Jan. 30, 1951 D. JOURNEAUX 2,539,912

ELECTRODE SPACING REGULATOR UTILIZING REFERENCE ELECTRODES

Filed March 8, 1947 4 Sheets-Sheet 1

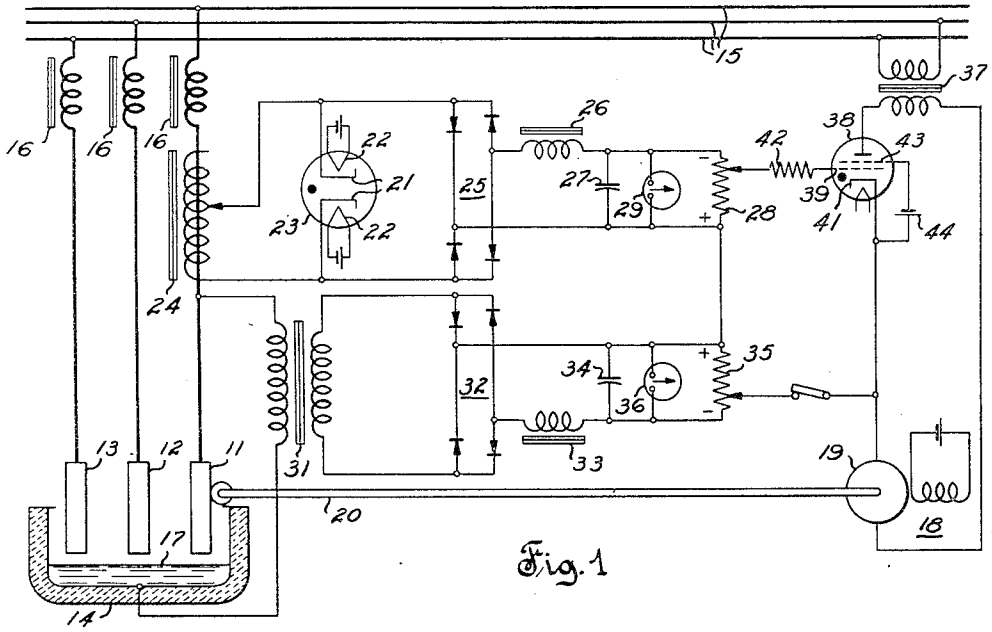


Fig. 1

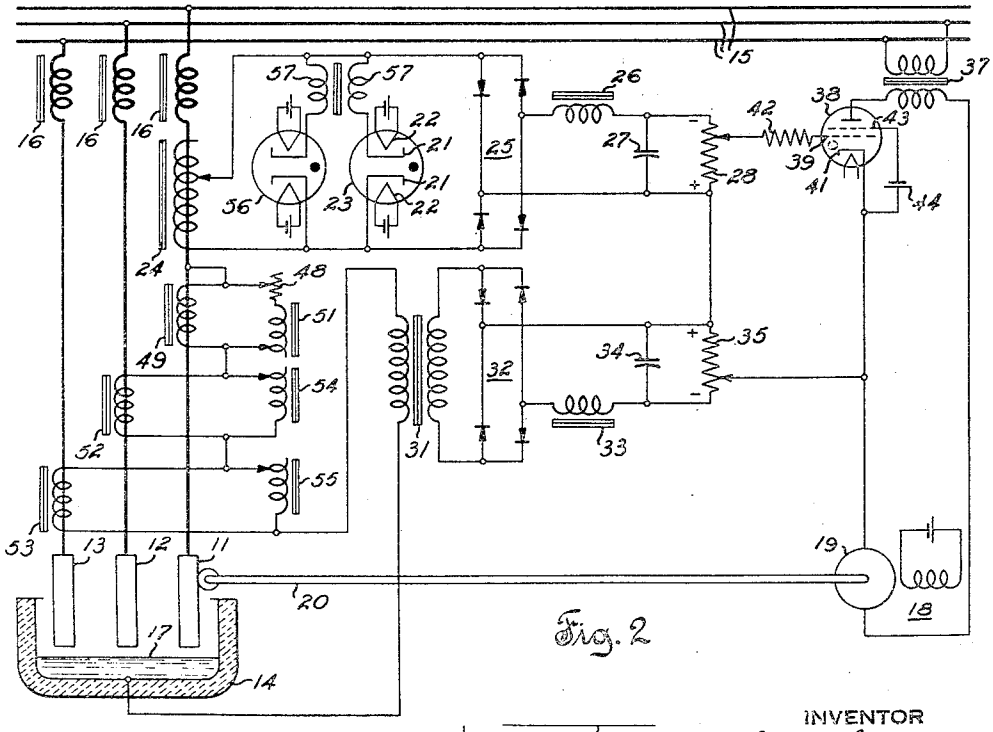


Fig. 2

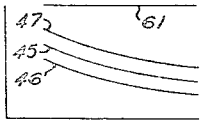


Fig. 3

INVENTOR

Didier Journeaux

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ELECTRODE SPACING REGULATOR UTILIZING REFERENCE ELECTRODES

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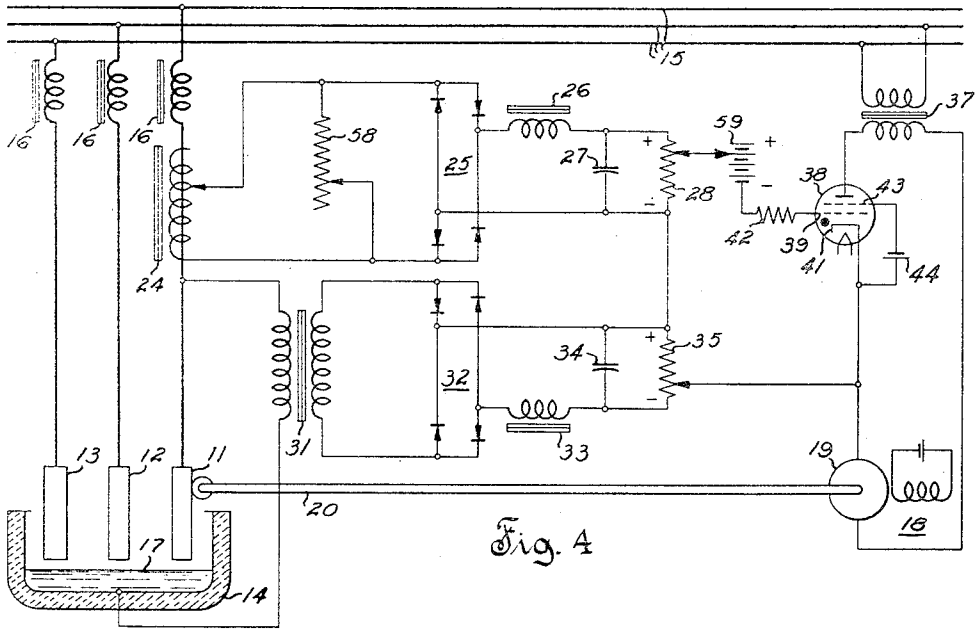


Fig. 4

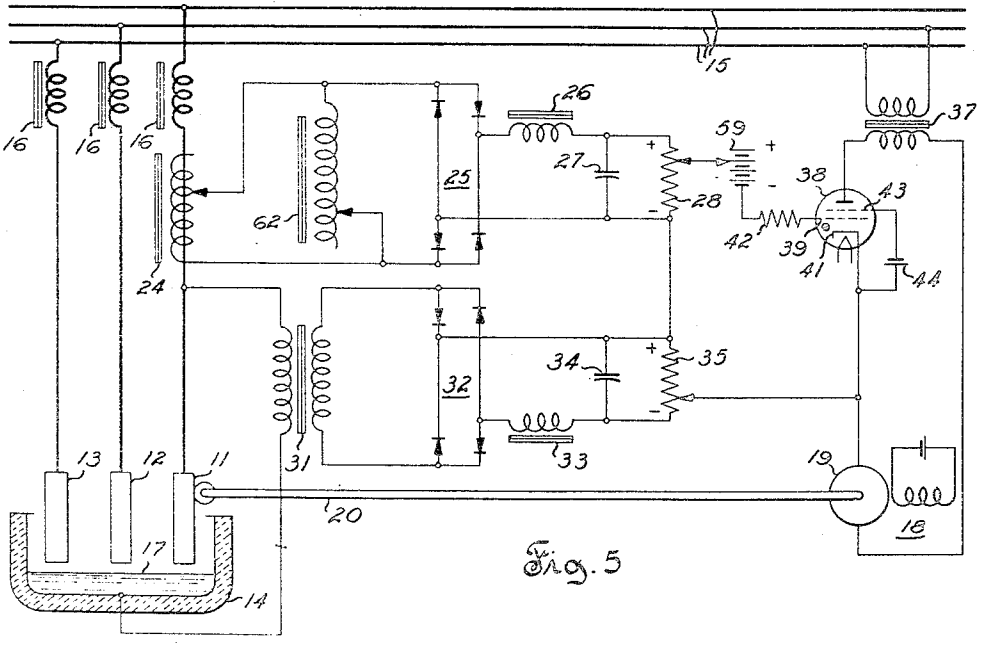


Fig. 5

INVENTOR

Didier Journeaux

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ELECTRODE SPACING REGULATOR UTILIZING REFERENCE ELECTRODES

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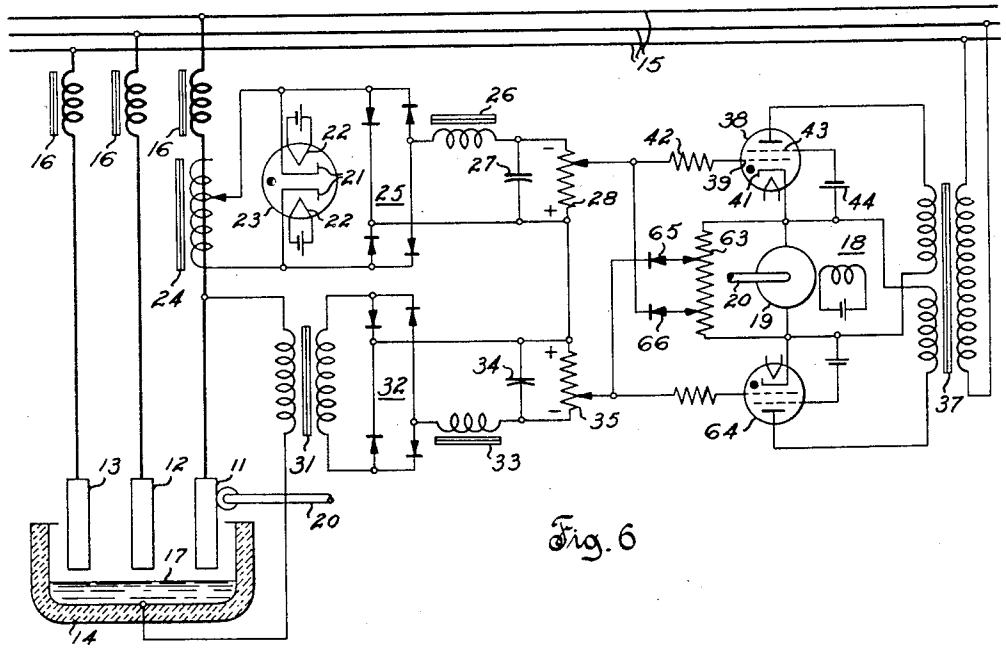


Fig. 6

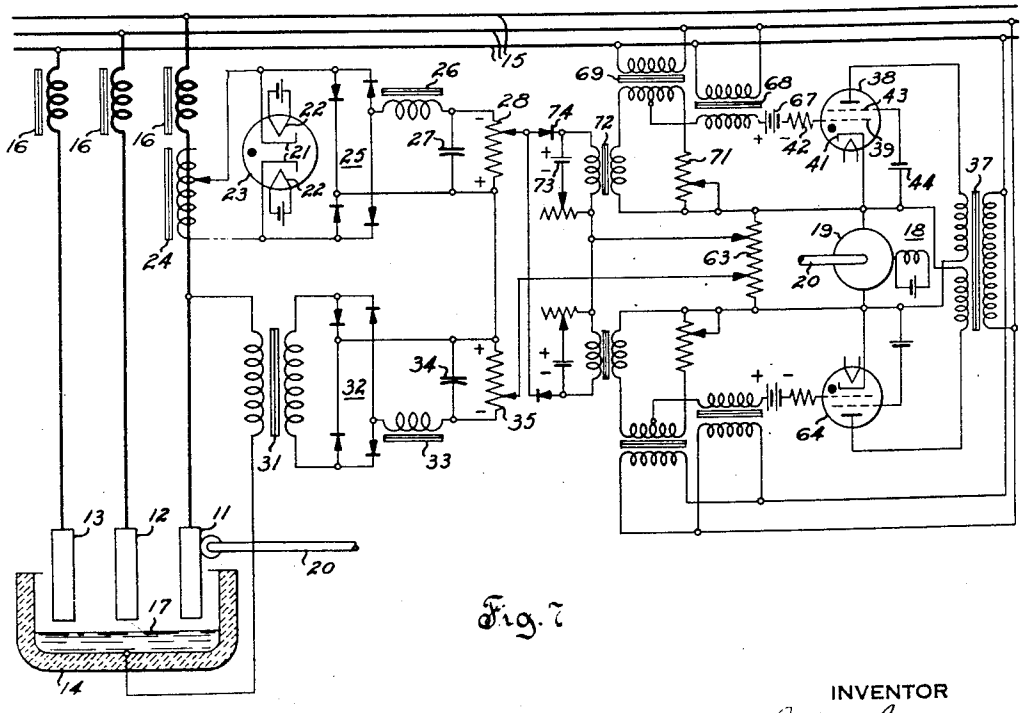


Fig. 7

INVENTOR

Didier Journeaux

Jan. 30, 1951 D. JOURNEAUX 2,539,912

ELECTRODE SPACING REGULATOR UTILIZING REFERENCE ELECTRODES

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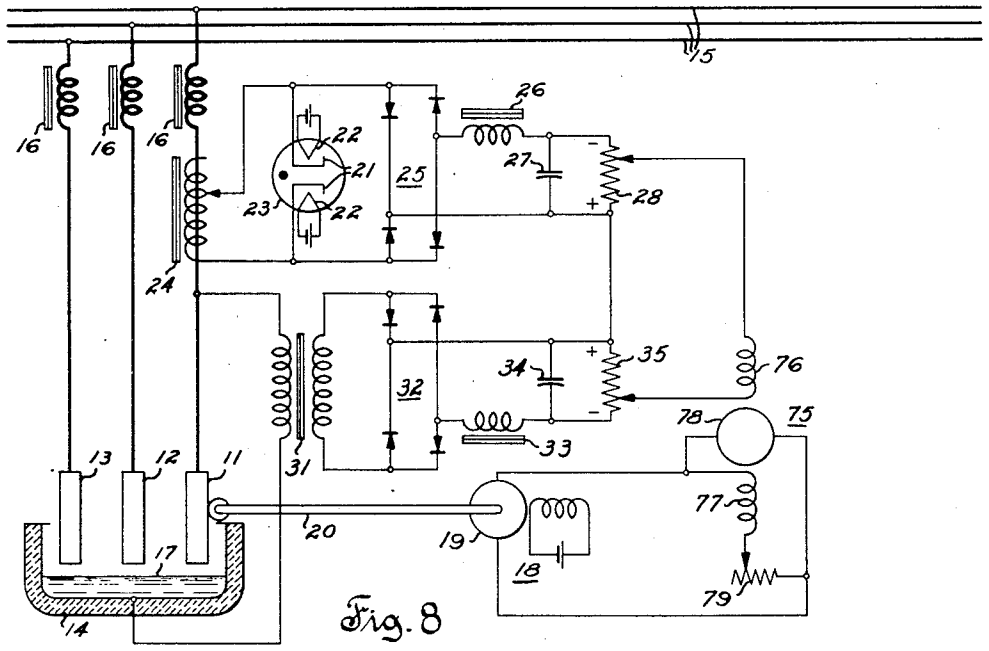


Fig. 8

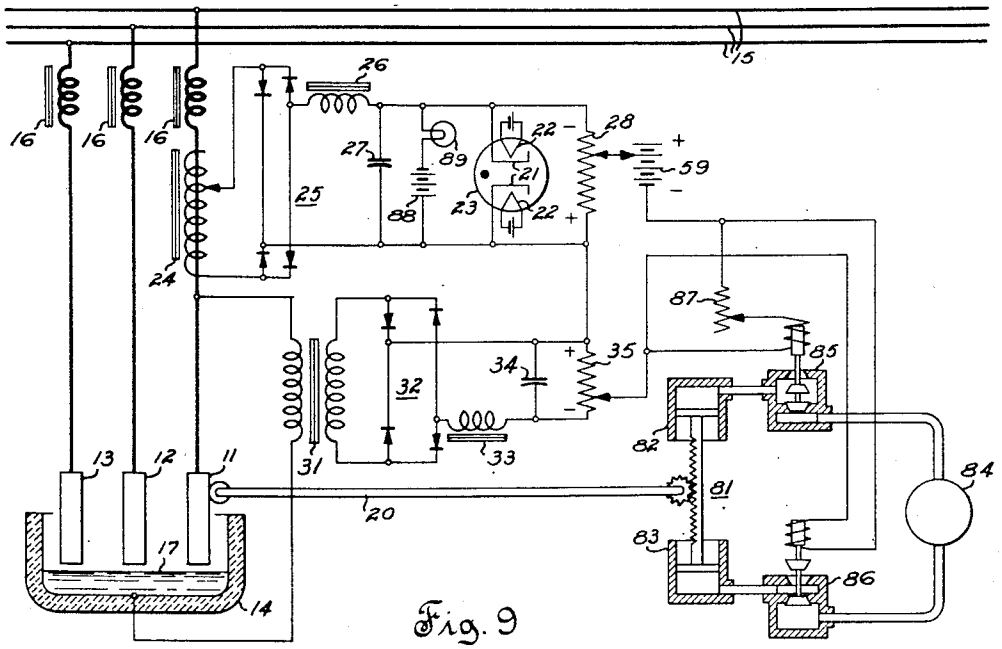


Fig. 9

INVENTOR

Didier Journeaux

Patented Jan. 30, 1951 2,539,912

UNITED STATES PATENT OFFICE

2,539,912

ELECTRODE SPACING REGULATOR UTILIZING REFERENCE ELECTRODES

Didier Journeaux, Milwaukee, Wis., assignor to Allis-Chalmers Manufacturing Company, Milwaukee, Wis., a corporation of Delaware

Application March 8, 1947, Serial No. 733,343

21 Claims. (Cl. 314—64)

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This invention relates in general to improvements in electric control systems, and more particularly to means for and methods of regulating the spacing of consumable electrodes between which current flows through a gaseous or liquid medium.

Electric current may be caused to flow between a pair of working electrodes through a fluid medium for different purposes such as electrolysis of salts, fusion and refining of metals, or chemical reaction between gases. The flow of current or discharge may take place over a wide range of spacings between the electrodes, but under a given set of operating conditions it is generally found advantageous to maintain the electrode spacing substantially constant. When the electrodes are of a consumable type, it is therefore necessary to readjust their spacing from time to time.

As it is generally not feasible to measure the spacing between the electrodes, the electrode actuating apparatus is frequently controlled in response to the current intensity through the electrodes. The action of such control is based on the assumption that there is a uniform relation between the current intensity and the electrode spacing, and it is therefore disturbed by fluctuations in the voltage of the source supplying current to the electrodes. In polyphase furnaces the current intensity through each pair of electrodes is also dependent upon the spacings of the other pairs of electrodes, so that inaccurate spacing of one pair of electrodes results in unnecessary and improper readjustments of the other pairs.

The above disadvantages may be obviated by controlling the spacing of each pair of working electrodes in accordance with the relative values of the voltage across the electrodes and of the voltage of a suitable standard of reference. The latter may consist of any suitable means or combination of means having a volt-ampere characteristic similar to the volt-ampere characteristic of the discharge between working electrodes maintained at the desired spacing. The desired electrode spacing need not necessarily be constant but may vary as a function of the current intensity.

When the discharge between the electrodes has a non-linear drooping volt-ampere characteristic, any type of standard of reference having a drooping volt-ampere characteristic may be utilized over a limited range of currents. To obtain the desired electrode spacing over a wide range of

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currents, the standard of reference should be a device having a non-linear drooping volt-ampere characteristic, such as a pair of reference electrodes carrying current of intensity in a predetermined relation to the current of the working electrodes. The voltages of the working electrodes and of the reference electrodes are measured by means of suitable indicating instruments or measuring circuits, and the spacing of the working electrodes is varied, either manually or by suitable responsive means, in accordance with the relative values of the measured voltages.

If the voltage measuring connections cannot directly be attached to the points of the working electrodes between which the discharge takes place, the voltage at some other point of the electrode circuit may be measured, and correction may be applied for the voltage drop in the circuit conductors.

It is therefore an object of the present invention to provide a system for regulating the spacing of a pair of electrodes which is unaffected by variations in the voltage of the source supplying current to the electrodes.

Another object of the present invention is to provide a system for regulating the spacing of a pair of electrodes which is unaffected by variations in the spacing of other electrodes connected in the same circuit.

Another object of the present invention is to provide a system for regulating the spacing of a pair of electrodes by which the spacing may be maintained substantially constant at all values of the current intensity through the electrodes.

Another object of the present invention is to provide a system for regulating the spacing of a pair of electrodes by which the electrode spacing may be caused to vary in a predetermined relation to the value of the current flow through the electrodes.

Another object of the present invention is to provide a system for regulating the spacing of a pair of electrodes in which a single standard of reference is utilized at all values of the current flow through the electrodes.

Another object of the present invention is to provide a method of regulating the spacing of a pair of electrodes in which the voltage actually appearing across the electrodes is compared with the voltage which would exist between the electrodes if their spacing had the desired value.

Another object of the present invention is to provide a method of regulating the spacing of a pair of electrodes in which the voltage across the

electrodes is compared with the voltage across a standard of reference having a volt-ampere characteristic similar to that of the electrodes.

Objects and advantages other than those above set forth will be apparent from the following description when read in connection with the accompanying drawing, in which:

Fig. 1 diagrammatically illustrates one embodiment of the invention for controlling the spacing of a pair of electrodes of a polyphase arc furnace, in which embodiment a gas discharge device is utilized as a standard of reference for controlling the electrode hoist motor through an electric valve;

Fig. 2 diagrammatically illustrates a modified embodiment of the invention differing from the embodiment illustrated in Fig. 1 in the provision of means for compensating the voltage drop in the circuit supplying current to the working electrodes;

Fig. 3 is a graph of the volt-ampere characteristics of the working electrodes and of the standard of reference;

Fig. 4 diagrammatically illustrates another modified embodiment utilizing the combination of a resistor and of a source of constant voltage as a standard of reference;

Fig. 5 diagrammatically illustrates another modified embodiment utilizing the combination of a reactor and of a source of constant voltage as a standard of reference;

Fig. 6 diagrammatically illustrates another modified embodiment in which a common measuring system is utilized for energizing the grids of electric valves controlling the advancing and withdrawing movements of the electrodes;

Fig. 7 diagrammatically illustrates another modified embodiment differing from the embodiment illustrated in Fig. 6 in the detail of the grid circuits of the valves;

Fig. 8 diagrammatically illustrates another modified embodiment in which the standard of reference controls a field winding of a generator supplying current to the electrode hoist motor; and

Fig. 9 diagrammatically illustrates another modified embodiment in which the standard of reference controls the supply of compressed air or other operating fluid to an electrode hoist motor of the fluid actuated type.

Elements having the same function are designated by the same character of reference in the different figures. It will be understood that elements shown in different figures may also be combined to form further embodiments of the invention.

Referring more particularly to the drawing by characters of reference, numerals 11, 12, 13 designate electrodes of an electric furnace 14 of the polyphase arcing type. Current is supplied to the electrodes from a suitable source of alternating current represented as a three-phase circuit 15 connected with the electrodes through suitable current limiting means such as reactors 16. The furnace contains a pool of molten metal 17 serving as an intermediate electrode of which different portions cooperate with electrodes 11, 12, 13 to constitute three pairs of electrodes.

Electrodes 11, 12, 13 are severally provided with hoisting means for maintaining the electrodes at a distance from pool 17 which may be constant or which may vary in dependence upon the current intensity through the electrodes. The hoisting means may be actuated manually, or each electrode may be provided with a hoist motor such as an electric motor 18 of the direct current type having an armature 19 connected with the electrode through a shaft 20.

The operation of the hoisting means of electrode 11 is controlled in dependence upon the relative values of the voltage across electrodes 11, 17 and of the voltage across a suitable standard of reference. The volt-ampere characteristic of the standard of reference should be generally similar to the volt-ampere characteristic of electrodes 11, 17 and should therefore generally be drooping when the discharge between electrodes 11, 17 is of the type designated as an arc. To obtain a control of maximum accuracy the volt-ampere characteristic of the standard of reference should further be non-linear.

The standard of reference may consist of a pair of reference electrodes 21 between which current may flow in the form of an arc discharge through a gaseous medium. Electrodes 21 may be maintained at operating temperature insuring the emission of electrons thereat by the current flowing therethrough or by the supply of heating current to a pair of filaments 22. Electrodes 21 may be the electrodes of gas discharge device 23 of any suitable known type such as an ordinary fluorescent lamp.

Means are provided to supply to electrodes 21 current of intensity in a predetermined relation to the current intensity through electrodes 11, 17 and through the working arc established therebetween, whereby a reference arc is drawn between electrodes 21. For example, electrodes 21 may be supplied with current proportional to the current of electrodes 11, 17 from the secondary winding of an adjustable current transformer 24 having its primary winding serially connected with electrode 11. The voltage across electrodes 21 is measured by a circuit comprising a rectifier 25 of any suitable known type, suitable current smoothing means such as a series reactor 26 associated with a shunt capacitor 27, and a voltage divider 28. An adjustable rectified control voltage proportional to the voltage of electrodes 21 is thereby made available between a terminal and the tap of voltage divider 28. A voltmeter 29 may be connected across voltage divider 28 to obtain a visual indication of the magnitude of the voltage across electrodes 21.

A similar indication of the voltage across electrodes 11, 17 and an adjustable rectified control voltage responsive thereto may be obtained by means comprising a potential transformer 31 associated with a rectifier 32, a series reactor 33, a shunt capacitor 34, a voltage divider 35 and a voltmeter 36. The reading of the voltmeter includes the voltage drop in the body of electrodes 11, 17 and in the portion of the conductors joining the electrodes to the primary winding of transformer 31, but such voltage drop is assumed to be negligible compared to the value of the arc voltage.

To control the spacing of electrodes 11, 17 automatically in response to the relative values of the voltages across electrodes 11, 17 and electrodes 21, armature 19 may intermittently be supplied with rectified current from circuit 15 through a transformer 37 and through an electric valve of any suitable type provided with a control electrode, such as a shield grid thyratron 38. The control grid 39 of thyratron 38 may be connected with the cathode 41 thereof through a circuit comprising differentially connected voltage dividers 28, 35 and a current limiting resistor 42

to render thyratron 38 differentially responsive to the rectified control voltages. The critical potential, above which control grid 39 must be brought to render 38 conductive, may be varied by impressing a suitable potential on shield grid 43 by means of a suitable source represented as a battery 44.

In operation, current supplied to furnace 14 flows from one of the conductors of circuit 15 through one of reactors 16 and electrode 11 and reaches the adjacent portion of electrode 17 in the form of a working arc. The current returns to another conductor of circuit 15 through another arc drawn between another portion of electrode 17 and electrode 12 or 13. In general, the volt-ampere characteristic of the arm drawn between electrodes 11, 17 is drooping and nonlinear. It will be assumed that the characteristic designated 45 in Fig. 3 is the characteristic of the arc at electrodes 11, 17 when the electrode spacing has the desired value. Such spacing may be constant or may depend upon the current intensity through the electrodes.

If the electrode spacing becomes too narrow, the volt-ampere characteristic will drop to a corresponding extent, as shown by curve 46 for example. If the electrode spacing becomes too wide, the volt-ampere characteristic will be boosted a corresponding extent, as shown by curve 47 for example. It will be assumed that curve 45 is also the volt-ampere characteristic of the combination of current transformer 24 with electrodes 21 and the circuit elements connected thereto, including voltage divider 28.

The voltage appearing across voltage divider 35 is a measure of the voltage actually present across electrodes 11, 17. The voltage appearing across voltage divider 28 is likewise a measure of the voltage across electrodes 21, and is also a measure of the voltage which would exist between electrodes 11, 17 if their spacing had the desired value. If the spacing of electrodes 11, 17 is correctly adjusted, voltmeters 29 and 36 therefore will always measure equal voltages regardless of the current intensity through electrodes 11, 12, 13 and 17 and regardless of the positions of electrodes 12, 13 with respect to electrode 17. If the spacing of electrodes 11, 17 is too wide, voltmeter 29 will have a lower reading than voltmeter 36, and if the spacing is too narrow, voltmeter 29 will have a higher reading than voltmeter 36.

If the grid control circuit of thyratron 38 is open, the spacing between electrodes 11, 17 may be adjusted manually in accordance with the relative values of the voltmeter readings to bring the voltages to equality. When the control grid circuit of thyratron 38 is closed as shown in Fig. 1, the potential of grid 39 with respect to the potential of cathode 41 is equal to the difference of the voltages of the portions of voltage dividers 28 and 35 comprised between the taps thereof. For the sake of simplicity it will be assumed that the critical potential of grid 39 is equal to the potential of the associated cathode 41.

When the spacing of electrodes 11, 17 is too wide, the voltage dividers bring grid 39 to a potential above the potential of cathode 41, and thyratron 38 therefore becomes conductive to transmit rectified current to armature 19.

The armature drives shaft 20 to lower electrode 11. As a result of the decrease in the spacing between electrodes 11, 17, the voltage of voltage divider 35 decreases relatively to the voltage of voltage divider 28 regardless of the current intensity through electrodes 11, 17. The potential of grid 39 is thereby caused to drop and, when such potential is again below cathode potential, thyratron 38 returns to the nonconductive condition and motor 18 stops. If the voltage dividers are properly adjusted the spacing between electrodes 11, 17 will then have the desired value.

The above described control system is operable only to cause motor 18 to lower electrode 11, but it will be understood that another similar control system may be provided to cause the motor to raise electrode 11 when the spacing between electrodes 11, 17 is too narrow. Additional motors and associated control systems will generally be provided for regulating electrodes 12 and 13.

It will be understood that device 23 may be so chosen that the voltage drop between electrodes 21 differs in value from the voltage drop between electrodes 11, 17. The tap of voltage divider 28 then should correspondingly be adjusted to maintain thyratron 38 responsive to differences above a predetermined value between the reference voltages impressed on the control grid circuit thereof from voltage dividers 28 and 35.

The connections between transformer 31 and the points of electrodes 11, 17 joined by the working arc include the entire body of electrode 11 and sometimes also a substantial portion of the connection between electrode 11 and the associated reactor 16, which will be designated electrode lead. The connections illustrated in Fig. 1 may then be retained if the combination of current transformer 24, electrodes 21 and voltage divider 28 can be adjusted to have the same volt-ampere characteristic as the circuit consisting of electrodes 11 and 17, the arc therebetween and the electrode lead portion inserted between the primary terminals of transformer 31.

If the volt-ampere characteristics cannot be matched by a suitable choice of device 23 and of the circuit elements associated therewith, the voltage drop in electrode 11 and in the electrode lead should be compensated. As shown in Fig. 2 the voltage drop component due to the resistance of the electrode body and of the electrode lead may be compensated by means of a resistor 48 supplied with current from a current transformer 49 having its primary winding serially connected with electrode 11. Another component due to the self-inductance of the electrode body and of the electrode lead may be compensated by the voltage in an inductive reactor 51 serially connected with resistor 48.

Other components resulting from the mutual inductive action between the circuits of electrodes 11, 12, 13 may be compensated by means of current transformers 52, 53 having their primary windings serially connected with electrodes 12, 13. The current transformer secondary windings are connected across reactors 54, 55 serially connecting resistor 48 and reactor 51 in the primary winding connections of transformer 31.

By suitably adjusting the portions of resistor 48 and of reactors 51, 54, 55 serially connected with the primary winding of transformer 31, the voltage impressed on such primary winding may be so corrected as to be substantially equal to the voltage actually present between the points of electrodes 11, 17 joined by the arc discharge. The system therefore operates substantially in the manner above described with respect to the embodiment illustrated in Fig. 1.

The control voltage appearing across voltage divider 35 then may be considered as being the difference between a component responsive to the voltage of the circuit supplying current to elec-

trode 11 and a component responsive to the voltage drop in the solid conductors of such circuit.

If the secondary current of current transformer 24 is higher than the rated current of device 23 even when the current transformer is adjusted for its lowest secondary current, device 23 may be connected in parallel with one or more additional devices of the same type such as device 56. The flow of current may be caused to divide equally between the parallel devices by means of inductively related windings 57 connected in series with the different devices.

In the embodiment illustrated in Fig. 4, the reference means comprise an adjustable resistor 58 and a source of direct current of suitable voltage and polarity represented as a battery 59 in the connection between grid 39 and cathode 41. The polarity of rectifier 25 is then reversed with respect to the polarity shown in Figs. 1 and 2. Thyratron 38 is accordingly responsive to the difference between the constant voltage of battery 59 and the sum of two control voltages proportional to the voltages across electrodes 11, 17 and across reference resistor 58.

The volt-ampere characteristic of battery 59 is a horizontal line such as line 61 in Fig. 3. The volt-ampere characteristic of resistor 58 is rising. It is a straight line if the resistor has a resistance which is independent of current and it is curved if the resistor is of a known non-linear type.

Resistor 58 is preferably so adjusted that curve 45, when read with respect to line 61, is the volt-ampere characteristic of the combination of current transformer 24, resistor 58 and voltage divider 28. Curve 45, when read with respect to the axis of abscissas, is then also the volt-ampere characteristic of the combination of current transformer 24, resistor 58, voltage divider 28 and battery 59. The potential impressed on grid 39 is then the same as in the embodiment illustrated in Fig. 1 under all operating conditions of the system and the operation remains substantially as above set forth.

As shown in Fig. 5, resistor 58 of Fig. 4 may be replaced by an adjustable inductive reactor 62. As a result of the connections of grid 39, thyratron 48 is again additively responsive to the two variable control voltages, of which one is produced in voltage divider 35 in response to the voltage across electrodes 11, 17 and the other is produced in voltage divider 28 in response to the current flow through electrodes 11, 17.

The volt-ampere characteristic of reactor 62 is rising and the volt-ampere characteristic of the combination of current transformer 24, reactor 62, voltage divider 28, and battery 59 is drooping. If reactor 62 is provided with a core in which the magnetic flux reaches the saturation range, the volt-ampere characteristic of the combination is rendered non-linear and may be adjusted to approximate curve 45 as in the previously considered embodiment.

Motor 18 may be prevented from moving electrode 11 past the desired position by causing the potential of grid 39 to be responsive to the joint action of the current through electrodes 11, 17, the voltage across such electrodes, and the speed of motor 18. For the latter purpose the terminal voltage of armature 19, or a portion of such voltage, may be introduced into the circuit connecting grid 39 with cathode 41. As shown in Fig. 6, a voltage divider 63 may be connected across armature 19 and the taps of voltage dividers 35 and 63 may be interconnected to permit adjustment of the relative values of the voltages introduced therefrom in the grid circuit.

Motor 18 may also be supplied with current to raise electrode 11 when the spacing between electrodes 11, 17 is too narrow by connecting armature 19 with an additional secondary winding of transformer 37 through a second thyratron 64. The connections of the control grids of thyratrons 38 and 64 are symmetrical with respect to voltage dividers 28 and 35. The connections of voltage divider 63 with voltage dividers 28 and 35 include rectifiers 65, 66 for preventing the flow of circulating current between the voltage dividers.

When motor 18 is at rest, no voltage is impressed on voltage divider 63. If the spacing between electrodes 11, 17 becomes too wide, thyratron 38 becomes conductive to supply current to armature 19 as above set forth with respect to the embodiment illustrated in Fig. 1. Armature 19 rotates to lower electrode 11 and the armature terminal voltage increases with the armature speed.

When the armature reaches a predetermined speed the potential impressed on grid 39 from armature 19 through voltage divider 63, rectifier 65, voltage dividers 35, 28 and resistor 42 brings grid 39 to a potential below cathode potential and thyratron 38 returns to the non-conductive condition. Armature 19 is thus de-energized and its speed decreases. The armature counter-electromotive force also decreases and the potential of grid 39 is thereby caused to rise above the critical values to render thyratron 38 again conductive.

Armature 19 is thus intermittently energized in such manner that its speed is varied in relation to the extent to which the spacing of electrodes 11, 17 departs from the desired value. While the electrodes are being returned to the proper spacing the speed of armature 19 gradually decreases, so that electrode 11 reaches the desired position at very low speed and does not overtravel.

If for any reacon the electrode spacing becomes too narrow, the voltage of voltage divider 35 becomes lower than the voltage of the voltage divider 28. The control grid potential of thyratron 64 is thus raised above the critical value and thyratron 64 becomes conductive to supply current to armature 19. The armature then rotates in the direction opposite to that above considered, and the operation of the system to raise electrode 11 takes place in a manner similar to that above set forth with respect to lowering of the electrode.

During lowering operation of electrode 11, if the speed of armature 19 becomes excessive, thyratron 64 will also become conductive to supply current to armature 19 in such sense as to decelerate the armature. Conversely, during raising operation of electrode 11, thyratron 38 may become conductive to supply decelerating current to armature 19.

In the embodiment illustrated in Fig. 7 the circuit connecting grid 39 with cathode 41 is impressed with three voltage components. A negative voltage component is supplied from a battery 67. An alternating voltage component of constant magnitude and phase is supplied from circuit 15 through a transformer 68. A second alternating voltage component of constant magnitude but lagging behind the voltage of transformer 68 to a variable extent is supplied from circuit 15 through a transformer 69 and a phase shifting circuit comprising a resistor 71 and a saturable reactor 72.

The saturating winding of reactor 72 may be supplied with a current component of predetermined magnitude from a battery 73. A variable

current component may be supplied to the saturating winding by connecting the latter in series with voltage dividers 28 and 35 across a portion of voltage divider 63. A rectifier 74 may be connected in series with the saturating winding to prevent reversal of the saturating current of reactor 72 in response to decrease of the electrode spacing below the desired value. The grid control circuit of thyratron 64 is similar to that of thyratron 38.

As long as the spacing of electrodes 11, 17 remains at the desired value, the voltages impressed on voltage dividers 28, 35 remain equal and the current through the saturating winding of reactor 72 remains constant. The grid circuits are so dimensioned that the alternating potential components impressed on grid 39 from transformers 68, 69 are then insufficient to overcome the negative potential impressed thereon from battery 67. The potential of grid 39 is then a periodic negative potential and thyratron 38 remains nonconductive.

If the spacing of electrodes 11, 17 become too wide and the difference between the voltages of voltage dividers 35 and 28 exceeds a predetermined value, the saturating current of reactor 72 is increased. The voltage impressed on the grid circuit from transformer 69 is thereby caused to advance in phase, and the resultant of the two alternating potential components impressed on grid 39 is thus caused both to advance in phase and to increase in magnitude. Grid 39 is thus caused to become periodically positive to render thyratron 38 periodically conductive. The movements of positive energization of grid 39 are advanced in dependence upon the magnitude of the departure of the electrode spacing from the desired value. Such advance is however subject to being reduced in dependence upon the speed of armature 19 by the action of the armature voltage through voltage divider 63. The electrode spacing is thereby caused to return to the desired value without overtravel.

If the electrode spacing is too narrow, thyratron 64 is energized to cause motor 18 to return electrode 11 to the desired position in a manner similar to that above described. The thyratrons also control the flow of decelerating current through armature 19 when the armature speed exceeds the speed corresponding to the extent of departure of electrode 11 from the desired position. In this manner, excess kinetic energy stored in armature 19 may be returned to circuit 15.

In the embodiment illustrated in Fig. 8, armature 19 is assumed to be supplied with current from a direct current generator 75 having a separately excited field winding 76 and a shunt field winding 77 connected across the associated armature 78. A field rheostat 79 in series with shunt field winding 77 may be so adjusted that field 77 alone will induce in armature 78 a voltage which may take indifferently any value consistent with operation of generator 75 within a range below the magnetic saturation range. Any energization of winding 76 with current of one or the other polarity will then cause maximum terminal voltage to be induced in armature 78 with one or the other polarity.

Winding 76 is so connected with voltage dividers 28 and 35 that no current flows through winding 76 when the spacing between electrodes 11, 17 is at the desired value. If the electrode spacing becomes too narrow by a predetermined amount, sufficient current will be supplied to field winding 76 to cause armature 78 to operate at maximum voltage of one polarity, and if the electrode spacing is too wide the armature voltage again will be maximum but of the other polarity. Armature 19 thus always receives maximum current of the correct polarity to return electrode 11 toward the desired position at the maximum speed. Overtravel of electrode 11 is limited by the action of field 76, which causes reversal of the voltage induced in armature 19 if the electrode overtravel reaches a predetermined value.

In the embodiment illustrated in Fig. 9, shaft 20 is assumed to be driven by a pneumatic motor 81 comprising a pair of opposed cylinders 82, 83. The cylinders may be supplied with compressed air from a reservoir 84 through an ordinary magnet valve 85 or through an inverted magnet valve 86. The solenoids of valves 85, 86 are connected across voltage dividers 28, 35 through a battery 59. The weight of the movable elements of the magnet valves is partly or entirely balanced by the current supplied to the solenoids from battery 59. A resistor 87 connected in series with the solenoid of valve 85 causes valve 85 to operate at a slightly higher voltage than valve 86.

As the valve solenoids consume current constantly, they modify the volt-ampere characteristic of the combination of the current transformer 24, electrodes 21 and voltage divider 28. The volt-ampere characteristic may be caused to match that of electrodes 11, 17 by suitable choice of device 23, by suitable adjustment of the taps of voltage divider 28 and battery 59, and by other adjustments. As shown in Fig. 9 the secondary current of current transformer 24 may be rectified before being supplied to electrodes 21 to supply thereto a current component proportional to the current of electrodes 11, 17. A constant current component may then also be supplied to electrodes 21 from a battery 88 through a constant current regulating device such as a device 89 comprising an iron filament in an atmosphere of hydrogen. An additional means is thereby provided for modifying the volt-ampere characteristic of any embodiment of circuit supplied from current transformer 24.

Voltage dividers 28, 35 and battery 59 are so adjusted that when the spacing of electrodes 11, 17 has the desired value, valve 86 is in the actuated position shown and valve 85 is in the unactuated position shown. Cylinders 82, 83 are then both at atmospheric pressure, but electrode 11 is maintained in position by the usual electrode balancing means (not shown).

If the spacing of electrode 11, 17 becomes too wide, the voltage impressed on voltage divider 35 becomes greater than the voltage impressed on voltage divider 28. The resultant voltage impressed on the solenoids is thereby decreased and valve 86 is de-actuated. Air is admitted from reservoir 84 into cylinder 83 to lower electrode 11. When the electrode has returned to the desired position, the voltage impressed on the solenoids returns to normal value and valve 86 is again actuated to release the air contained within cylinder 83, and motor 81 stops.

Likewise, if the spacing of electrodes 11, 17 becomes too narrow, the voltage impressed on the solenoids is increased and valve 85 is actuated. Air is admitted from reservoir 84 into cylinder 82 to raise electrode 11. When the electrode has returned to the desired position, valve

85 is again de-actuated to relieve the air pressure within cylinder 82, and motor 81 stops.

Although but a few embodiments of the present invention have been illustrated and described, it will be apparent to one skilled in the art that various changes and modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims. Features disclosed but not claimed in this application are claimed in my copending application Serial No. 171,771, filed July 1, 1950.

It is claimed and desired to secure by Letters Patent:

1. In a control system for a pair of working electrodes between which current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said working electrodes and means for controlling the operation of said motor comprising a pair of reference electrodes, means for drawing a reference arc between said reference electrodes, said reference arc producing a reference voltage measurable at said reference electrodes, and means for comparing the value of said reference voltage with the value of the voltage across said working arc for varying the magnitude of the voltage impressed on said motor.

2. In a control system for a pair of working electrodes between which current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising a pair of reference electrodes for sustaining the flow of current therebetween, means for supplying to said reference electrodes current proportional to the current flowing through said working electrodes, and means for comparing the value of the voltage across said reference electrodes with the value of the voltage across said working electrodes for varying the magnitude of the voltage impressed on said motor.

3. In a control system for a pair of working electrodes between which alternating current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising a pair of reference electrodes for sustaining the flow of alternating current therebetween, means for supplying to said reference electrodes alternating current proportional to the alternating current flowing through said working electrodes, means for producing rectified voltages proportional to the voltages across said working electrodes and said reference electrodes, and means responsive to the difference between the values of said rectified voltages for varying the magnitude of the voltage impressed on said motor.

4. In a control system for a pair of working electrodes between which current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising an electric valve having main and control electrodes, a pair of reference electrodes for sustaining the flow of current therebetween, means for supplying to said reference electrodes a current proportional to the current flowing through said working electrodes, and means for controlling the potential of said control electrode comprising means responsive to the difference between the values of voltages appearing across said working electrodes and said reference electrodes.

5. In a control system for a pair of working electrodes between which alternating current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising an electric valve having main and control electrodes, a pair of reference electrodes for sustaining the flow of alternating current therebetween, means for supplying to said reference electrodes alternating current proportional to the current flowing through said working electrodes, means for producing rectified voltages proportional to the voltages appearing across said working electrodes and said reference electrodes, and means responsive to the difference between the values of said rectified voltages for controlling the potential of said control electrode.

6. In a control system for a pair of working electrodes between which alternating current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising an electric valve having main and control electrodes, a pair of reference electrodes for sustaining the flow of alternating current therebetween, means for supplying to said reference electrodes an alternating current proportional to the current flowing through said working electrodes, means for producing rectified voltages proportional to the voltages appearing across said working electrodes and said reference electrodes, and means for impressing the difference between the values of said rectified voltages between said main electrode and said control electrode of said electric valve for varying the magnitude of the voltage impressed on said motor.

7. The method of controlling the spacing of a pair of working electrodes between which current is flowing through a fluid medium comprising the steps of serially connecting a pair of reference electrodes by means of a current proportional to the current flowing through said working electrodes, measuring the voltage across said working electrodes, measuring the voltage across said reference electrodes, and varying said spacing in accordance with the relative values of said voltages.

8. In a control system for a pair of working electrodes between which alternating current is flowing in the form of a working arc, said arc having a predetermined drooping volt-ampere characteristic, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising voltage reference means, means for drawing in said reference means an alternating current reference arc having a current intensity proportional to the current intensity of said working arc, said reference arc having a drooping volt-ampere characteristic, and means for comparing the value of the voltage across said reference arc with the value of the voltage across said working arc for varying the magnitude of the voltage impressed on said motor.

9. In a control system for a pair of working electrodes between which alternating current is flowing in the form of a working arc, said arc having a predetermined non-linear volt-ampere characteristic, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising voltage reference means, means for drawing in said reference means an alternating

current reference arc having a current intensity proportional to the current intensity of said working arc, said reference arc having a non-linear volt-ampere characteristic, and means for comparing the value of the voltage across said reference arc with the value of the voltage across said working arc for varying the magnitude of the voltage impressed on said motor.

10. In a control system for a pair of working electrodes between which alternating current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said working electrodes and means for controlling the operation of said motor comprising a pair of reference electrodes, means for drawing an alternating current reference arc between said electrodes, said reference arc producing a reference voltage measurable at said reference electrodes, and means for comparing the value of said reference voltage with the value of the voltage across said working arc for varying the magnitude of the voltage impressed on said motor.

11. In a control system for a pair of working electrodes between which alternating current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising a pair of reference electrodes for sustaining the flow of alternating current therebetween, means for supplying to said reference electrodes alternating current proportional to the alternating current flowing through said working electrodes, and means for comparing the value of the voltage across said reference electrodes with the value of the voltage across said working electrodes for varying the magnitude of the voltage impressed on said motor.

12. The method of controlling the spacing of a pair of electrodes between which current of predetermined intensity at any particular instant of time is flowing through a fluid medium, comprising the preliminary step of initially comparing the values of the voltage actually present across the electrodes only for a certain spacing with the values of the voltage which would exist between said electrodes if their spacing always had an arbitrarily selected predetermined value and the electrode current retained said predetermined intensity to obtain a certain voltage difference, and the subsequent step of adjusting the spacing of said electrodes to again obtain said certain voltage difference.

13. The method of controlling the spacing of a pair of working electrodes between which a current is flowing in the form of an electric arc having a predetermined volt-ampere characteristic, comprising the step of establishing a second arc between a pair of reference electrodes, said second arc having a predetermined volt-ampere characteristic substantially identical to said predetermined volt-ampere characteristic, the preliminary step of initially comparing the volt-ampere characteristics of said working arc and said reference arc for a certain spacing of said working electrodes to obtain a certain difference in volt-ampere characteristics, and the subsequent step of adjusting the spacing of said electrodes to again obtain said certain difference in volt-ampere characteristics.

14. In a system comprising a circuit of solid conductors of substantial impedance connecting a pair of working electrodes to a current source for the flow of current therebetween and through a fluid medium, the combination of a motor for controlling the spacing of said working electrodes, means for producing a control voltage responsive to the voltage of said source, means responsive to the magnitude of said flow of current for producing a compensating voltage proportional to the voltage drop in said solid conductors and said electrodes, reference electrodes, means for supplying to said reference electrodes a current proportional to the current flowing through said working electrodes to produce a reference voltage across said reference electrodes, and means responsive to the difference between said control voltage and the sum of said compensating voltage and said reference voltage for controlling the operation of said motor.

15. The method of controlling the spacing of a pair of electrodes between which current of varying intensity is flowing through a fluid medium, comprising the steps of supplying a reference device with current of intensity proportional to the current intensity through said electrodes, measuring the voltage across said electrodes and a conductor supplying current to said electrodes, variably correcting said voltage in magnitude and in phase for the varying value and phase of the voltage drop in said conductor and in said electrodes, measuring the voltage across said reference device, and varying said spacing in accordance with the relative values of said corrected voltage and of said voltage across said reference device.

16. In a control system for a pair of working electrodes between which current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said working el ctrodes, a pair of reference electrodes, means for supplying to said reference electrodes a constant direct current component and a second direct current component proportional to the current through said working electrodes to produce a reference arc across said reference electrodes, said reference arc producing a reference voltage measurable at said reference electrodes, a source of constant unidirectional voltage, and means responsive to the difference between a voltage proportional to the voltage appearing across said working electrodes and the sum of said constant voltage and a voltage proportional to said reference voltage for controlling the operation of said motor.

17. In a control system for a pair of working electrodes between which current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said working electrodes, a pair of reference electrodes for sustaining the flow of current therebetween, means for supplying to said reference electrodes a current proportional to the current flowing through said working electrodes to produce a reference voltage across said reference electrodes, means for producing a control voltage responsive to the voltage across said working electrodes, a source of constant voltage, and means responsive to the difference between said control voltage and the sum of said constant voltage and a voltage proportional to said reference voltage for controlling the operation of said motor.

18. In a control system for a pair of working electrodes between which current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said electrodes and means for controlling the operation of said motor comprising a pair of reference electrodes for sustaining the flow of alternating current therebetween, means for supplying to said refer-

ence electrodes an alternating current proportional to the current flow through said working electrodes, means connected with said reference electrodes for producing a reference voltage proportional to the voltage drop between said reference electrodes, and means responsive to the difference above a predetermined value between the value of said reference voltage and the value of the voltage across said working electrodes for varying the magnitude of the voltage impressed on said motor.

19. In a control system for a pair of working electrodes between which alternating current is flowing in the form of a working arc, the combination of a motor for controlling the spacing of said electrodes, and means for controlling the operation of said motor comprising a pair of reference electrodes, means for supplying to said reference electrodes a rectified current component proportional to the current intensity through said working electrodes, means for producing a rectified voltage proportional to the voltage appearing across said working electrodes, and means responsive to the difference between the values of the voltage across said reference electrodes and of said rectified voltage for varying the magnitude of the voltage impressed on said motor.

20. In a control system for a pair of electrodes between which current is flowing in the form of an arc, the combination of a motor for controlling the spacing of said electrodes, means responsive to the current flow through said electrodes for producing a reference voltage, means responsive to the voltage across said electrodes for producing a control voltage, means responsive to the speed of said motor for producing a stabilizing voltage having a polarity dependent upon the direction of rotation of said motor, and means responsive to the difference between said control voltage and the sum of said reference voltage and said stabilizing voltage for controlling the operation of said motor.

21. In a control system for a pair of electrodes between which current is flowing in the form of an arc, the combination of a motor having an armature for controlling the spacing of said electrodes, means responsive to the current flow through said electrodes for producing a reference voltage, means responsive to the voltage across said electrodes for producing a control voltage, means responsive to the voltage of said armature for producing a stabilizing voltage having a polarity dependent upon the polarity of said armature voltage, and means responsive to the difference between said control voltage and the sum of said reference voltage and said stabilizing voltage for controlling the operation of said motor.

DIDIER JOURNEAUX.

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