

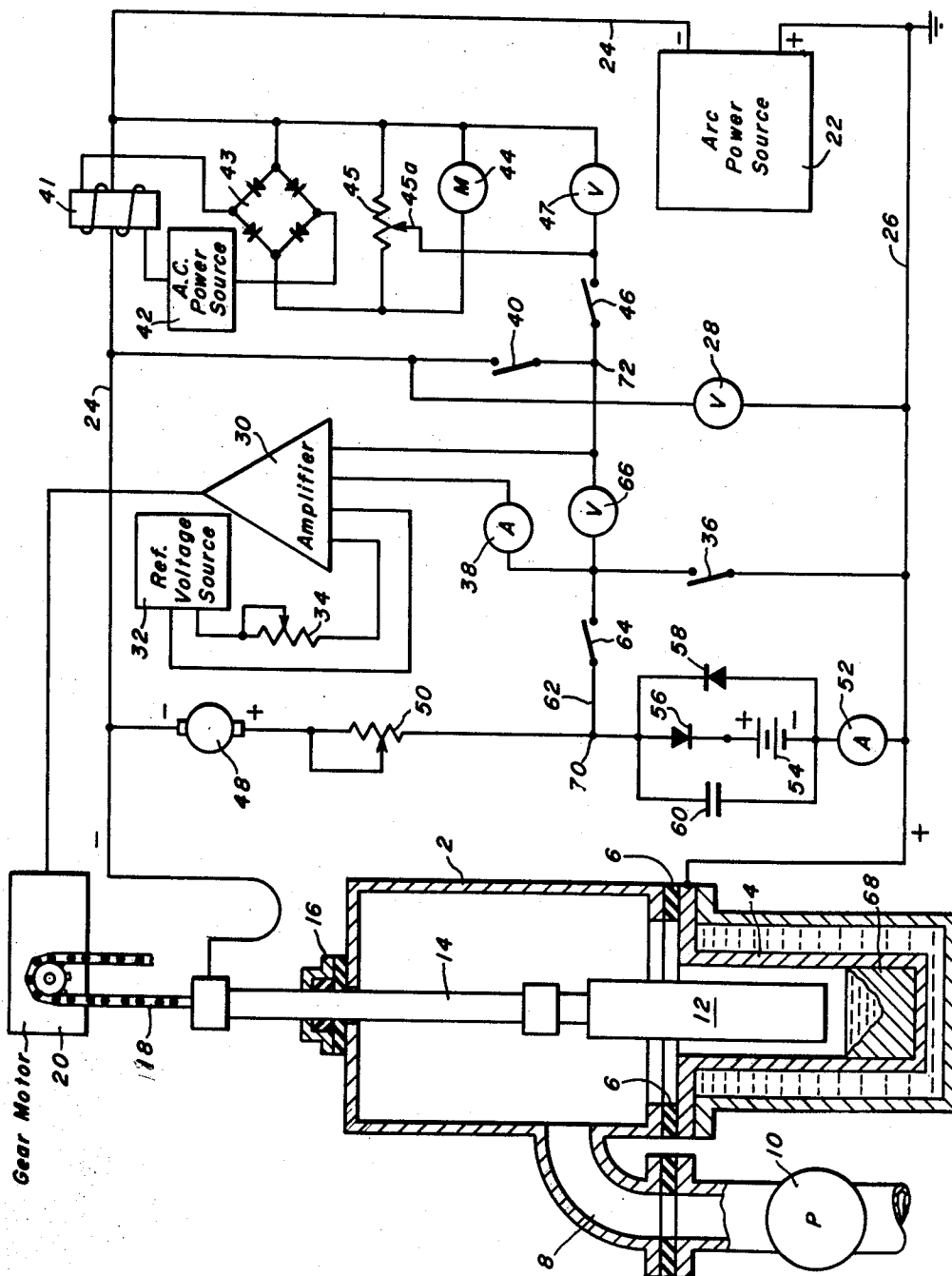
June 8, 1965

R. E. LYMAN

3,188,376

ELECTRODE POSITION CONTROL IN VACUUM ARC FURNACE

Filed March 29, 1962



INVENTOR.
RICHARD E. LYMAN
By *Donald G. Dalton*
Attorney

1

2

3,188,376 ELECTRODE POSITION CONTROL IN VACUUM ARC FURNACE

Richard E. Lyman, Homewood, Ill., assignor to United States Steel Corporation, a corporation of New Jersey
Filed Mar. 29, 1962, Ser. No. 183,588
5 Claims. (Cl. 13—31)

This invention relates to a control for positioning the electrode in a vacuum arc furnace and more particularly to such a control in a consumable arc furnace. Controls for this purpose are old and the control is usually based on maintaining a constant value of voltage across the arc. These controls work satisfactorily if no side arcing occurs. However, when side arcing occurs the control raises the electrode away from the metal bath in an attempt to restore the arc value to the control voltage. If the side arcing occurs intermittently for periods of short duration there will be erratic control of the arc with resulting surface and sub-surface defects in the ingot. As the electrode moves upwardly the side arcing increases so that the control will not return the electrode to the most favorable position, but will continue to move the electrode away from the bath. In vacuum arc casting there is very little increase in arc voltage due to separation of the electrode and molten pool after the electrode is positioned a short distance from the molten pool.

It is therefore an object of my invention to provide an electrode position control for a vacuum arc furnace in which the control ignores voltage decreases due to side arcing, but will move the electrode as required by consumption of the electrode during the melt.

It is also an object of my invention to provide such a control which will position the electrode at the most efficient operating position with respect to the molten pool.

These and other objects will be more apparent after referring to the following specification and attached drawing, in which:

The single figure is a schematic diagram of the vacuum arc furnace with the control connected thereto.

Referring more particularly to the drawing reference numeral 2 indicates a vacuum tank which is connected to a water cooled crucible 4 by means of a vacuum seal 6. The vacuum tank 2 and crucible 4 are evacuated through a pipe 8 by means of a vacuum pump 10. An electrode 12 is supported within crucible 4 by means of an electrode holder 14 which extends through a vacuum seal 16 at the top of the vacuum tank 2. A chain 18 is attached to the top of the electrode 14 and is connected to a gear motor 20. A direct current power source 22 has its negative lead 24 connected to the electrode 14 and its positive lead 26 connected to the crucible 4. The power source 22 is conventional and usually has a drooping volt-ampere characteristic to protect the rectifying devices in the power supply from damaging overload currents when the arc gap is short-circuited while allowing a substantial open-circuit voltage to facilitate initiation of the melting arc. A volt meter 28 is connected across the leads 24 and 26. An amplifier 30 controls the operation of gear motor 20. The amplifier 30 may be a rotating amplifier such as the General Electric Amplidyne, a static magnetic amplifier, a static magnetic amplifier in combination with a rotating amplifier, a static magnetic amplifier in combination with a direct current motor generator set or any other power system commonly used for electrode position control. A D.C. power source 32 is connected to the amplifier 30 through an adjustable resistor 34 to obtain an adjustable reference voltage. The lead 26 is connected through a switch 36 and ammeter 38 to amplifier 30. The lead 24 is connected through switch 40 to amplifier 30.

An arc-current measuring circuit may be provided and as shown consists of a saturating core reactor 41 arranged in lead 24, an A.C. power source 42, a rectifier 43, an electric meter 44 calibrated in amperes of arc current, an adjustable resistor 45 having an arm 45a which may be connected to amplifier 30 through a switch 46. By adjusting the arm 45a a voltage signal 47 proportional to arc current can be obtained from this circuit for control purposes. The parts so far described are conventional and other similar controls may be used as shown in the Electro-Chemical Society book "Arcs in Inert Atmospheres and Vacuum" which is edited by W. E. Kuhn and which includes papers presented at a Symposium on April 30 and May 1, 1956, in San Francisco, California.

According to my invention I provide an adjustable D.C. power source consisting of a D.C. generator 48 having its negative pole connected to lead 24 and its positive pole connected to adjustable resistor 50. An ammeter 52, battery 54 and blocking rectifier 56 are connected in series with resistor 50. The battery 54 must have a voltage greater than the maximum voltage reduction due to side arcing. A blocking rectifier 58, similar to but oppositely arranged, is connected in parallel with battery 54 and rectifier 56. A capacitor 60 is connected in parallel with battery 54 and rectifier 56. A lead 62 is connected between resistor 50 and rectifier 56 and is connected to amplifier 30 through a switch 64.

Conventional electrode position control based on arc voltage can be obtained by closing switches 36 and 40 and opening switches 46 and 64. In this case the feedback voltage 66 is equal to the arc voltage shown on volt meter 28. Amplifier 30 compares this voltage with the reference voltage from power source 32 and, if the feedback voltage is too great, the amplifier 30 applies a voltage to gear motor 20 which causes it to lower the electrode 12 so as to reduce the length of the arc between pool 68 and decrease the arc voltage. If the feedback voltage is too small the amplifier applies a voltage to gear motor 20 which causes it to raise the electrode 12 and thus lengthen the arc in an attempt to increase the voltage across it.

Conventional electrode position control based on combined arc-voltage and arc-current signals can be obtained by closing switches 36 and 46 and leaving switches 40 and 64 open. In this case feedback voltage 66 is less than the arc voltage because of the voltage 47 appearing between arm 45a and lead 24. The control action in this case is similar to that based on arc-voltage alone except that the control system will attempt to increase the arc voltage as the arc current is increased. Conventional control based on combined arc-voltage and arc-current signals aggravates the difficulties encountered by side arcing since a larger error signal will be sensed during side-arc. In the first case the feedback voltage is proportional to arc voltage alone and in the latter case the feedback voltage is proportional to arc voltage and to the arc current voltage in combination. In the claims the term "proportional to arc voltage" will be used to describe both of these situations.

In the operation of my improved control, switch 36 is opened and switch 64 is closed. The feedback voltage 66 is now the voltage appearing between points 70 and 72. If switch 40 is closed and switch 46 open the feedback voltage 66 is the sum of the arc voltage and the voltage between wire 26 and point 70. Since this is the basis of most controls for vacuum arc melting the operation of the control will be discussed with this arrangement. However, it will be understood that the switch 40 could be opened and switch 46 closed so that the feedback voltage 66 would be equal to the sum of the arc voltage, the voltage 47 of the current-measuring circuit and the voltage between wire 26 and point 70.

In a typical installation the voltage of power source 22 will be 32 volts, that of generator 43 will be 90 volts and that of battery or similar D.C. power source 54 at least 8 volts and preferably 12 volts. The amplifier 30 will draw about 1.45 amperes at 32 volts. The rectifiers 56 and 58 have an 0.18 ohm forward resistance at 1.1 amperes; 4.0 milliamperes reverse leakage current at 12 inverse volts. The capacitor 60 has a rating of 250 microfarads. Amplifier 30 will operate on a change of 1/4 volt.

In setting up my circuit for operation the adjustable resistance 50 is adjusted so that the forward current through rectifier 58 as indicated by ammeter 52 just reaches zero when the arc is in the normal mode of discharge and with the proper separation between the electrode 12 and the liquid bath 68. In this condition the resistance 34 is adjusted so that amplifier 30 will cause gear motor 20 to lower the electrode 12 until the arc is restored to its initial length and the arc voltage to its initial value. If side arcing occurs there will be a corresponding decrease in the arc voltage, but this will not cause a change in feedback voltage 65 since no reverse current can flow through rectifier 58 nor can forward current flow through rectifier 56 until the voltage of battery 54 is exceeded by the voltage between wire 26 and point 70. If, however, a short circuit occurs between the electrode 12 and the molten pool 68 the arc voltage will go to zero and the feedback voltage 66 will be reduced to the voltage of battery 54 so that amplifier 30 will cause gear motor 20 to raise the electrode 12 out of contact with the molten pool. The purpose of capacitor 60 is to prevent any unbalanced rectification of ripple voltage components in the arc voltage by the rectifiers 56 and 58 from causing a D.C. component to flow between lead 26 and point 70.

It will be seen that my circuit provides a semi-deadband control by energizing the internal feedback circuit of the amplifier from an adjustable D.C. power source 43 in such a manner that when the control is balanced with a preselected value of voltage appearing across the furnace arc, a null current condition exists in the control-circuit connections at the furnace. Decreased arc voltage within the semi-deadband does not affect the magnitude of feedback circuit current, but increased arc voltage causes increased feedback circuit current which in turn causes the regulator to respond by lowering the electrode.

While one embodiment of my invention has been shown and described, it will be apparent that other adaptations and modifications may be made without departing from the scope of the following claims.

I claim:

1. In a vacuum arc furnace including a crucible for holding a pool of molten metal, a consumable electrode adapted to be moved toward and away from the molten metal in said crucible, and a source of electric current having one lead to the crucible and a second lead to the electrode; a control for positioning said electrode comprising means for moving said electrode toward and away from said molten metal, an amplifier having its output connected to said means for moving said electrode toward and away from said molten metal, means providing a voltage proportional to arc voltage to said amplifier, means preventing arc voltage decreases due to side arcing of less than a predetermined amount from reaching said amplifier including an adjustable D.C. power source, means for permitting flow of current toward said adjustable D.C. power source only connected in series with said adjustable D.C. power source across said leads, a D.C. power source, means for permitting flow of current away from said adjustable D.C. power source only connected in series with said last named power source and in parallel with said means for permitting flow of current toward said adjustable D.C. power source only, and an electrical connection extending to said amplifier from

a position between said adjustable D.C. power source and said means for permitting flow of current toward said adjustable D.C. power source only.

2. In a vacuum arc furnace including a crucible for holding a pool of molten metal, a consumable electrode adapted to be moved toward and away from the molten metal in said crucible, means for moving said electrode toward and away from said molten metal, and a source of electric current having one lead to the crucible and a second lead to the electrode; a control for positioning said electrode comprising an amplifier having its output connected to said means for moving said electrode toward and away from said molten metal, means providing a reference voltage to said amplifier, means providing a voltage proportional to arc voltage to said amplifier, a blocking rectifier, an adjustable D.C. power source connected in series with said rectifier across said leads, said blocking rectifier permitting flow of current toward said adjustable D.C. power source only, a D.C. power source, a second blocking rectifier connected in series with said last named power source and in parallel with said first blocking rectifier, said second blocking rectifier permitting flow of current away from said adjustable D.C. power source only, a capacitor connected in parallel with said rectifiers, and an electrical connection extending to said amplifier from a position between said adjustable D.C. power source and said rectifiers.

3. In a vacuum arc furnace including a crucible for holding a pool of molten metal, a consumable electrode adapted to be moved toward and away from the molten metal in said crucible, means for moving said electrode toward and away from said molten metal, and a D.C. power source having its negative lead connected to said electrode and its positive lead connected to said crucible; a control for positioning said electrode comprising an amplifier having its output connected to said means for moving said electrode toward and away from said molten metal, means providing a voltage proportion to arc voltage to said amplifier, an adjustable D.C. power source having its negative pole connected to said negative lead, a connection between the positive pole of said last named D.C. power source and said positive lead, means in said last named connection permitting flow of current toward said adjustable D.C. power source only, a battery, means for permitting flow of current away from said adjustable D.C. power source only connected in series with said battery and in parallel with said means for permitting flow of current toward said adjustable D.C. power source only, and an electrical connection extending to said amplifier from a position between said adjustable D.C. power source and said means for permitting flow of current toward said adjustable D.C. power source only.

4. In a vacuum arc furnace including a crucible for holding a pool of molten metal, a consumable electrode adapted to be moved toward and away from the molten metal in said crucible, and a source of electric current having one lead to the crucible and a second lead to the electrode; a control for positioning said electrode comprising means for moving said electrode toward and away from said molten metal, an amplifier having its output connected to said means for moving said electrode toward and away from said molten metal, means providing to said amplifier a voltage proportional to increases and decreases in arc voltage, and means preventing the operation of said amplifier to move said electrode away from said molten metal when said arc voltage decreases are due to side arcing of less than a predetermined value.

5. In a vacuum arc furnace including a crucible for holding a pool of molten metal, a consumable electrode adapted to be moved toward and away from the molten metal in said crucible, and a source of electric current having one lead to the crucible and a second lead to the electrode; a control for positioning said electrode comprising means for moving said electrode toward and away

5

from said molten metal, an amplifier having its output connected to said means for moving said electrode toward and away from said molten metal, means providing to said amplifier a voltage proportional to increases and decreases in arc voltage from a particular desired value, a feedback circuit associated with said amplifier, a semi-deadband control for energizing said feedback circuit, said semi-deadband control including means for preventing decreased arc voltage from affecting the magnitude of feedback circuit current while permitting increased arc voltage to increase feedback circuit current to move said electrode toward said metal bath.

5

10

6

References Cited by the Examiner

UNITED STATES PATENTS

2,121,644	6/38	Thompson	13—13
2,889,386	6/59	Gruber et al.	13—13
2,915,572	12/59	Buehl	13—31 X
2,916,536	12/59	Gruber et al.	13—31 X
2,942,045	6/60	Johnson	13—31 X
2,956,098	10/60	Gruber et al.	13—13
3,042,731	7/62	Gruber et al.	13—13

RICHARD M. WOOD, *Primary Examiner.*JOSEPH V. TRUHE, *Examiner.*