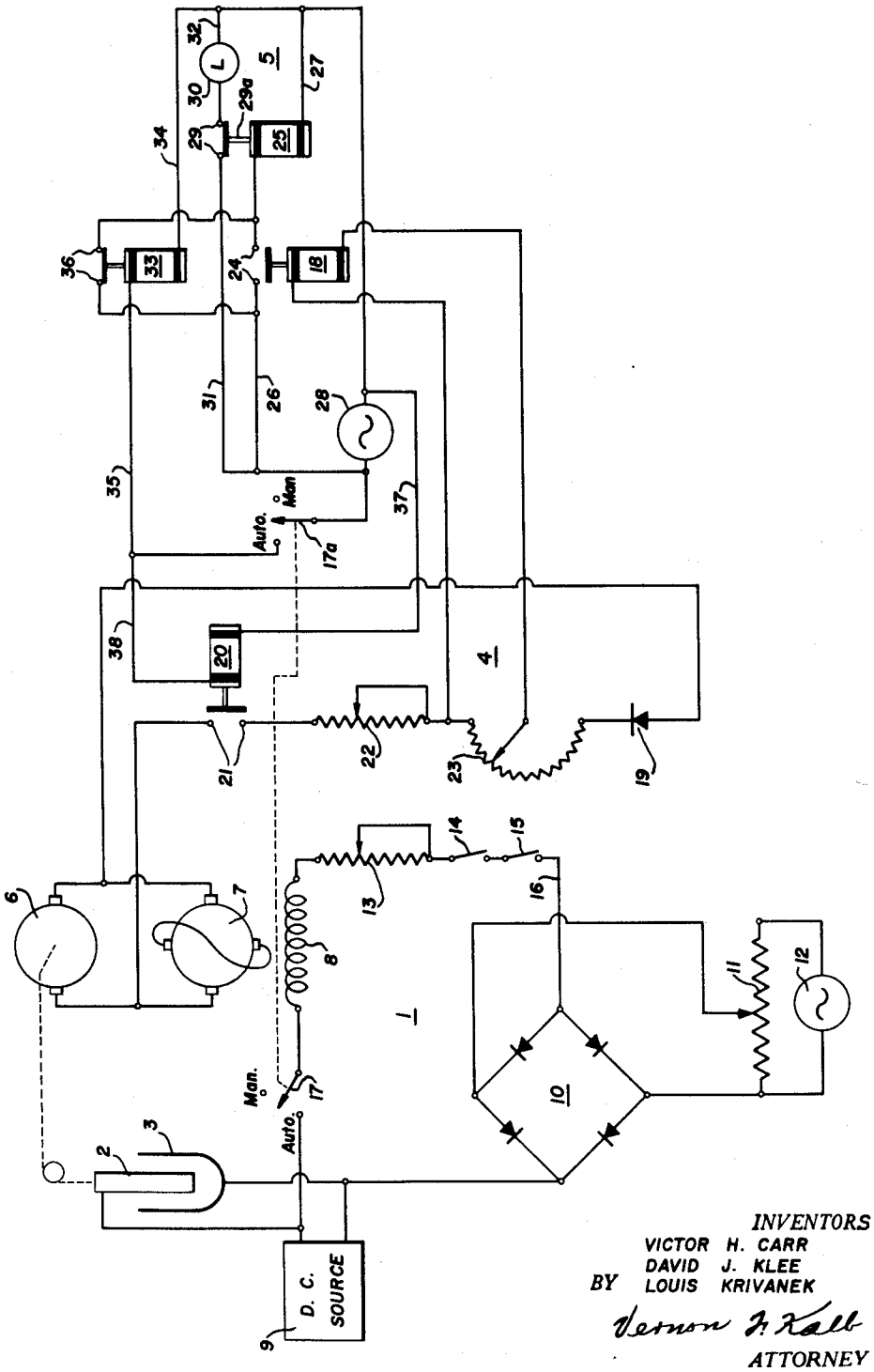
June 21, 1960 V. H. CARR ET AL 2,942,138

ELECTRODE DRIVE CONTROL CIRCUIT

Filed June 29, 1959



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United States Patent Office 2,942,138 Patented June 21, 1960

2,942,138

ELECTRODE DRIVE CONTROL CIRCUIT

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Filed June 29, 1959, Ser. No. 823,375

11 Claims. (Cl. 314—69)

The present invention relates to electrode drive control circuits, and more particularly to control circuits for the electrode drive of a consumable electrode type electric arc furnace.

In an electric arc furnace of the consumable electrode type, the heat for the furnace is provided by an electric arc between a molten pool of metal, that serves as one electrode for the arc, and a second electrode that is movable relative to the molten pool of metal. The second electrode is consumed by the heat of the arc, so for proper operation of such a furnace, which, among other things, requires a constant arc voltage to be applied between the two electrodes, the position of the second electrode must be adjusted relative to the molten pool to compensate for the consumption of the electrode. The metallurgical characteristics of the molten pool of metal, and consequently of the ingot formed, are affected if the distance between the second electrode and the molten pool is not accurately controlled. In particular, if the distance between the second electrode and the pool is allowed to become too large, a glow discharge condition may be established which may make the resultant ingot metallurgically unacceptable if the condition is not corrected almost immediately after it is established. Furthermore, safety of operation necessitates accurate control of the electrode, since, if the arc gap is too long, there may be a tendency of the arc to wander from the center of the pool toward the wall of the crucible with the attendant possibility of a burn-through of the crucible wall. On the other hand, if the arc gap becomes so small that the movable electrode touches the pool, the electrode may become welded to the molten pool, as the metal therein cools due to the arc being extinguished by such contact.

One known method of providing an accurate automatic control of electrode movement is to connect a control circuit that is responsive to the arc voltage to an electrode drive mechanism so that the electrodes are driven apart if the arc voltage falls below a predetermined level and driven toward one another if the arc voltage rises above a predetermined level. While such a control circuit is generally satisfactory for normal furnace operation, it does not perform certain functions which it is desirable to provide for purposes of ease and safety of operation. For example, when a glow discharge condition occurs between the electrodes, the arc voltage drops and thus causes such a drive mechanism to drive the electrodes apart, or at least stop them from being driven toward one another. Such a reversal or stoppage of the electrode movement is undesirable, because it promotes the growth of the glow discharge condition rather than counteracting its growth, and thus causes a metallurgically unacceptable ingot to be formed.

Apparatus has been developed in the prior art for detecting a glow discharge condition in arc furnaces; however, all such apparatus heretofore has been characterized by having a relatively slow response time that frequently allows the glow discharge condition to grow to

destructive magnitude before it is detected. Consequently, manufacturers have been confronted with the problem that an ingot formed during a manufacturing run in which a glow discharge condition occurs has often been metallurgically unacceptable.

A solution to this problem is provided by our invention which provides means for detecting a glow discharge condition in an arc furnace within a very short interval of time after such a condition has started; therefore, the furnace operator is alerted to take corrective measures before the condition can grow to a sufficient magnitude to damage the ingot.

Accordingly, it is a specific object of our invention to provide in an automatic electrode drive control system of the type which is responsive to relative movement between the two electrodes of an arc furnace, an improved control circuit whereby a glow discharge condition is detected within a predetermined time interval such that harmful effects resulting from the glow discharge condition are prevented.

It is another object of our invention to provide, in a control system of the type just described, an improved arrangement for continuously monitoring the relative movement between two electrodes and for energizing a signal if the relative movement varies from a predetermined desirable pattern of operation.

It is a further object of our invention to provide a drive control circuit for relatively movable members, which has time delay signal actuating means responsive to a deviation from the normal operating condition of the movable member drive to energize a signal which informs an operator of the abnormal condition.

Further objects and advantages of our invention will become apparent as the following description proceeds and the features of novelty which characterize our invention will be pointed out with particularity in the claims annexed to and forming a part of this specification.

In carrying out the objects of our invention in one form thereof, there is provided a basic type of automatic control circuit for an electrode drive, which is known in the prior art and which generally comprises an amplidyne, the armature of which is connected to a reversible direct current motor, which in turn is drivingly coupled to one of a pair of electrodes. The field current of the amplidyne is responsive to variations between a fixed reference voltage and the arc voltage between the pair of electrodes so that when the reference voltage is higher than the arc voltage, the motor will be energized by the amplidyne to effect separation of the electrodes, while if the arc voltage is higher than the reference voltage, the motor will drive the electrodes toward one another.

To the basic electrode drive control circuit is added a circuit which provides means for detecting a glow discharge condition, and means for signalling an operator within a predetermined timed interval of short duration, while at the same time allowing the basic drive control circuit to effect frequent stoppages or reversals in the direction of the relative movement of the electrodes, without causing the signal means to be sporadically actuated by such normal operation.

Briefly stated, to the basic electrode drive control circuit has been added a circuit that detects either a reversal in the direction of relative motion between the pair of electrodes (assuming the electrodes are moving toward one another), or a stoppage of relative motion between the electrodes, such as will occur if a glow discharge condition exists between the electrodes. This motion detecting circuit is connected to another circuit containing time delay means for actuating a signal. In operation, the motion detecting circuit responds to a stoppage or reversal in the direction of the relative movement of the electrodes by actuating the time delay circuit,

The time delay circuit, when thus actuated, initiates a timed signal actuating cycle of predetermined duration. If no further actuation is received by the time delay circuit from the motion detecting circuit, the signal means is actuated by the time delay circuit at the end of the predetermined timed interval to inform an operator of the abnormal electrode movement and the possible glow discharge condition of which it may be indicative. If, however, prior to the expiration of the predetermined timed interval, the electrodes again move toward one another, the motion detecting circuit will respond to this movement by causing the time delay circuit to terminate the timed signal actuating cycle and reset the timing mechanism.

For a complete understanding of the invention, together with objects and advantages thereof, reference is made to the following description, taken in conjunction with the accompanying drawing which depicts in schematic form an electrode drive control circuit embodying our invention.

With reference to the drawing, we have shown a basic type of electrode drive control circuit **1** for effecting relative movement between an electrode **2** and a crucible **3**. In addition to the basic drive control circuit, we have shown an electrode motion detecting circuit **4**, and a time delay signal actuating circuit **5**. These added circuits, **4** and **5**, operate in conjunction to detect an abnormal rate of movement between electrode **2** and crucible **3**, such as will result if a glow discharge condition occurs between these elements, and to signal an operator if such a condition prevails for a predetermined interval of time.

The illustrated basic electrode drive control circuit **1** comprises a reversible direct current motor **6** drivingly coupled to the electrode **2** and energized by an amplidyne **7**. The primary amplidyne control field **8**, which determines the output voltage polarity of amplidyne **7**, and consequently the direction of rotation of motor **6**, is energized by both a direct current source **9** and the output of a bridge rectifier **10**. The input terminals of rectifier **10** are supplied through auto-transformer **11** from an alternating current source **12** of reference voltage. The relative magnitude of the reference voltage, as adjusted by auto-transformer **11**, and the voltage of the direct current source **9** determines the direction of current through amplidyne field **8**. In addition to the foregoing components, the basic drive control circuit comprises means for electrically connecting one side of control field **8** through a variable resistor **13**, a pair of series-connected normally closed electrode movement limit switches **14** and **15**, a line **16**, and rectifier **10** to one side of power source **9**. The other side of control field **8** is electrically connected through automatic-manual switch **17** (**17** is shown on the drawing as having an "auto" and a "man" position) to the other side of direct current source **9**. Direct current source **9**, in addition to supplying control field **8**, provides the arc voltage to form an arc between electrode **2** and crucible **3**, or the contents thereof.

In operation, the basic electrode drive control circuit **1** is utilized to maintain a predetermined spacing between electrode **2** and crucible **3** by adjusting auto-transformer **11** to a reference voltage consistent with such spacing. After the circuit is thus oriented, if the arc voltage becomes larger than the reference voltage, current through the amplidyne field **8** will be in a direction to effect energization of the motor **6** in an electrode lowering direction. Conversely, when the arc voltage is lower than the reference voltage, current passes through the field **8** in the opposite direction to effect raising of the electrode **2**. Thus, an automatic adjustment of electrode position is provided in response to a differential between arc voltage and a predetermined reference voltage.

The motion detecting circuit **4**, which detects any variation in motion or direction of movement of electrode **2** and actuates time delay signally circuit **5** in response to such variations, comprises a voltage responsive relay **18** electrically connected in series with a unidirectional current passing means, shown as a rectifier **19**, across the output of amplidyne **7**. This circuit arrangement causes relay **18** to be energized when the output voltage of amplidyne **7** is of one polarity, while causing relay **18** to be de-energized when the output voltage of amplidyne **7** is zero or of the opposite polarity. It is thus apparent, since the direction of rotation of motor **6**, and consequently the movement or direction of movement of electrode **2**, is also dependent upon the magnitude or polarity of the output voltage of amplidyne **7**, that the energization of relay **18** is a direct function of the movement of electrode **2**.

In addition to these components of motion detecting circuit **4**, namely, rectifier **19** and voltage responsive relay **18**, this circuit includes the normally open contacts **21** of relay **20**. The contacts **21** are in series with these components (**18** and **19**) to prevent high voltage surges across these components in a manner that will be more fully described below. In order to regulate the sensitivity of relay **18** to variations of the output voltage of amplidyne **7**, there is arranged in series with rectifier **19** and relay **18** a variable current limiting resistor **22** and a portion of the resistance of potentiometer **23**. The remaining portion of the resistance of potentiometer **23** is placed in parallel with relay **18**. The movable contact of potentiometer **23** is connected to one side of the actuating coil of relay **18** and the other side of the actuating coil of relay **18** is connected to the fixed terminal of potentiometer **23** that is common with one end of variable resistor **22**. A coarse adjustment of the sensitivity of relay **18** to variations in the output voltage of amplidyne **7** is afforded by varying the value of resistor **22**. For example, by reducing the value of resistance **22** in series with relay **18**, a greater sensitivity of the relay is obtained. A finer adjustment of the sensitivity of relay **18** is obtained by varying the value of potentiometer **23**. For example, to increase the sensitivity of relay **18** to variations in the output voltage of amplidyne **7**, the resistance of potentiometer **23** that is placed in parallel with the actuating coil of relay **18** is increased.

The time delay signalling circuit **5**, which is responsive to the energization of relay **18** and, therefore, to variations in the relative movement of electrode **2**, serves to signal an operator if an abnormal variation in relative electrode movement continues for a predetermined length of time. The time delay circuit **5** is made directly responsive to the motion detecting circuit **4** by arranging normally open contacts **24** of relay **18** in series with the actuating coil of time delay relay **25**. These components, **24** and **25**, are connected to opposite sides of a power source **28** by lines **26** and **27** respectively. Relay **25** is of the time closing type, so its armature **29***a* will be biased to the closed position on contacts **29** when the actuating coil of relay **25** is de-energized, and the armature **29***a* will be held open when the actuating coil is energized. In order to provide an indication of abnormal electrode movement, a signal means, shown as a lamp **30**, is arranged in series with contacts **29** and these components, **29** and **30**, are connected by lines **31** and **32** respectively to opposite sides of power source **28**.

It will be apparent that when relay **18** is energized to close its contacts **24** the actuating coil of time delay relay **25** will be energized to open contacts **29** by moving armature **29***a* away from contacts **29** so that the lamp **30** is de-energized. Now, if relay **18** is de-energized due to a variation in the voltage of amplidyne **7**, as described above, contacts **24** will open and relay **25** will be de-energized. When relay **25** is de-energized, armature **29***a* will start to close contacts **29**, but since relay **25** is a time closing relay, this closing cycle takes a predetermined length of time dependent upon the initial setting of the timing means (not shown) of relay

25. If relay 18 is not re-energized before the expiration of the predetermined interval of time required for armature 29*a* to close contacts 29, lamp 30 will be energized by the closing of contacts 29 and the operator will thus be informed of the abnormal electrode movement. However, if relay 18 is re-energized prior to the expiration of the time closing interval, contacts 24 will be reclosed and relay 25 will be re-energized thus resetting the time closing cycle of armature 29*a* to contacts 29 so when relay 25 is again de-energized, the entire predetermined interval of time will have to expire before lamp 30 is energized. During normal operation of the furnace, the signal lamp will never be lit because electrode 2 will always move toward crucible 3 at least once during the interval of time required for solenoid armature 29*a* to close contacts 29, and thus continually reset armature 29*a* so it never engages contacts 29.

The function of relay 33 is to properly orient the time delay circuit 5 when switch 17*a* is moved from its "auto" to its "man" position. (It will be understood that the schematically indicated switches 17 and 17*a* are intended to be parts of a single control switch so they open and close in unison.) The actuating coil of relay 33 is connected by line 34 to one side of source 28 and by line 35 through "auto" position of switch 17*a* to the opposite side of source 28. Normally closed contacts 36 of relay 33 are arranged in parallel with normally open contacts 24 of relay 18 so that when switch 17*a* is moved from its "auto" to its "man" position, the actuating coil of time delay relay 25 will be energized through contacts 36 to effect opening of contacts 29 and the de-energization of lamp 30. The time delay signal circuit 5 is thus reset for another cycle of automatic operation when switch 17*a* is moved from its "man" to its "auto" position.

As mentioned above, the normally open contacts 21 of relay 20 are in series with the rectifier 19 and the actuating coil of relay 18 of the motion detecting circuit 4. The actuating coil of relay 20 is connected by line 37 to one side of power source 28, and by line 38 through the "auto" position of switch 17*a* to the other side of power source 28. By placing contacts 21 of relay 20 in series with the actuating coil of relay 18 and rectifier 19, the circuit across the output of amplidyne 7 is interrupted when switch 17*a* is in its "man" position. Such a circuit interruption is desirable, because manual adjustment of electrode 2 may result in high voltages across amplidyne 7 that would damage either relay 18 or rectifier 19.

The overall operation of the basic electrode drive control circuit, the motion detecting circuit, and the time delay signalling circuit is as follows:

To initiate operation of the electrode drive control circuit to effect a melting operation in the crucible 3, switch 17—17*a* is placed in its "man" position and power sources 9, 12, and 28 are energized. Switch 17—17*a* is then moved to its "auto" position which, since the electrode 2 is out of contact with the contents of crucible 3 and an arc has not been initiated, will cause current through amplidyne field 8 in such a direction that the amplidyne 7 energizes the drive motor 6 to lower electrode 2 toward crucible 3. Electrode 2 will be driven toward crucible 3 until it contacts the contents of the crucible 3, because, until this occurs, no arc is formed between electrode 2 and the contents of crucible 3. The voltage between these members (2 and 3) is much higher than the reference voltage of source 12 prior to the formation of an arc. When electrode 2 contacts the contents of crucible 3, the arc voltage drops to zero and the motor 6 is reversed due to the reversal of current through amplidyne field 8. Motor 6 raises the electrode 2 away from the crucible 3 until the arc voltage equals the reference voltage and then drives the electrode 2 toward the crucible 3 at a rate that compensates for the consumption of electrode 2.

The closing of switch 17—17*a* to its "auto" position also energizes the actuating coil of relay 20 to thus close contacts 21 and place the series connected rectifier 19 and relay 18 of the motion detecting circuit 4 across the output terminals of amplidyne 7. In addition, the actuating coil of relay 33 is energized by the closing of switch 17*a* and opens contacts 36 to thus de-energize the actuating coil of the time delay relay 25, and initiate the time closing of the contacts 29 of time delay relay 25.

In normal operation of the arc furnace, the electrode 2 will move toward the crucible 3 at a rate commensurate with the rate of consumption of the electrode 2. During such normal operation, although the direction of movement of electrode 2 is predominantly toward crucible 3, the electrode movement will be stopped frequently and may even be reversed for short intervals of time. The voltage across the armature of amplidyne 7 will, therefore, be such that either a continuous current or closely spaced pulses of current will be passed through rectifier 19 and the actuating coil of relay 18. Therefore, due to the adjustment of potentiometer 23, contacts 24 will be either continuously closed or closed at frequent closely spaced intervals to energize the time delay relay 25 and prevent it from closing contacts 29. However, if a glow discharge condition occurs between the electrode 2 and either the contents of crucible 3 or the contents and the sides of crucible 3, the voltage between these members will drop to such a level that current through control field 8 of amplidyne 7 will either cease or the direction of current through field 8 will be reversed. Either of these conditions will cause a voltage to appear across the armature of amplidyne 7 such that rectifier 19 will prevent any current through the actuating coil of relay 18; therefore, this relay will open contacts 24 and thus de-energize the coil of the time delay relay 25 and initiate a timed closing interval of contacts 29. If the glow discharge condition continues, the electrode 2 will not move toward the crucible 3 to cause a reversal of current through control field 8 of amplidyne 7, so the actuating coil of relay 18 will not be energized during the timed interval required for armature 29*a* to close contacts 29, and the signal lamp 30 will be energized through contacts 29 and lines 31 and 32 to thus inform an operator that the furnace is operating in an abnormal condition.

To correct the abnormal condition, the operator switches switch 17—17*a* to its "man" position and manually moves the electrode toward the crucible 3 a sufficient distance to re-establish a normal arc between electrode 2 and the contents of crucible 3. Due to the fact that the glow discharge condition is detected in its early stages by the sensitive actuation of the motion detecting circuit made possible by the fine adjustment of potentiometer 23 and the coarser adjustment of variable resistor 22, it is not necessary, and usually not desirable, to interrupt the arc between the electrode 2 and the contents of crucible 3; therefore, switch 17—17*a* is not provided with contacts that interrupt the arc voltage. When switch 17—17*a* is moved from its "auto" position to its "man" position following the energization of signal lamp 30, the actuating coil of relay 33 is de-energized and normally closed contacts 36 are thus allowed to close. The closing of contacts 36 establishes a circuit from the power source 28 through line 26 to the actuating coil of the time delay relay 25 and thence through line 27 to the opposite side of the power source 28, so the time delay relay 25 is again energized or reset and opens contacts 29 by moving armature 29*a* away from contacts 29, thereby to extinguish signal lamp 30. The control circuit is thus reset so switch 17—17*a* can be moved to its "auto" position again and normal operation of the furnace continued.

While we have shown and described a particular embodiment of our glow discharge detection circuit, it will be obvious to those skilled in the art that various modi-

fications may be made in our circuit without departing from our invention in its broader aspects. For instance, the time delay signal actuating means could be coupled through mechanical means, such as a slip clutch, to the movable electrode thereby to afford means, other than the disclosed voltage responsive means, for detecting a stoppage in the movement or a reversal in the direction of movement of the electrode. In such an arrangement, it is apparent that the clutch mechanism could be directly coupled to a means for resetting the time delay relay. Furthermore, it will be apparent that while the disclosed invention is particularly applicable to the control of the electrode movement of an arc furnace, it is not limited to such an application, but rather may be utilized to control the movement of any apparatus that is designed to move at a relative constant rate in a given predetermined direction, or that is designed to move predominantly in a single given direction with only brief intervals of reversal in direction or stoppage of movement occurring during normal operation.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. In an automatic control system for an arc furnace having two relatively movable electrodes, means for applying an arc voltage across said electrodes, means for providing a reference voltage, means for comparing the arc voltage with the reference voltage, control means responsive to the relative magnitudes of the arc voltage and the reference voltage for moving said electrodes toward each other when the arc voltage is greater than the reference voltage and for moving said electrodes away from each other when the arc voltage is lower than the reference voltage, signal means for indicating an abnormal condition, time delay means for energizing said signal means following a predetermined time interval after actuation of said time delay means, means dependent upon relative movement of the electrodes for actuating said time delay means and initiating said predetermined time interval when movement of said electrodes toward each other ceases, and means responsive to resumption of movement of said electrodes toward each other for resetting the time delay means, said time delay means effecting actuation of said signal means unless said resetting means is actuated prior to the expiration of said predetermined time interval.

2. In an automatic control system for an arc furnace having two relatively movable electrodes, means for applying an arc voltage across said electrodes, means for providing a reference voltage, means for comparing the arc voltage with the reference voltage, control means responsive to the relative magnitude of the arc voltage and the reference voltage for moving said electrodes toward each other when the arc voltage is greater than the reference voltage and for moving said electrodes away from each other when the arc voltage is lower than the reference voltage, signal means for indicating an abnormal condition, time delay means for energizing said signal means following a predetermined time interval after actuation of said time delay means, means dependent upon movement of the electrodes for energizing said time delay means when said electrodes move toward each other, said movement dependent means being operable to de-energize said time delay means and initiate said predetermined time interval when movement of said electrodes toward each other ceases, and means responsive to resumption of movement of said electrodes toward each other for resetting the time delay means, said time delay means effecting actuation of said signal means unless said resetting means is actuated prior to the expiration of said predetermined time interval.

3. In an automatic control system for an arc furnace having two relatively movable electrodes, means for applying an arc voltage across said electrodes, means for providing a reference voltage, means for comparing the arc voltage with the reference voltage, control means responsive to the relative magnitudes of the arc voltage and the reference voltage for moving said electrodes toward each other when the arc voltage is greater than the reference voltage and for moving said electrodes away from each other when the arc voltage is lower than the reference voltage, signal means for indicating an abnormal condition, time delay means for energizing said signal means following a predetermined time interval after actuation of said time delay means, means electrically connected to said control means for actuating said time delay means and initiating said predetermined time interval when movement of said electrodes toward each other ceases, and means responsive to resumption of movement of said electrodes toward each other for resetting the time delay means, said time delay means effecting actuation of said signal means unless said resetting means is actuated prior to the expiration of said predetermined time interval.

4. In an automatic control system as defined in claim 3, means for varying the duration of the predetermined time interval, and means for varying the sensitivity of the time delay actuating means.

5. In an automatic control system for an arc furnace having two relatively movable electrodes, means for applying an arc voltage across said electrodes, means for providing a reference voltage, means for comparing the arc voltage with the reference voltage, control means responsive to the relative magnitudes of the arc voltage and the reference voltage for moving said electrodes toward each other when the arc voltage is greater than the reference voltage and for moving said electrodes away from each other when the arc voltage is lower than the reference voltage, signal means for indicating an abnormal condition, time delay means for energizing said signal means following a predetermined time interval after actuation of said time delay means, voltage responsive means and unidirectional current passing means electrically connected to said control means for controlling said time delay means, said voltage responsive means and said unidirectional current passing means being effective to actuate said time delay means and initiate said predetermined time interval when the electrodes become stationary and to reset the time delay means when the electrodes move toward each other, whereby said time delay means effects actuation of said signal means unless said time delay means is reset prior to the expiration of said predetermined time interval.

6. In an automatic control system for an arc furnace having two relatively movable electrodes, means for applying an arc voltage across said electrodes, means for providing a reference voltage, control means responsive to the relative magnitudes of the arc voltage and the reference voltage for moving said electrodes toward each other when the arc is greater than the reference voltage and for moving said electrodes away from each other when the arc voltage is lower than the reference voltage, said control means including a direct current motor for driving at least one of said electrodes, signal means for indicating an abnormal condition, means for energizing said signal means following a predetermined time interval after actuation of said time delay means, voltage responsive means and unidirectional current passing means electrically connected to said control means whereby current is passed through the voltage responsive means when the polarity of the voltage across the motor is such that the motor drives the electrodes together and current through the voltage responsive means is prevented when the polarity of the voltage across the motor is such that the motor drives the electrodes apart, said voltage responsive means and said unidirectional current passing means being effective to actuate said time delay means and initiate the predetermined time interval when the electrodes become stationary and to reset the time delay means when the electrodes move toward each other,

whereby said time delay means effects actuation of said signal means unless said time delay means is reset prior to the expiration of said predetermined time interval.

7. In an automatic control system for an arc furnace having two relatively movable electrodes, means for applying an arc voltage across said electrodes, means for providing a reference voltage, means for comparing the arc voltage with the reference voltage, control means responsive to the relative magnitude of the arc voltage and the reference voltage for moving the electrodes toward each other when the arc voltage is greater than the reference voltage and for moving the electrodes away from each other when the arc voltage is lower than the reference voltage, signal means for indicating an abnormal condition, a time delay closing relay having an actuating coil and a pair of normally closed contacts, means for energizing the relay and the signal means, means for electrically connecting the normally closed relay contacts and the signal means in series across the relay energizing means whereby the signal means is energized following a predetermined time interval after actuation of said time delay relay, a voltage responsive relay having an actuating coil and a pair of normally open contacts, unidirectional current passing means, means for electrically connecting the actuating coil of said voltage responsive relay in series with the unidirectional current passing means, means for electrically connecting the normally open contacts of the voltage responsive relay in series with the actuating coil of the time delay relay, and means for electrically connecting the series connected unidirectional current passing means and the actuating coil of the voltage responsive relay to the control means to provide a current through the actuating coil of the voltage rseponsive relay to energize and reset the time delay relay when the arc voltage is less than the reference voltage and to prevent current through said actuating coil when the arc voltage is greater than the reference voltage, whereby said time delay relay effects actuation of said signal means unless said time delay relay is reset prior to the expiration of said predetermined time interval.

8. In an automatic control system for an arc furnace having two relatively movable electrodes, means for applying an arc voltage across said electrodes, means for providing a reference voltage, means for comparing the arc voltage with the reference voltage, control means responsive to the relative magnitudes of the arc voltage and the reference voltage for moving the electrodes toward each other when the arc voltage is greater than the reference voltage and for moving the electrodes away from each other when the arc voltage is lower than the reference voltage, an electric lamp for indicating an abnormal condition, a time delay relay for energizing said lamp following a predetermined time interval after actuation of said time delay relay, voltage responsive means for controlling the actuation of the time delay relay, unidirectional current passing means for controlling the energization of the voltage responsive means, and means for electrically connecting the voltage responsive means and the unidirectional current passing means to the control means for controlling said time delay relay, said voltage responsive means and said unidirectional current passing means being effective to initiate said predetermined time interval when movement of said electrodes toward each other ceases and to energize and reset said time delay relay when said electrodes move toward each other, said time delay relay effecting energization of said electric lamp unless said resetting means is actuated prior to the expiration of said predetermined time interval.

9. In an automatic control system for regulating relative movement between two members, control means for effecting movement of one of said members, signal means for indicating an abnormal condition, time delay means for actuating said signal means following a predetermined time interval after actuation of said time delay means, means responsive to relative movement between said members in a first direction with respect to one of the members for actuating said time delay means to initiate said predetermined time interval, and means responsive to relative movement between the two members in a second direction with respect to said one of the members for resetting the time delay means, said time delay means effecting actuation of said signal means unless said second direction of relative movement occurs prior to the expiration of said predetermined time interval.

10. In an automatic control system for regulating relative movement between two members, an electric motor for effecting movement of one of said members, means for energizing said motor, signal means for indicating an abnormal condition, time delay means for actuating said signal means following a predetermined time interval after actuation of said time delay means, and unidirectional current passing means electrically connected in series with voltage responsive means and connected to the motor energizing means for controlling said time delay means, said voltage responsive means being responsive to a stoppage of current through the unidirectional current passing means to actuate said time delay means to initiate said predetermined time interval, said voltage responsive means being responsive to current through the unidirectional current passing means to reset the time delay means, said time delay means effecting actuation of said signal means unless current passes through the unidirectional current passing means prior to the expiration of said predetermined time interval.

11. In an automatic control system for regulating relative movement between two members, an electric motor for effecting movement of one of said members, signal means for indicating an abnormal condition, a time delay relay for energizing said signal means following a predetermined time interval after actuation of the time delay relay, unidirectional current passing means electrically connected to the electric motor, a voltage responsive relay electrically connected in series with the unidirectional current passing means for controlling the energization of said time delay relay, said voltage responsive relay being operable to de-energize the time delay relay to initiate said predetermined time interval when the unidirectional current passing means blocks current from the voltage responsive relay, said voltage responsive relay being further operable to energize the time delay relay to reset said relay when the unidirectional current passing means passes current to the voltage responsive relay, whereby the time delay relay actuates the signal means unless the drive motor is energized to cause current to pass through the unidirectional current passing means and voltage responsive relay prior to the expiration of the predetermined time interval.

No references cited.