Sept. 22, 1953 C. W. VOKAC ET AL 2,653,269

HYDRAULIC-ELECTRICAL APPARATUS FOR AUTOMATICALLY REGULATING THE POSITION OF DIRECT ARC ELECTRIC FURNACE ELECTRODES

Filed July 16, 1952 2 Sheets-Sheet 1

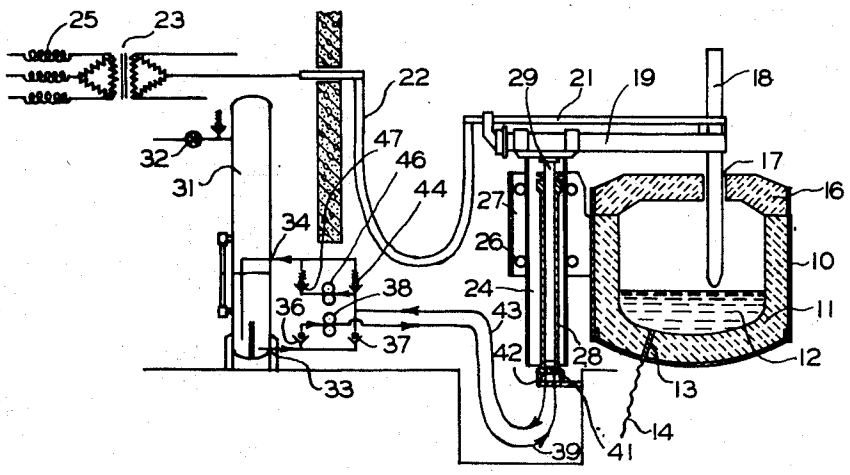


FIG. 1

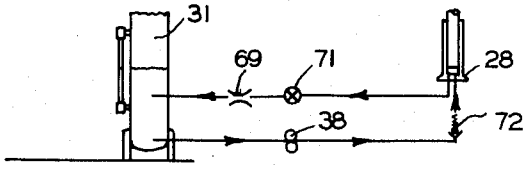


FIG. 2

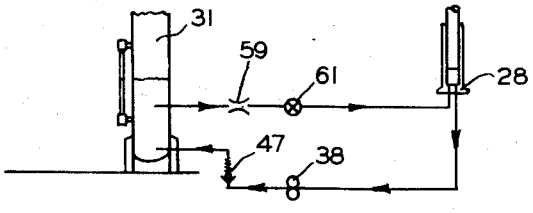


FIG. 3

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Filed July 16, 1952 2 Sheets-Sheet 2

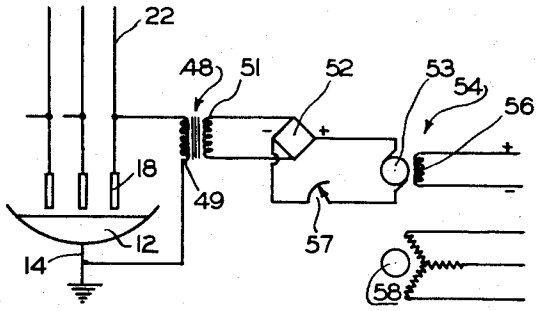


FIG. 4

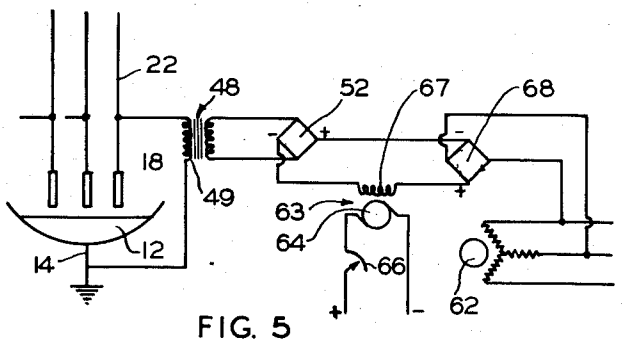


FIG. 5

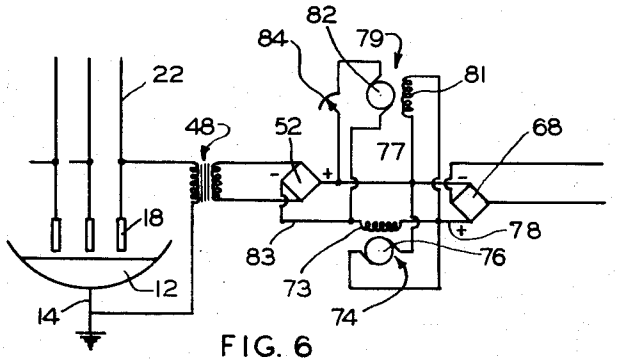


FIG. 6

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HYDRAULIC-ELECTRICAL APPARATUS FOR AUTOMATICALLY REGULATING THE POSITION OF DIRECT ARC ELECTRIC FURNACE ELECTRODES

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Application July 16, 1952, Serial No. 299,294

15 Claims. (Cl. 314—61)

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This invention refers to hydraulic-electrical apparatus for automatically regulating the position of direct arc electric furnace electrodes in such manner as to maintain the arc current and voltage substantially at predetermined levels.

Direct arc electric furnaces usually utilize three movable electrodes connected to a suitable three phase transformer, the electrodes being supported in an upright position by horizontal electrode arms extending across the roof of the furnace. The electrodes extend downwardly through the furnace roof into close proximity with a charge of metal in the furnace hearth and are moved upwardly and downwardly by suitable mechanism coupled to the electrode arms, the latter being suitably supported in guides for vertical movement. In some instances this movement is accomplished by cable and winch devices coupled to the arms, and in other instances by hydraulic piston and cylinder assemblies, the latter being considered preferable due to their greater responsiveness. Downward movement of the electrode is accomplished by withdrawing fluid from the hydraulic cylinder, allowing the electrode arm and electrode to move downward by gravity, reverse movement being accomplished by the introduction of liquid into the cylinder.

During operation of the furnace, the condition of the arc circuit through each electrode varies abruptly, thus necessitating rapid movement of the electrode to compensate for the change in circuit condition and return the circuit to the desired condition. Inadequate and improper response of the electrode may result in breaking of the arc, dipping the electrode into the molten metal, or shorting the arc circuit for excessive periods.

There are available conventional control devices for signaling changes in the condition of the arc circuit, these signals being amplified and transmitted to the motors and pumps or winches connected to the electrodes. The response of the system to such a signal is, however, not instantaneous, due to the inertia inherent in such devices, with the result that there is a considerable lag between the generation of such a signal and responsive movement of the electrode. The signaling devices currently employed, while satisfactory in some respects, are relatively expensive and complex.

An important object of this invention is to provide automatic electric-hydraulic electrode position control means for direct arc electric furnaces adapted for quickly changing the position of the electrode in response to a variation in the condition of the arc circuit with only a minimum of delay due to inertia and other causes.

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Another important object of this invention is to provide apparatus of the type described which is easily adjusted and relatively inexpensive, highly responsive, durable, efficient, and which moves the electrode at a rate proportional to the degree of variation of the arc circuit from normal.

A further important object of this invention is to provide improved electrical signaling means for controlling the electrode positioning means on a direct arc electric furnace.

Other important objects, as well as the many advantages of this invention, will be disclosed in the course of the following description and in the appended drawings, in which:

Fig. 1 is the diagrammatic elevation of an electric furnace illustrating the hydraulic electrode positioning apparatus;

Fig. 2 is a partial diagrammatic illustration of a modified form of hydraulic electrode positioning device;

Fig. 3 is a partial diagrammatic illustration of another modified form of hydraulic electrode positioning device;

Fig. 4 is a circuit diagram of a suitable electric control system for use with the hydraulic electrode positioning apparatus;

Fig. 5 is a circuit diagram of a modified form of control apparatus, and

Fig. 6 is a circuit diagram of another form of electrical control apparatus for use with the hydraulic electrode positioning apparatus.

In brief, this invention contemplates use of two electrically driven positive displacement hydraulic pumps disposed between the hydraulic electrode positioning cylinder and a fluid accumulator or reservoir. One of the pumps constantly forces fluid from the accumulator into the cylinder, while the other of the pumps constantly withdraws fluid from the cylinder and discharges into the accumulator. The electrode is elevated by allowing the rate at which fluid is discharged into the cylinder to exceed the rate at which fluid is discharged therefrom, the reverse action occurring when the cylinder is lowered. This variation in the effective rates of pump discharge is accomplished by varying the speed of either or both of the unidirectional motors coupled to the pumps. In its simplest form, a constant speed motor is coupled to a

small pump which discharges fluid into the cylinder. A shunt wound direct current motor having a constantly energized field is coupled to a second pump of somewhat larger capacity which withdraws fluid from the cylinder. The armature of the direct current motor is energized through a current rectifier by the secondary of a transformer, the primary of which is connected across the arc between the electrode and furnace ground. Variation in the arc thus varies the armature current of the direct current motor and increases or decreases the discharge rate of the second pump through a range which includes a point at which the volume discharges of the pumps are equal. As subsequently described, both motors may be made to vary oppositely in speed from the same signal, which increases the responsiveness of the system.

It will be noted that it is not necessary at any time to reverse the direction of rotation of either pump or motor. As a result, the delay of inertia usually encountered between transmission of the signal requiring a change of electrode position and the response of the electrode to such a signal is reduced. The rate at which the pumps respond to such signals is directly proportional to the strength of such signals which is in turn directly proportional to the degree of variation in the condition of the arc circuit. As a result, the rate of electrode movement is proportional to the variation in the arc circuit.

It will be understood that a complete hydraulic system and electrical control system is applied to each of the furnace electrodes. For simplicity, only one such system will be described, it being understood that three such units would be required to control the three electrodes of a three phase direct arc furnace.

Referring to Fig. 1, a conventional electric furnace shell 10 is lined with a refractory 11 and adapted to receive an electrically conductive charge, indicated at 12. A conventional ground rod 13 having a lead 14 extends through the shell 10 and refractory 11 into electrical contact with the charge 12. A roof 16 extends over the shell 10 and is provided with an opening 17 for an upright electrode 18 of carbon or graphite. A generally horizontal electrode arm 19 supports the electrode 18 and a bus 21, the latter being connected electrically to the electrode 18 and to flexible conductors 22, which communicate with the secondary of a power transformer 23. Variable impedance devices 25 of conventional design are inserted on either the primary or secondary side of the transformer 23 to limit and control the transformer. An upright channel 24 is coupled to the arm 19 and is mounted for generally vertical movement between rollers 26 rotatably carried by a bracket 27 on the shell 10. A ram cylinder 28 is supported within the channel 24 and is reciprocally sealed around a ram 29, the exposed end of which engages the channel 24 or the electrode arm 19 in such manner that upward movement of the ram 29 forces the arm 19 and electrode 18 upwardly.

An accumulator 31 is provided with an air inlet valve 32, a liquid outlet 33 and a liquid inlet 34. The outlet 33 is connected to a check valve 36 and to a second check valve 37, the former communicating with the inlet of a suitable positive displacement rotary liquid pump 38. The specific design of the positive displacement pump 38 is not critical and may suitably be either of the gear type or the vane type as desired. The outlet of the pump 38 communicates via a conduit 39 with an inlet 41 in the cylinder 28. An outlet 42 for the cylinder 28 communicates with a conduit 43, which in turn communicates with the inlet of a spring loaded check valve 44, the outlet of the check valve 37 and with an inlet for a rotary positive displacement liquid pump 46 similar to pump 38. The outlet side of the spring loaded check valve 44 communicates with the accumulator inlet 34 and with the discharge side of a second spring loaded relief valve 47, the inlet of which communicates with the outlet of the pump 46.

Referring to Fig. 4, a transformer 48 has a primary winding 49 connected to one of the conductors 22 as close to the electrode 18 as possible and to the lead 14 for the ground rod 13, thus placing primary winding 49 in shunt connection across an arc formed between the electrode 18 and the charge 12. The secondary winding 51 of the transformer 48 is connected to a rectifier 52, the output of which is connected to an armature 53 of a direct current motor generally designated as 54, preferably of the type having a shunt field winding 56. A variable resistor 57 is disposed in the output circuit of the rectifier 52 for varying the current flowing through the armature 53. The field winding 56 is preferably energized from a suitable constant source of direct current. The motor 54 is coupled directly to the pump 46 and rotates in such direction as to withdraw liquid from the cylinder 28, discharging into the accumulator 31. A constant speed alternating motor 58 is coupled to the pump 38 and rotates continuously at a substantially constant speed in such direction as to continuously force liquid from the accumulator 31 into the cylinder 28.

Although not essential in all instances, air under pressure can be introduced into the accumulator 31 through the valve 32, the relief valves 44 and 47 being then adjusted to prevent flow of liquid from the cylinder 28 into the accumulator 31 when the pumps 38 and 46 are not running. Usually, the pressure of the air in the accumulator 31 should be sufficient to only partially counterbalance the weight of the electrode 18 and arm 19. The electrode 18, at the initiation of furnace operation, is held above the charge 12 until the pumps 38 and 46 are placed in operation by energizing the motors 54 and 58. The output of the pump 46 under operating conditions should ordinarily be approximately twice the output of the pump 38, in order that it be able to overcome the effect of the pump 38 when motor 54 is operating at maximum speed. As the circuits to the electrode 18 and the motors 54 and 58 are first closed, there is no arc between the electrode 18 and the charge 12. Primary winding 49 of the transformer 48 will therefore receive maximum energization with the result that the full output of the recifier 52 is passed through the armature 53. Since the shunt winding 56 is already energized, the motor 54 will be driven at maximum speed, thus driving the pump 46 at such rate that its discharge substantially exceeds the discharge of the pump 38, which is driven at a constant speed by the motor 58. Liquid discharged by the pump 46 is forced through the relief valve 47 into the accumulator 31 for recirculation. Operation of the pump 46 under these conditions withdraws liquid from the cylinder 28, allowing the electrode to move downwardly at a rapid rate. At the moment the electrode 18 contacts the charge 12 the resistance between the electrode and the charge 12 falls to virtu-

ally zero, with the result that the current available to the primary 49 of the transformer 48 is substantially reduced. This reduces the current flowing to the armature 53, thus quickly reducing the motor speed and allowing the pump 38 to drive the ram 29 upwardly, thus drawing an arc between the electrode 18 and the charge 12. As the arc is drawn, the current flowing through the primary winding 49 gradually increases, which increases the speed of the motor 54 until the arc has reached the desired length, at which time the discharge of the pump 46 will be equal to the discharge of the pump 38. Should the arc break or fail to strike, motor 54 will quickly accelerate, thus again lowering the electrode and striking or re-establishing the arc. The operator can select the desired arc length by the manipulation of the resistor 57, which increases or decreases the speed of the motor 54.

Maintaining rotation of the motors 54 and 58 under virtually all operating conditions imparts to the device certain highly desirable characteristics. For example, when the motor is running, greater torque is available for effecting a change of speed. Also, the effect of "slip" or minor leakage in the pump is inconsequential. Since neither motor is at any time reversed, the undesirable friction and hydraulic phenomena experienced in passing such a rotating system through a stationary or motionless condition are avoided.

It will be noted that the function of the motor 58 and the pump 38 which it drives are to supply liquid under pressure at a constant rate to the cylinder 28. It is therefore possible to substitute for the pump 38 and motor 58 an orifice 59 (Fig. 3), provided pressure of air in accumulator 31 is maintained substantially constant and sufficient for forcing liquid into the cylinder 28 at the desired rate. A valve 61 may be interposed between the orifice 59 and the cylinder 28 blocking flow of fluid through the orifice. In this form of device the pump 38 is driven by motor 54, as previously described, and discharges into the accumulator 31 preferably through the spring loaded relief valve 47. Should the power supply fail, the electrodes will be automatically raised.

The speed of a direct current shunt wound motor may be varied and will increase within limits as the current to the armature is increased from a low initial point. Weakening the field of such a motor will also increase the motor speed, assuming constant armature energization. It is therefore possible, as illustrated in Fig. 5, to utilize a constant speed alternating motor 62 connected to the pump 46 for driving the electrode 18 downwardly, and a variable speed motor 63 coupled to the pump 38 for driving the electrode upwardly. The motor 63 in this instance is preferably a shunt wound direct current motor having an armature 64 connected through a suitable variable resistor 66 to a constant source of direct current. The transformer 48, as in Fig. 4, energizes rectifier 52 but in this instance the rectifier 52 is constructed in such manner as to have an output voltage equal only to approximately 50 per cent of that needed to fully energize a field winding 67 for the motor 63. The output of rectifier 52 is therefore connected in series with the field winding 67 and with a second rectifier 68 having a substantially equal voltage output but constantly energized from a suitable source. Under such circumstances the voltage output of the rectifiers 52 and 68 are added and when fully energized combine to supply the necessary maximum voltage of the field winding 67.

In operation, primary winding 49 of the transformer 48 will be fully energized when no arc exists between electrode 18 and the charge 12. Under such circumstances the output voltage of the rectifier 52 will be at a maximum, thus supplying in combination of this output of the rectifier 68 full energization to the field winding 67 of the motor 63 and holding this motor at its normal speed. The pump 46, driven by the motor 62, will thus be sufficient to move electrode 18 downwardly at the desired rate. As the electrode 18 contacts the charge 12, the energization of the transformer 48 will be greatly reduced, thus reducing the output of the rectifier 52 and weakening the field 67. This permits the motor 63 to increase its speed, thus raising the electrode 18 and drawing the arc. The energization of the field winding 67 varies only between limits, the lower limit being fixed by the output of rectifier 68.

Again it will be noted that the motor 62 driving the pump 46 serves only to discharge liquid into the accumulator 31 at a constant rate. An orifice 69 (Fig. 2) may therefore be substituted for the motor 62 and pump 46 if desired, it being understood that under such circumstances the pressure of air in the accumulator 31 is suitably reduced to permit the flow of fluid from the cylinder 28 to the accumulator 31 through the orifice 69. A valve 71 may be interposed between the orifice 69 and the cylinder 28 to check the flow of oil if desired. Pump 38 is, of course, coupled under such circumstances to the motor 63, the latter being energized as indicated in Fig. 5, and discharging through the spring loaded relief valve 72 similar to valve 47.

It has been demonstrated that the variation in the output of the transformer 48 may be made to increase or decrease the speed of a suitable direct current motor. It is also possible, as illustrated in Fig. 6, to utilize the output of the transformer 48 to accomplish both of these effects simultaneously in two motors, thereby still further increasing the speed of response of the system. As indicated in Fig. 6, the output of rectifier 52 is connected in series with a suitable source of direct current such as a constantly energized rectifier 68, the combined voltages of the two rectifiers being sufficient to energize a field winding 73 for a D. C. shunt wound motor 74 to its maximum degree, the winding 73 being inserted in series between the rectifiers 68 and 52. The motor 74 is coupled to pump 38 (Fig. 1), and utilizes an armature 76 connected across wire 77, which connects rectifier 52 with rectifier 68, and wire 78 which connects rectifier 68 with the field winding 73. The pump 46 is connected to a D. C. shunt wound motor 79 having a shunt field winding 81 in series with the armature 76. The armature 82 of the motor 79 is connected across the wire 77 and a wire 83, the latter connecting field winding 73 with the rectifier 52. A variable resistor 84 may be inserted in the circuit to the armature 82 for speed control.

When no arc exists between armature 18 and the charge 12 and the transformer 48 is fully energized, the maximum current will flow to the armature 82 of the motor 79 as well as to the field 73 of the motor 74. The speed of the motor 79 will therefore be at a maximum while the speed of the motor 74 is at a minimum, thus moving the electrode 18 downwardly at the desired maximum speed. As the electrode 18 contacts the charge 12 the output of the rectifier 52 is reduced, which not only reduces the current flowing to the armature 82, slowing down the motor 79, but

also weakens the field 73 which increases the speed of the motor 74, thus driving the electrode upwardly as in previous instances. Operation of the rheostat 84 by the operator controls position of the electrode 18 with respect to charge 12.

In the various modifications described it will be noted that a relationship must exist between the discharge volumes of the two pumps employed under various conditions, always including an intermediate condition in which the discharge volumes are equal. This can be obtained by various expedients. For example, referring again to Fig. 1, the pump 38 is driven at a constant speed by the motor 58 and therefore has a predetermined discharge volume to move the electrode downwardly. The discharge volume of the pump 46 must be capable of exceeding the discharge volume of the pump 38 and to move the electrode upwardly the volume of the pump 46 must fall below the discharge volume of the pump 38. If the motors 54 and 58 operate at the same normal maximum speeds, then the capacity of the pump 46 should be approximately twice the capacity of the pump 38, thus requiring the motor 54 to operate at only half of the normal speed to hold the electrode substantially motionless. If the pumps 46 and 38 are of the same capacity, then the normal maximum speed of the motor 54 driving pump 46 under the conditions described should be approximately twice the normal maximum speed of the motor 58. It will also be understood that other conventional flows of voltage regulating devices may be substituted for the variable resistors. For example, variable auto-transformers may be employed for this purpose in either the input or output circuits of the potential control transformers or substituted therefor.

The type of variable speed motor employed is not critical, although shunt wound direct current motors are generally most satisfactory. Compound wound or series wound motors may be substituted but in so doing certain potentially undesirable characteristics are unnecessarily added.

Furthermore, it will be noted that the control system herein described is applicable also to single and two phase electric furnace circuits.

From the foregoing it will be apparent to those skilled in the art that apparatus has been provided which to a marked degree attains the objectives of this invention. The sensitivity and high rate of response of the apparatus are effective in substantially reducing the violent current surges to which furnace electrode circuits are normally subject, not only in magnitude, but also in frequency and duration, resulting in a far more suitable and satisfactory circuit condition. The cost of the apparatus to perform these functions has been reduced appreciably and the apparatus simplified, the latter being reflected in reduced maintenance costs. The efficiency of the furnace is, of course, increased for various reasons including the ability of the control system to maintain the desired arc under virtually all circumstances. The improved electrode position control also permits better metallurgical control by avoiding dipping of the electrodes in the molten metal, and also prolongs the life of the refractory linings through better regulation of the heat developed by the arcs.

We claim:

1. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying electrode position, the improvement which includes first means for forcing liquid into the confining means, second means in hydraulic series with the first means for withdrawing liquid from the confining means, one of said first and second means comprising a positive displacement hydraulic pump and pump control means responsive to variations in the arcing gap varying the pump discharge volume through a range including an intermediate point at which the volume discharge of the first means equals the volume discharge of the second means.

2. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying electrode position, the improvement which includes first liquid metering means having an outlet, second liquid metering means having an inlet communicating with the outlet for said first means, both said inlet and said outlet communicating with the liquid confining means, one of said first and second metering means comprising a rotary positive displacement hydraulic pump and pump control means responsive to variations in the arcing gap varying the pump discharge volume through a range including an intermediate point at which the volume discharge of the first means equals the volume discharge of the second means.

3. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying electrode position, the improvement which includes first liquid metering means having an outlet, second liquid metering means having an inlet communicating with the outlet for said first means, both said inlet and said outlet communicating with the liquid confining means, one of said first and second means comprising a positive displacement hydraulic pump having a rotatable driving shaft and a unidirectional variable speed electric motor coupled to said driving shaft and control means responsive to variations in the arcing gap of the electrode varying the speed of said motor and thereby the discharge volume of the pump through a range including an intermediate point at which the volume discharge of the first means equals the volume discharge of the second means.

4. The structure defined in claim 3 wherein the other of said first and second means comprises an orifice and means maintaining the volume discharge of such orifice substantially constant.

5. The structure defined in claim 3 wherein the other of said first and second means comprises a second rotary positive displacement pump and a substantially constant speed motor coupled to said second pump.

6. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying electrode position, the improvement which includes first liquid metering means having an outlet, second liquid metering means hav-

ing an inlet communicating with the outlet for said first means, both said inlet and said outlet communicating with the liquid confining means, said first and second liquid metering means comprising first and second rotary positive displacement pumps, each coupled respectively to first and second motors, the speed of said motors being variable through a range including an intermediate point at which the volume discharge of the first pump is equal to the volume discharge of the second pump, and motor speed control means responsive to variations in the arcing gap of the electrode for simultaneously increasing the speed of one motor and decreasing the speed of the other motor.

7. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying electrode position, the improvement which includes first means for forcing liquid into said confining means, second means in hydraulic series with the first means for withdrawing liquid from the confining means, one of said first and second means comprising a positive displacement hydraulic pump, a transformer having a primary winding connected between the electrode and furnace ground, a variable speed motor coupled to said pump and energized by said transformer, the speed of said motor varying with the transformer output and through a range including an intermediate speed at which the discharge volume of the first means equals the discharge volume of the second means.

8. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap between the electrode and a grounded charge, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying the electrode position, the improvement which includes a first positive displacement pump having an outlet, a second positive displacement pump having an inlet communicating with the outlet of the first pump, both said inlet and said outlet communicating with the liquid confining means, liquid supply means for the first pump, first and second motors coupled respectively to the first and second pumps, one of said motors being a variable speed direct current motor and means responsive to variation in the arcing gap varying the speed of said motor through a range including an intermediate point at which the discharge volumes of said pumps are equal, said last mentioned means including a transformer connected between the electrode and furnace ground and a rectifier connected between the transformer and the variable speed motor.

9. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap between the electrode and a grounded charge, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying the electrode position, the improvement which includes a first positive displacement pump having an outlet, a second positive displacement pump having an inlet communicating with the outlet of the first pump, both said inlet and said outlet communicating with the liquid confining means, liquid supply means for the first pump, first and second motors coupled respectively to the first and second pumps, one of said motors being a direct current motor having an armature and a field, a substantially constant current source connected to the field and variable armature current supply means responsive to variations in the arcing gap for varying the speed of said motor and thereby the discharge volume of the pump through a range including an intermediate point at which the discharge volumes of said pumps are equal.

10. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap between the electrode and a grounded charge, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying the electrode position, the improvement which includes a first positive displacement pump having an outlet, a second positive displacement pump having an inlet communicating with the outlet of the first pump, both said inlet and said outlet communicating with the liquid confining means, liquid supply means for the first pump, first and second motors coupled respectively to the first and second pumps, one of said motors being a direct current motor having an armature and a field, a substantially constant current source for said armature and variable field current supply means responsive to variations in the arcing gap for varying the speed of said motor and thereby the discharge volume of the pump through a range including an intermediate point at which the discharge volumes of said pumps are equal.

11. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap between the electrode and grounded charge, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying the electrode position, the improvement which includes a first positive displacement pump having an outlet, a second positive displacement pump having an inlet communicating with the outlet of the first pump, both said inlet and said outlet communicating with the liquid confining means, liquid supply means for the first pump, first and second motors coupled respectively to the first and second pumps, one of said motors being a direct current motor having an armature and a field, a substantially constant current source connected to the field and variable armature current supply means responsive to variations in the arcing gap for varying the speed of said motor and thereby the discharge volume of the pump through a range including an intermediate point at which the discharge volumes of said pump are equal, said variable armature current supply means include a transformer connected between the electrode and furnace ground and a rectifier connected between the transformer and said armature.

12. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap between the electrode and a grounded charge, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying the electrode position, the improvement which includes a first positive displacement pump having an outlet, a second positive displacement pump having an inlet communicating with the outlet of the first pump, both said inlet and said outlet communicating with the liquid confining means, liquid supply means for the first pump, first and second motors coupled respectively to the first and second pumps, one of said motors

being a direct current motor having an armature and a field, a substantially constant current source for said armature and variable field current supply means responsive to variations in the arcing gap for varying the speed of said motor and thereby the discharge volume of the pump through a range including an intermediate point at which the discharge volumes of said pumps are equal, said variable field current supply include a transformer connected between the electrode and furnace ground and a rectifier connected between the transformer and said field.

13. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap between the electrode and a grounded charge, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying the electrode position, the improvement which includes a first positive displacement pump having an outlet, a second positive displacement pump having an inlet communicating with the outlet of the first pump, both said inlet and said outlet communicating with the liquid confining means, liquid supply means for the first pump, first and second motors coupled respectively to the first and second pumps, both of said motors having direct current field and armature windings, a substantially constant current source connected to the field of the first motor and to the armature of the second motor and a variable control current source connected with the armature of the first motor and the field of the second motor, said control current being variable responsive to variation in the arcing gap for simultaneously varying the speeds of said motors inversely through a range including an intermediate point at which the output volumes of said pumps are equal.

14. In an electric arc melting furnace of the type having an electrode movable for varying the arcing gap between the electrode and a grounded charge, conductor means for supplying electric current to the electrode and telescopic liquid confining means coupled to the electrode for varying the electrode position, the improvement which includes a first positive displacement pump having an outlet, a second positive displacement pump having an inlet communicating with the outlet of the first pump, both said inlet and said outlet communicating with the liquid confining means, liquid supply means for the first pump, first and second motors coupled respectively to the first and second pumps, both of said motors having direct current field and armature windings, a substantially constant current source connected to the field of the first motor and to the armature of the second motor, a variable control current source connected to the armature of the first motor and to the field of the second motor and means for maintaining a predetermined minimum energization of the field of said second motor, said control current being variable responsive to variation in the arcing gap for varying the speeds of said motors inversely through a range including an intermediate point at which the output volumes of said pumps are equal.

15. The structure defined in claim 13 in which the variable control current source includes a transformer having a primary winding connected between the electrode and furnace ground, a secondary winding and a rectifier energized by the said secondary.

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