 Australia ---------- July 31, 1947