Jan. 16, 1968 R. W. ROBERTS 3,364,295

CONTROL SYSTEM FOR VACUUM ARC FURNACE

Filed June 12, 1964

Fig. 1.

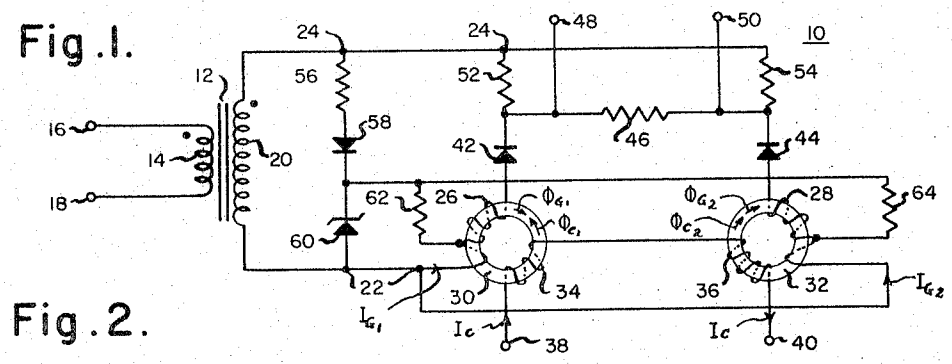


Fig. 2.

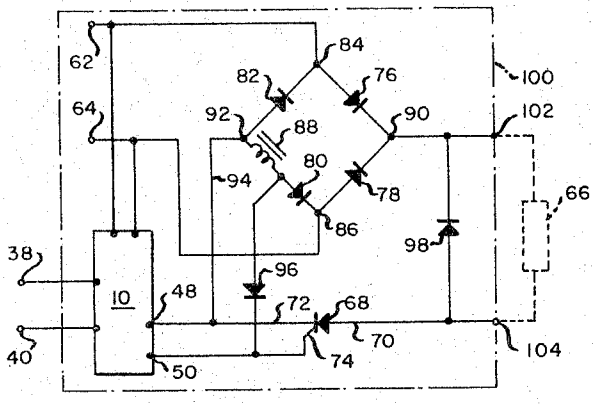


Fig. 2a.

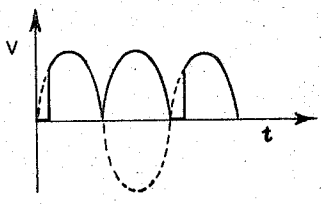
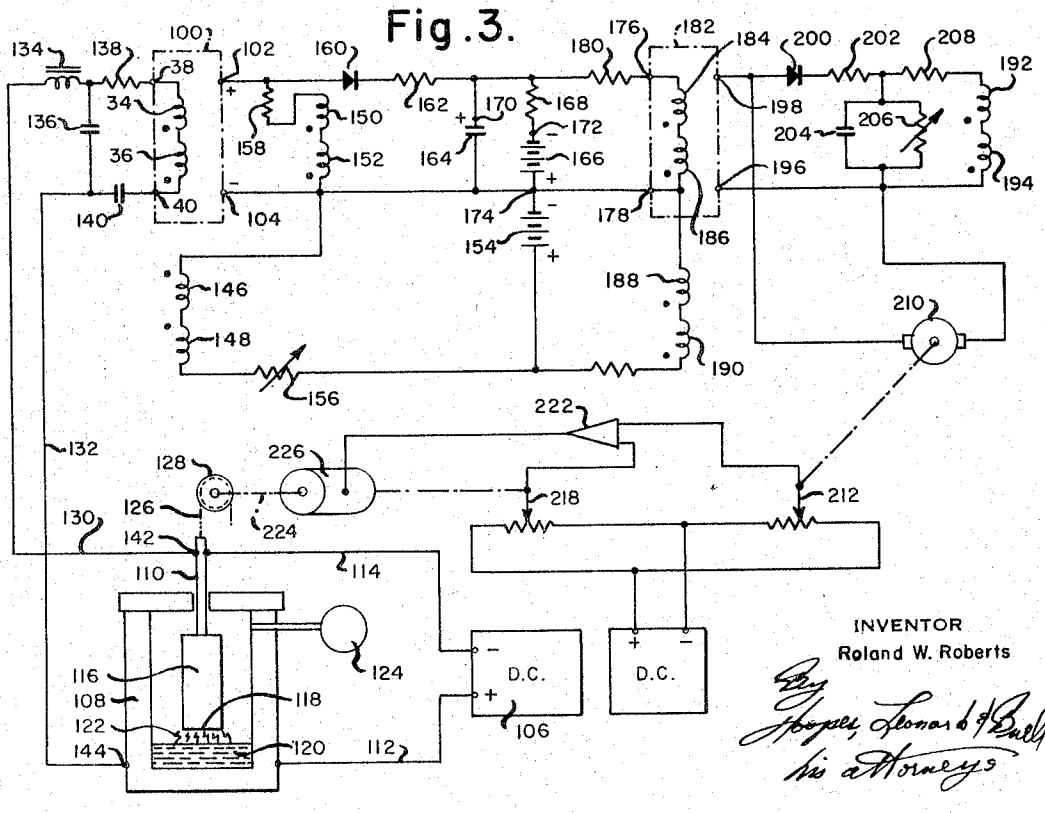


Fig. 3.



INVENTOR
Roland W. Roberts

Fay, Hoppes, Leonard & Ruff
his attorneys

United States Patent Office 3,364,295
Patented Jan. 16, 1968

3,364,295

CONTROL SYSTEM FOR VACUUM ARC FURNACE

Roland W. Roberts, Fox Chapel, Pa., assignor to Norbatrol Electronics Corporation, a corporation of Pennsylvania

Filed June 12, 1964, Ser. No. 374,785
13 Claims. (Cl. 13—13)

This invention relates to a control system for controlling the position of a ram in a vacuum arc melting furnace. More particularly, the invention relates to an improved system for continuously adjusting the ram feed rate of a consumable electrode in a vacuum arc furnace.

Certain types of furnaces are provided for the purification of metals. Generally, a ram holds the metal to be purified within the furnace. The metal comprises an electrode which is remelted under a high vacuum by means of a DC electric arc. It is normal practice to position the ram by electro-mechanical means. The rate of linear movement of the ram is made proportional to the difference between the average DC voltage across the arc which is formed between the base of the furnace and the electrode material being melted and a reference voltage. The operation of this type of system is entirely dependent upon the amount of voltage across the arc which is determined by the length of the arc. The increment of arc voltage change for a unit incremental change in arc length (defined generally as arc voltage gradient) is a function of the metal or alloy being melted. A metal which exhibits a very low value of arc voltage gradient approaching zero cannot be satisfactorily melted by the usual control system.

To solve this problem, one solution has been advanced. The solution uses the randomly spaced pulsations present in the DC arc voltage. The rate of occurrence of these pulsations is an indication of the average arc length and melting rate. The pulse rate increases with an increasing melting rate and a decreasing arc length. The pulses are counted during a fixed time interval by a digital electronic counting means. The total from this count is compared with a desired reference count and the ram is moved by an amount dependent on the count error between the actual count and the reference count.

The disadvantage of this solution is that it produces an undesirable step motion of the ram. This is due to the fact that the time interval in which the pulses are counted is substantial.

The present invention approaches a smooth uniform ram feed rate using less complex equipment.

I provide a control system for controlling the position of a ram in an arc melting furnace comprising means detecting voltage pulses present across the arc, means quantizing and amplifying the detected voltage pulses and coupled to the means detecting, means integrating the difference between the amplified quantized voltage pulse and a fixed reference voltage, the means integrating coupled to the means quantizing, and means linearly moving the ram at a rate dependent upon the difference between the integral voltage from the means integrating and a fixed reference voltage.

I preferably provide that the means quantizing and amplifying converts input pulses of random amplitude and duration from the means detecting into corresponding pulses of fixed amplitude and duration. The means integrating integrates the difference between fixed amplitude pulses from the means converting and a fixed reference voltage.

I preferably provide that the means converting be a bistable amplifier having a control winding and an output. The control winding is electrically connected to the output of the means detecting. The bistable amplifier converts pulses of random amplitude and duration from the means detecting into corresponding pulses of fixed amplitude and duration.

I preferably provide that the integrating means comprises a capacitor coupled to the positive output of a bistable amplifier and a DC voltage coupled across the capacitor and having a negative polarity with respect to the positive output of the bistable amplifier so that when an electrical charge coming from the bistable amplifier is built up on the capacitor, it is discharged through the negative side of the DC source and the voltage developed across the capacitor is the integral of the difference between the pulse rate of the bistable amplifier and the voltage from the DC source.

I preferably provide that the means linearly moving the ram at a rate dependent upon the difference between the integral voltage across the capacitor in the integrating circuit and a fixed reference voltage comprises a pulse oscillator coupled to the integrating circuit. The pulse oscillator drives an electric motor which controls a ram positioning servo system means which drives the ram at a rate which is dependent upon the rate of pulses present across the arc.

In the foregoing I have set out certain objects, purposes and advantages of this invention. Other objects, purposes and advantages will be apparent from the following description in which

FIGURE 1 is a schematic of a half wave push-pull self-saturating magnetic amplifier;

FIGURE 2 is a schematic circuit diagram of a bistable amplifier providing a controlled DC voltage at a load;

FIGURE 2*a* is a graph of voltage versus time; and

FIGURE 3 is a schematic of a control system for a consumable electrode vacuum arc furnace.

Referring to FIGURE 1 I have illustrated a push-pull half wave self-saturating magnetic amplifier generally shown as **10** which comprises a transformer core **12** around which primary winding **14** having terminals **16** and **18** is wound. A secondary winding **20** is wound around the core **12** and terminated at junction points **22** and **24**. Gate windings **26** and **28** are wound around cores **30** and **32**, respectively. Control windings **34** and **36** having terminals **38** and **40** are wound around cores **30** and **32**.

The gate windings **26** and **28** are in series with rectifiers **42** and **44**, respectively. The output from the magnetic amplifier **10** is taken across resistor load **46** at terminals **48** and **50**. Gate resistor loads **52** and **54** are connected to junction point **24**. Resistor **56** in series with rectifier **58** which is connected to zener diode **60** are all connected between junction points **24** and **22**.

The bias circuit comprises resistors **62** and **64** tapping gate windings **26** and **28**, respectively.

The operation of the magnetic amplifier in the absence of a control current flowing through the control windings **34** and **36** is as follows: An AC source is put across terminals **16** and **18** of the primary winding **14**. When terminal **18** is positive, current I_{G_1} and I_{G_2} will flow from junction point **22** through gate windings **26** and **28** to produce a flux ϕ_{G_1} and ϕ_{G_2}, respectively. ϕ_{G_1} and ϕ_{G_2} are shown moving in the direction of the arrow on the figure. Assuming ideal conditions in which $\phi_{G_1}=\phi_{G_2}$, cores **30** and **32** will fire (that is they will saturate) at the same time and produce a chopped since wave voltage across resistors **52** and **54**. The voltage across resistor **46** is the difference of the two voltages at resistor **52** and **54**. In this situation the output voltage between terminals **48** and **50** is zero. Now when the AC source goes negative and terminal **16** is positive with respect to terminal **18**, current flows through rectifier **58**, resistors **62** and **64** whereby the flux is driven back or reset to the high gain region. On the next half cycle when terminal **18** is again positive the cores are fired again.

Now assume that a control current flows through control windings **34** and **36** so as to make terminal **38** positive with respect to terminal **40**. The direction of the control current shown in this situation is shown in FIGURE 1 by I_C which produces a flux ϕ_{C_1} and ϕ_{C_2} in the direction shown on the FIGURE 1.

The control winding **34** and the control current through it are such that ϕ_{G_I} tends to oppose ϕ_{G_1}. The flux produced by the control current tend to opposed the flux produced by the gate current. The control winding **36** and the control current through it are such that ϕ_{C_2} tends to add to ϕ_{G_2}. Therefore, whenever terminal **18** is positive with respect to terminal **16** and terminal **38** is positive with respect to terminal **40**, core **32** will saturate prior to core **30** because of the relationship of the fluxes in the respective cores. The opposing fluxes in core **30** cause it to take a longer time to saturate. The adding fluxes in core **32** cause it to take less time to saturate. Therefore, between the time core **32** saturates until just before core **30** subsequently saturates, there is a voltage difference present across resistor **46** in which terminal **50** is positive with respect to terminal **48**. This voltage is in the form of a pulse. Throughout the specification the term first polarity refers to the time when terminal **50** is positive with respect to terminal **48**. In order to make terminal **48** positive with respect to terminal **50** (which is referred to as a second polarity) all that need be done is to reverse the polarity of I_C and make terminal **40** positive with respect to terminal **38**. This produces the opposite result in the cores by changing the direction of the flux produced by the control current I_C. In this situation core **30** saturates prior to core **32** and terminal **48** has a positive pulse voltage with respect to terminal **50**.

Referring to FIGURE 2 a rectifier circuit couples an AC source at terminals **62** and **64** with a load **66**. The rectifier circuit is controlled by a silicon controlled rectifier **68**, hereinafter referred to as SCR. The SCR has an anode **70**, a cathode **72**, and a gate **74**. The gate **74** and cathode **72** are connected directly to the output terminals **50** and **48** of the magnetic amplifier **10**. A full wave rectification bridge circuit comprising rectifiers **76**, **78**, **80**, and **82** are connected to the AC source at terminals **84** and **86**. Rectifier **80** has an inductor **88** in series with it. The DC terminal **90** of the bridge circuit is connected directly to the load **66**. The other DC terminal **92** of the bridge circuit is connected to the load **66** through SCR **68**. The means coupling the inductor **88** to the gate **74** and cathode **72** of SCR **68** comprises lead **94** and rectifier **96**. Rectifier **98** is used whenever inductive loads are applied at load **66**.

The circuit described above operates as follows: Assume an output pulse from the magnetic amplifier **10** in which terminal **50** is positive with respect to terminal **48**. This pulse triggers SCR **68**. It must be remembered throughout the specification during the discussion of the SCR's that in order to trigger the SCR a positive voltage only must be applied at the gate. A negative voltage at the gate of the SCR will not fire or trigger it. Triggering or firing refers to the time when the anode conducts current to the cathode as though a switch were thrown between the anode and the cathode. Until the SCR is triggered, it appears as an open switch and the only way to close the switch is to apply a positive voltage at the gates.

When AC terminal **62** is positive with respect to terminal **64** and at the same time assume terminal **50** produces a positive voltage with respect to terminal **48**, the SCR is triggered. Current will flow from the AC terminal **62** to terminal **84**, through rectifier **76**, to terminal **90**, through load **66**, through SCR **68**, to terminal **92**, through inductor **88**, through rectifier **80**, to the AC terminal **86** of full wave rectifier bridge circuit, and return to the AC source terminal **64**. In order to keep an SCR conducting after it has once been triggered, the anode current cannot be permitted to fall to zero. If the anode current falls to zero, then the SCR must be retriggered, even though the anode voltage subsequently goes positive. After the first half cycle in the particular circuit described is ended, the current must go to zero. In order to retrigger the SCR **68** in the absence of a voltage pulse from the magnetic amplifier **10**, an inductor **88** is used. When the current approaches zero across the load **66** and in the anode **70** of the SCR **68**, the flux in inductor **88** collapses and produces a current through rectifier **96** thereby applying positive voltage on the gate **74** and retriggering the SCR **68**. At that moment terminal **64** turns positive with respect to terminal **62** in the AC source and sufficient current flows through the anode **70** from the full wave rectifier bridge circuit during the remainder of the second half cycle until the current again approaches zero when terminal **62** begins to turn positive with respect to terminal **64**. When terminal **64** is positive with respect to terminal **62**, the current flows to the AC terminal **86** of the bridge circuit, through rectifier **78**, to the DC terminal **90** of the bridge circuit, through the load **66**, through the SCR **68**, through lead **94**, to the AC terminel **92** at the bridge circuit, through rectifier **82**, to terminal **84** of the bridge circuit, returning to AC source terminal **62**. The voltage across the load **66** appears as shown in graph of FIGURE 2*a*. The dotted lines on the graph represent the voltage between the AC terminals **64** and **62**. A solid line represents the actual voltage as seen across load **66**. The magnetic amplifier has its power supplied from the same AC source through a pair of leads so that when terminal **62** is positive the AC voltage on the terminal **18** of the magnetic amplifier is positive.

I have shown a bistable amplifier that switches power from an AC source to a load **66** depending upon the polarity and magnitude of the control current at terminals **40** and **38** of the magnetic amplifier **10**. The AC power was switched in such a manner as to produce a full cycle of controlled DC voltage at the load **66** as shown in the graph.

Referring to FIGURE 3 a DC current regulated arc power supply **106** is applied to crucible housing **108** and ram **110** through leads **112** and **114**. Ram **110** holds ingot **116**. Ingot **116** is melted by an arc **122** between the bottom surface **118** of the ingot **116** and molten metal **120** resting on the bottom of crucible housing **108**. Vacuum pump **124** creates a vacuum within the crucible housing **108** thereby facilitating the electric arc melting technique. As the ingot **116** is being melted, the ram **110** holding ingot **116** is lowered by a chain **126** wound on pulley **128**.

The length of the arc **122** is a function of the rate of melting. Random pulses of varying amplitude and duration are present in the voltage across the arc **122**. The rate of occurrence of these random pulses is a function of the length of the arc **122**. The rate of occurrence of the voltage pulses present in the arc **122** increases with an increasing melting rate and a decreasing arc length **122**. Therefore, the rate of random pulses is used to control in a smooth feeding manner the lowering of the ram **110** on chain **126** from pulley **128**. Leads **130** and **132** couple the arc voltage to a standard L-C filter having a low-pass characteristic designed to remove any rectifier ripple and other high frequency noise. The L-C filter comprises inductor **134** and capacitor **136**. The output of the L-C filter is coupled to terminals **38** and **40** of the bistable amplifier **100** through resistor **138** and coupling capacitor **140**. The effect of the L-C filter coupled between terminals **38** and **40** of the bistable amplifier **100** and junction points **142** and **144**, is to detect randomly occurring pulses of varying duration and amplitude between terminals **142** and **144**.

Bistable amplifier **100** acts as a pulse quantizer and amplifier which converts the random pulses into pulses of uniform amplitude and uniform duration. Therefore, one pulse delivered between terminals **138** and **140** will produce one pulse of uniform amplitude and duration between outputs **102** and **104** of bistable amplifier **100**. The output of L-C filter is coupled through terminals **38** and

40 to the control windings 34 and 36 of the bistable amplifier 100 referred to in FIGURE 1 and in FIGURE 2. The polarity of the control windings 34 and 36 from terminals 38 and 40 is such that an increase in magnitude in the arc voltage across arc 122 will tend to turn ON the output of the bistable amplifier 100. Control windings 146 and 148 are wound in the same displacement as control windings 34 and 36 and likewise control windings 150 and 152 are wound in the same displacement at control windings 34 and 36. Control windings 146 and 148 are coupled to a DC source 154 through resistor 156. The polarities of control windings 146 and 148 and voltage source 154 are such as to tend to turn OFF the output of the bistable amplifier 100 by creating an opposing magnetomotive force to the magnetomotive force produced by current flowing through control windings 34 and 36. Control windings 150 and 152 in series with resistor 158 have a polarity that also produces an opposing magnetomotive force to the magnetomotive force produced by current in control windings 34 and 36, and therefore tends to turn OFF the output of bistable amplifier 100. Therefore, when the output from the bistable amplifier 100 between terminals 102 and 104 is switched ON as a result of a pulse of sufficient magnitude being applied to the input terminals 38 and 40 of the bistable amplifier 100, the output at terminals 102 and 104 will be switched OFF immediately after one full cycle of output. The magnitude of the magnetomotive force produced by windings 34 and 36 must be greater than the opposing magnetomotive force produced by windings 146 and 148 to turn ON bistable amplifier 100. DC source 154 and variable resistor 156 coupled to windings 146 and 148 act as a sensitivity control for the pulse input to bistable amplifier 100. The sensitivity control selects the minimum pulse input to bistable amplifier 100 which turns it ON.

The output of the bistable amplifier 100 is coupled through rectifier 160 and resistor 162 to an integrator and reference network comprising a capacitor 164 and a DC source 166 in series with a resistor 168 all in parallel with the capacitor 164. The DC source 166 is the Reference and forms part of the integrator network. The capacitor 164 has a positive reference terminal 170. The DC source 166 has a negative polarity terminal 172 and a positive polarity terminal 174. For each output pulse from the bistable amplifier 100, an approximately fixed value of electrical charge is placed on the positive reference 170 of the capacitor 164. This function is generally achieved whenever the voltage across the capacitor 164 at any one time is much smaller compared to the output voltage from the bistable amplifier 100. The amount of charge delivered to the capacitor 164 is determined by the valve of the resistor 162. This value is selected to achieve a desired pulse rate. The rectifier 160 prevents the capacitor 164 from discharging back through the bistable amplifier 100. The battery 166 provides a constant current discharge from the positive reference 170 of the capacitor 164. To approach a constant current discharge characteristic curve, the voltage of DC source 166 should be much greater than the operating value of the voltage across capacitor 164. When the desired average pulse rate is present in the voltage across the arc 122, the capactior 164 will receive equal average charging and discharging currents. Under this condition the capacitor 164 voltage will remain constant at whatever value may be present. If the voltage pulse rate detected in the arc 122 is greater than the preset desired value of voltage pulse rate, then the capacitor 164 will receive a greater average charging current than is being taken away by the discharge circuit and the capacitor 164 voltage will increase at a rate directly dependent upon the magnitude of the difference (error) in average pulse rate. If the average input voltage pulse rate is less than preset value of voltage pulse rate, then the capacitor 164 voltage will decrease at a proportional rate. The value of the voltage across the capacitor 164 is represented by the following formula:

(1) $$V\ (\text{capacitor}) = \frac{1}{C}\int_0^t i\ (\text{capacitor})\ dt$$

(2) $$i\ (\text{capacitor} = (\text{constant}\ (K))\ (\text{pulse per minute})/R_{162} - i\ (\text{discharge})$$

(3) $$i\ (\text{discharge}) = \frac{V_{166}}{R^{168}}$$

The DC source 166 with resistors 162 and 180 determines the unique pulse rate at which the capacitor voltage will remain constant, i.e., the value of the DC source 166 is calibrated against a desired pulse rate present in the DC arc voltage.

The output of the integrating capacitor is coupled at terminals 176 and 178 through resistor 180 to a pulse oscillator circuit which comprises a bistable amplifier 182, rectifier 200 in series with resistor 202, an RC network having capacitor 204 in parallel with resistor 206, a resistor 208 in series with feedback windings 192 and 194. Terminals 176 and 178 are the input control winding terminals of bistable amplifier 182. Bistable amplifier 182 has the same internal circuitry as preceding bistable amplifier 100 and terminals 176 and 178 correspond to terminals 38 and 40 of bistable amplifier 100. Control windings 184, 186, 188, 190, 192 and 194 occupy the same displacement within bistable amplifier 182. Control windings 188 and 190 are of such a polarity that whenever current is flowing from DC source 154, the magnetomotive force produced tends to turn ON bistable amplifier 182. Control windings 184 and 186 are of such a polarity that current flowing through them produces a magnetomotive force which tends to turn OFF bistable amplifer 182. Feedback control windings 192 and 194 are of such a polarity that when current flows through them the magnetomotive force produced tends to turn OFF bistable amplifier 182.

A net magnetomotive force is produced at the input of bistable amplifier 182 by windings 184, 186, 188 and 190. Whenever the net magnetomotive force is positive, the bistable amplifier tends to turn ON.

When the bistable amplifier 182 is turned ON for one full cycle of output, an appreciable charge is built up on capacitor 204 and a current passes through feedback windings 192 and 194, turning bistable amplifier 182 OFF. The charge approaches a semi-peak of the output voltage from the bistable amplifier 182. In the absence of any output from bistable amplifier 182, the current then discharges from capacitor 204 slowly through both the resistor 206 of the semi-peak charging RC network and the negative feedback windings 192 and 194. When the voltage across capacitor 204 has dropped to a value in which the magnetomotive force produced by the feedback windings 192 and 194 is approximately equal to the net positive magnetomotive force produced by windings 184, 186, 188, and 190, bistable amplifier 182 will turn ON again for one cycle completing one full cycle of operation of the pulse oscillator.

The resistor 206 adjusts the proportionality between the pulse rate of bistable amplifier 182 and the input control current in windings 184 and 186.

The exponential nature of the discharge of the capacitor 204 after being charged during one cycle of output from the bistable amplifier 182 causes a time interval between output pulses of bistable amplifier 182 which is a function of the net positive magnetomotive force produced by windings 184, 186, 188 and 190. Therefore, the pulse rate of the pulse oscillator is controllable by the pulse rate present in the arc 122.

The purpose of the above-described pulse oscillator network is to drive a potentiometer gear motor 210 in a continuous series of incremental steps in which the motor 210 will move a step typically every few seconds de-

pendent on the difference between a reference and the charge on the integrating capacitor.

The potentiometer gear motor **210** is mechanically coupled to a servo network system. The motor **210** is mechanically coupled to the command position arm **212**. The servo network system comprises position command arm **212** and follower arm **218**. The voltage taken from position command arm **212** and follower arm **218** is fed to amplifier **222**. In the event there is an unbalance between the position command arm **212** and follower arm **218**, there will be a voltage present (error voltage) at the amplifier **222**. The output of the amplifier **222** is electrically coupled to mechanical drive means **226**. The output voltage from amplifier **222** rotates the mechanical drive means **226**. Mechanical drive means **226** is mechanically coupled to follower arm **218** and moves the follower arm **218** so as to restore the balance tending to create a zero input voltage to amplifier **222**. The mechanical drive means **226** is mechanically coupled to pulley **128** through shaft **224**. When the mechanical drive means **226** rotates, the ram **110** is lowered from the pulley **128** into the crucible **108**. The pulse oscillator motor drives the position command arm which regulates the ram positioning servo system and produces a means for driving the ram downwardly at a very low speed which is proportional to the difference between the integrating capacitor voltage and the fixed reference **166**.

Whenever ingot **116** is melting at a faster rate than desired, arc **122** will become shorter in length. The shortened length of arc **122** causes an increased rate of voltage pulses which are detected by the low band pass filter and quantized and amplified into pulses of fixed duration and amplitude by bistable amplifier **100**. The increased pulse rate is impressed across integrating capacitor **164** causing a slow increase in capacitor voltage. This causes more current to flow in control windings **184** and **186** thereby reducing the net positive magnetomotive force acting to turn ON bistable amplifier **182**. Bistable amplifier **182** therefore remains OFF and position command motor **210** remains stationary for a longer interval of time. Whenever this happens, there is a balance between the position command arm **212** and the follower arm **218** and the input and output voltages of amplifier **222** is zero whereby the mechanical drive means **226** ceases to rotate for a longer interval of time and the ram **110** is lowered at a slower rate. This condition will remain until the rate of pulses present in arc **122** is decreased. This is brought about by increasing the arc length **122** which would be a natural result if the ram **110** is momentarily stopped from lowering the ingot **116** into the crucible housing **108**. The average feed rate is then automatically adjusted to the value that gives the desired preset arc voltage pulse rate.

While I have illustrated and described a preferred embodiment and practice of my invention, it will be understood that this invention may be otherwise practiced within the scope of the following claims.

I claim:

1. A control system for controlling the position of a ram in an arc melting furnace comprising:

(1) Means detecting voltage pulses present across the arc;

(2) Means quantizing and amplifying the detected voltage pulses and coupled to the means detecting;

(3) Means integrating the difference between the amplifier quantized voltage pulses and a reference, the means integrating coupled to the means quantizing; and

(4) Means linearly moving the ram at a rate dependent upon the integral voltage from the means integrating.

2. A control system for controlling the position of a ram in an arc melting furnace comprising:

(1) Means detecting voltage pulses present across the arc;

(2) Means converting input pulses of random amplitude and duration from the means detecting, into corresponding pulses of fixed amplitude and duration;

(3) Means integrating the difference between the fixed amplitude pulses from the means converting and a reference, the means integrating coupled to the means converting; and

(4) Means linearly moving the ram at a rate dependent upon the integral voltage from the means integrating.

3. A control system for controlling the position of a ram in an arc melting furnace comprising:

(1) Means detecting voltage pulses present across the arc and having an output;

(2) A bistable amplifier having a control winding and an output, the control winding electrically connected to the output of the means detecting, the bistable amplifier converting pulses of random amplitude and duration from the means detecting into corresponding pulses of fixed amplitude and duration;

(3) Means integrating the difference between the fixed amplitude pulses from the bistable amplifier and a reference forming part of the means integrating, the means integrating coupled to the output of the bistable amplifier; and

(4) Means linearly moving the ram at a rate dependent upon the integral voltage from the means integrating.

4. A control system for controlling the position of a ram in an arc melting furnace as recited in claim **3** wherein the means integrating comprises:

(1) A capacitor;

(2) Means coupling the DC pulses from the bistable amplifier to the capacitor; and

(3) Reference means discharging the capacitor.

5. A control system for controlling the position of a ram in an arc melting furnace as recited in claim **3** wherein the means linearly moving the ram at a rate dependent upon the integral voltage developed across the capacitor comprises:

(1) A pulse oscillator means;

(2) Means coupling the pulse oscillator means to the integral voltage developed across the capacitor; and

(3) A ram positioning servo means driving the ram at a rate dependent upon the rate of pulses from the pulse oscillator, the servo means coupled to the output of the pulse oscillator.

6. A control system for controlling the position of a ram in an arc melting furnace as recited in claim **4** wherein the means coupling the DC pulses from the bistable amplifier to the capacitor comprises a rectifier and a resistive load in series connecting the bistable amplifier output to the capacitor.

7. A control system for controlling the position of a ram in an arc melting furnace as recited in claim **4** wherein the reference means discharging the capacitor comprises a DC source.

8. A control system for controlling the position of a ram in an arc melting furnace as recited in claim **4** wherein the means linearly moving the ram at a rate dependent upon the integral voltage developed across the capacitor comprises:

(1) A pulse oscillator means;

(2) Means coupling the pulse oscillator means to the integral voltage developed across the capacitor;

(3) A motor electrically coupled to the pulse oscillator, the output voltage of the pulse oscillator controlling the rotation of the motor; and

(4) A ram positioning servo means driving the ram at a rate dependent upon the rate of pulses from the pulse oscillator, the servo means coupled to the motor.

9. A control system for controlling the position of a ram in an arc melting furnace as recited in claim **4** wherein the means detecting voltage pulses present across the arc comprises a band pass filter connected across the arc.

10. A control system for controlling the position of a ram in an arc melting furnace as recited in claim 4 wherein the means detecting voltage pulses present across the arc comprises an inductor capacitor low frequency pass network connected across the arc.

11. A control system for controlling the position of a ram in an arc melting furnace as recited in claim 8 wherein the pulse oscillator means comprises:

(1) A bistable amplifier having an input coupled to the integral voltage across the capacitor; and

(2) Means applying delayed negative feedback to the bistable amplifier input.

12. A control system for controlling the position of a ram in an arc melting furnace as recited in claim 8 wherein the pulse oscillator means comprises:

(1) A bistable amplifier having an input coupled to the integral voltage;

(2) A feedback winding providing an opposing magnetomotive force to the net input magnetomotive force to the bistable amplifier; and

(3) A semi-peak charging RC network coupled to the output of the bistable amplifier providing current through the feedback winding whereby a delayed negative feedback is produced.

13. A control system for controlling the position of a ram in an arc melting furnace as recited in claim 8 wherein the ram positioning servo means comprises:

(1) A compound potentiometer coupled to the motor;

(2) An amplifier having an input coupled to the command potentiometer;

(3) An electro-mechanical drive means coupled electrically to the output of the amplifier, the electromechanical drive means driving the ram; and

(4) A follower potentiometer mechanically coupled to the electromechanical drive means and electrically coupled to the amplifier input, when the voltage across the input of the amplifier is zero, the electromechanical drive means ceases its rotation until an unbalance exists between the command potentiometer and follower potentiometer.

References Cited

UNITED STATES PATENTS

3,187,078	6/1965	Murtland et al.	13—13
3,188,376	6/1965	Lyman	13—13 X

BERNARD A. GILHEANY, *Primary Examiner.*

R. N. ENVALL, JR., *Assistant Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,364,295 January 16, 1968

Roland W. Roberts

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, lines 53, 57 and 61, "quantizing", each occurrence, should read -- quantitizing --. Column 2, line 62, "since" should read -- sine --. Column 3, line 8, "$\emptyset_{G_1}$", first occurrence, should read -- $\emptyset_{C_1}$ --; line 9, "tend" should read -- tends --; same line 9, "opposed" should read -- oppose --; line 63, "gates" should read -- gate --. Column 4, line 20, "terminel" should read -- terminal --; line 69, "quantizer" should read -- quantitizer --. Column 5, line 10, "at" should read -- as --; line 62, "capactior" should read -- capacitor --. Column 7, line 31, "quantized" should read -- quantitized --; line 62, quantizing" should read -- quantitizing --. Column 10, line 3, "compound" should read -- command --; line 10, "electromechanical" should read -- electro-mechanical --.

Signed and sealed this 7th day of October 1969.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents