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ELECTRIC RESISTANCE FURNACE

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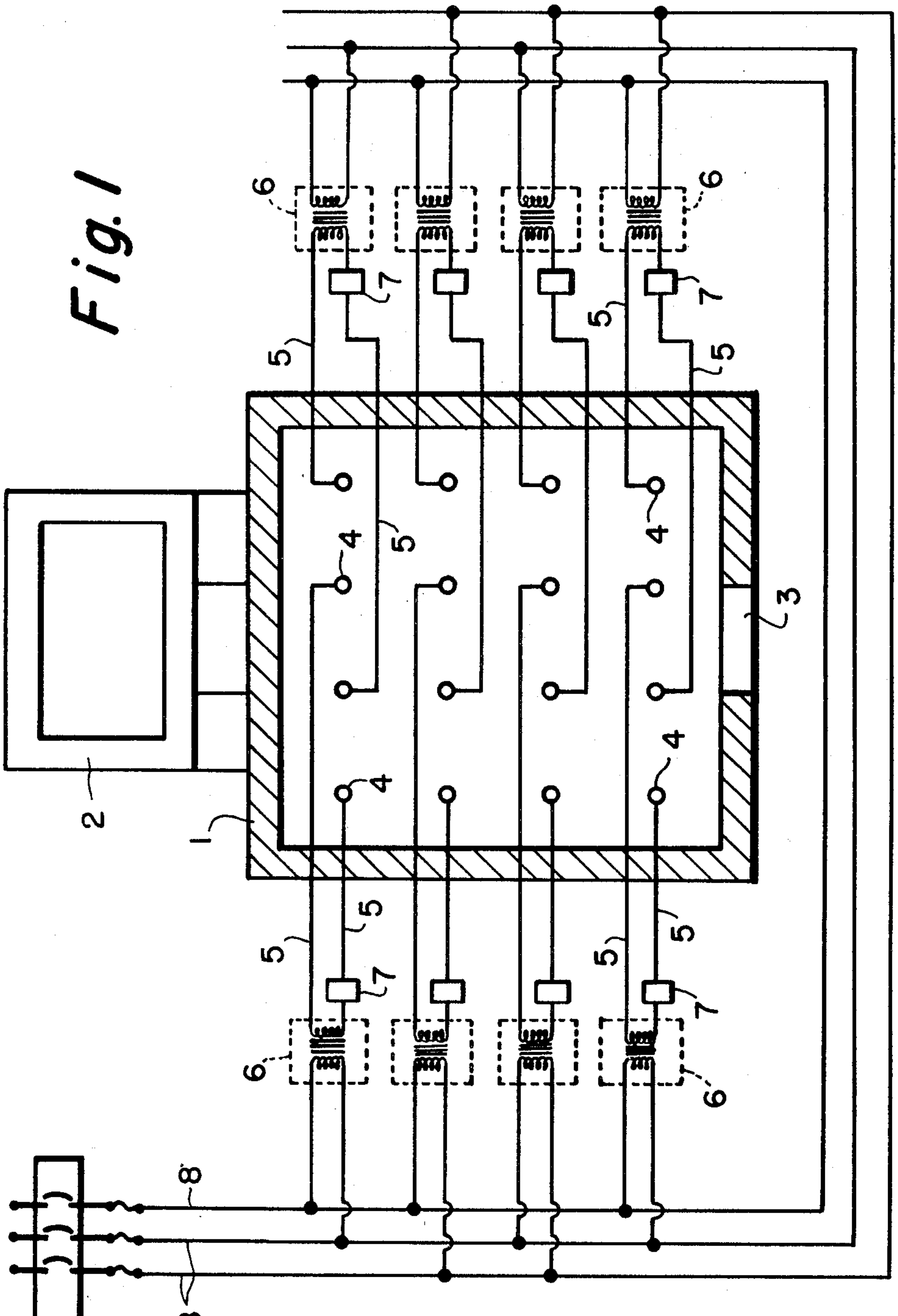

Fig. 1

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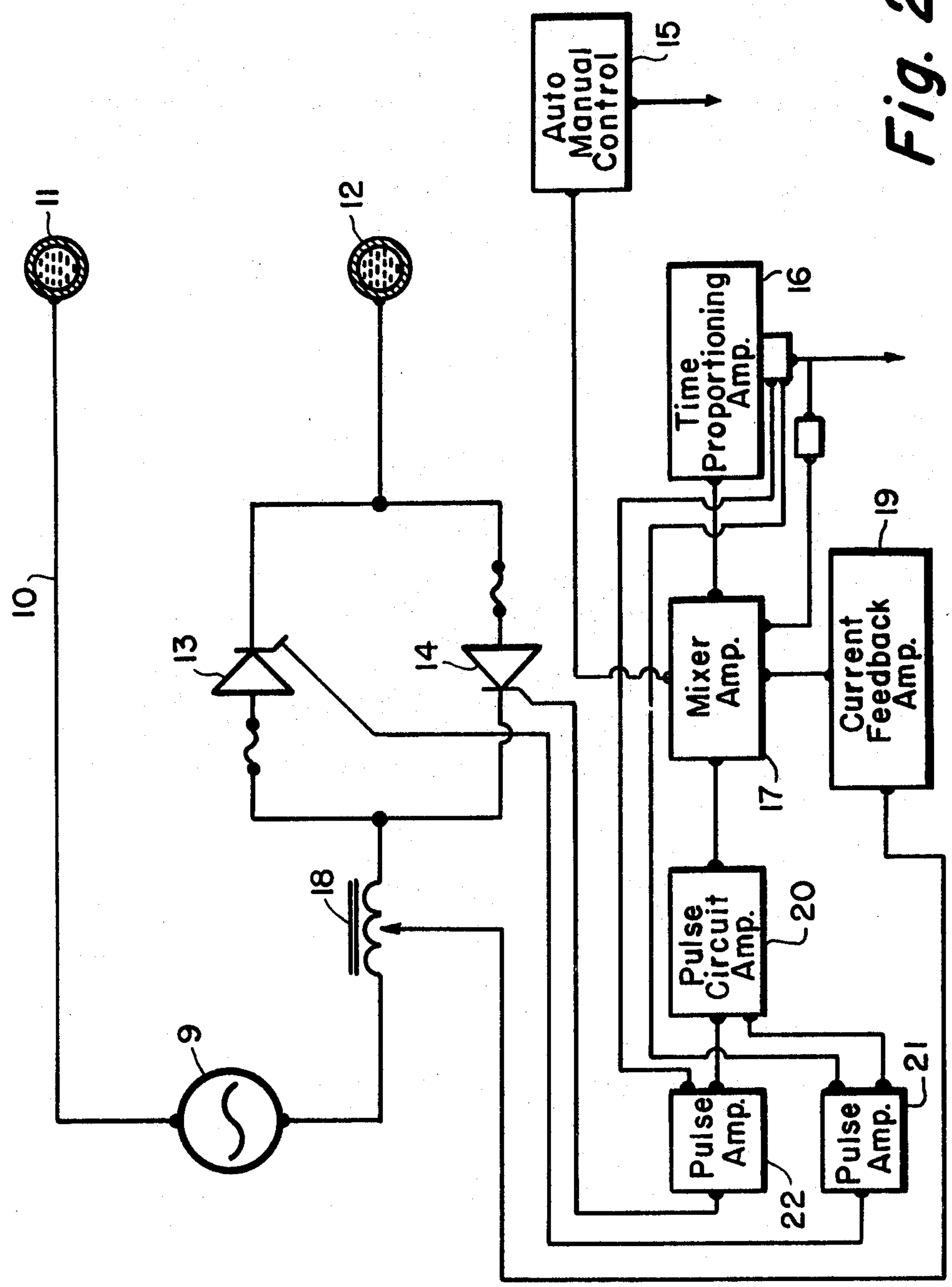

Fig. 2

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1

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ELECTRIC RESISTANCE FURNACE

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ABSTRACT OF THE DISCLOSURE

An electric resistance furnace having an even number of vertical electrodes where each pair of electrodes is part of an independent circuit which contains a current-control means and a constant voltage source. A uniform temperature is maintained throughout the furnace by individually controlling the current in each circuit. The current is preferably controlled using solid state gated switch controls, particularly silicon controlled rectifiers.

This invention relates to an electric resistance furnace having an even number of vertical electrodes and, for each pair of electrodes, an independent circuit containing a current-control means and a constant voltage source. More specifically, it relates to the use of solid state gated switch controls, particularly silicon controlled rectifiers, as control devices in such furnaces.

A recent innovation in the glass-making industry in the United States has been the use of electric furnaces; see, for example, Lambert U.S. Patent 2,636,913. While electric furnaces are inherently more efficient and less expensive than furnaces using chemical fuels, they have not been widely accepted by the glass industry because they are difficult to control. A lack of control results in low quality metals, in particular, it leads to "hot spots" which blister and seed the glass.

The difficulties in controlling electric resistance furnaces begin with the fact that most utility companies require that uses of large power blocks, such as electric furnaces, be on three-phase current in order to provide a uniform power requirement. This means that the electrodes will be on different phases and that current will flow between the electrodes as a result of these phase differences. This interphasal current creates an interrelationship between the electrodes so that varying the current supplied to any one electrode affects the current flow in many other electrodes; the furnace cannot therefore be well-controlled.

The difficulty in controlling the furnace is compounded by the fact that glass has a negative resistance, that is, its resistance decreases with a rise in temperature. If the voltage is constant, a decrease in the resistance of glass in a portion of the furnace will result in a greater current flow in that area under Ohm's law $E=IR$. Since the heat generated in a resistor is proportional to the average value of the square of the current in a circuit using alternating current, the resulting increased current flow will raise the temperature of the glass in that portion of the furnace. The increased temperature will lower the resistance of the glass still further, again increasing the current flow and the temperature. This cascading effect results in excessively high temperatures which produce blisters and seeds in the glass and on occasion has even resulted in an entire furnace burning up. Until my invention, no one has found a effective way of overcoming these problems.

In my invention the electrodes are paired and each pair of electrodes is part of an independent electrode circuit; the current in each circuit is individually controlled. Each circuit is independent in that current cannot flow from one circuit to another circuit except by flowing through the glass, and since the current in each circuit is controlled individually, very little current can flow between circuits by flowing through the glass. Thus, in a three-phase sys-

2

tem most of the interphasal current is eliminated. "Hot spots" do not develop since an increased current flow in any circuit is immediately controlled, where "control" means the ability to maintain the average value of the square of the current at a desired level in spite of variations in the resistance of the melt.

FIGURE 1 is a diagrammatic planar view of an electric furnace showing the electrode placement and the basic circuitry.

FIGURE 2 is a block diagram of an example of a circuit for actuating gated switch controls, here shown as two silicon controlled rectifiers.

My electric furnace may be used to melt any materials which can be resistance melted in an electric furnace. The principal use for my furnace is producing glass, in which case the charge materials are usually mainly sand, soda, and lime plus various minor additives. Detergent base materials such as sodium silicates or metasilicates may also be melted in my furnace.

My invention is also applicable to electric booster furnaces, that is, furnaces which are heated with both chemical fuels and electricity. It should be understood that the term "electric resistance furnace" includes booster furnaces. The electric power used in the furnace must be alternating current; almost any frequency may be used although extremely high or low frequencies should be avoided.

My electric resistance furnace is preferably of a square or rectangular design since that design has fewer construction problems and is well-suited for the placement of paired electrodes, although other designs may also be found suitable, as, for example, a circular design. A provision is made for admitting charge materials at one side of the furnace and for tapping the melt at the base of the other side.

An even number of electrodes are placed vertically throughout the furnace. I have found that the electrodes must be vertical since disproportional amounts of current flow from the tips of horizontal electrodes which causes hot spots at the tips, while current flows from the entire length of vertical electrodes. Almost any even number of electrodes may be used, although this invention is not applicable if only two electrodes are used since there then would be only one electrode circuit; thus, this invention applies only if at least four electrodes are used so that there may be at least two circuits which are independent of each other. It is preferable to use at least six electrodes and more than twenty electrodes is usually unnecessary.

The electrodes are preferably placed so that a checker board of equal rectangles, preferably squares, is formed. Thus, in a square formation each electrode will be substantially equidistant from at least two other electrodes, which will also be true in other suitable electrode placement schemes. The distance between electrodes will depend upon the characteristics of the compounds being melted and the current supplied to the electrodes. The distance between the furnace walls and the peripheral electrodes should be such that the electrodes are not too close to the walls as the walls will then deteriorate rapidly, and not too far away from the walls as a layer of glass will then solidify on the walls. If soda-lime glass glass is being melted, the closest electrodes, whether or not they are in the same circuit, should be separated by about 3 feet to 4 feet 6 inches and the peripheral electrodes should be about 2 to 3 feet from the walls. Two electrodes in a circuit need not be adjacent electrodes in the furnace, but they must be close enough for current to flow between them.

The electrodes pass through openings in the base of the furnace and are long enough to extend throughout the depth of the melt, but they must not extend into the blanket of charge materials which floats on top of the melt or the electrodes will rapidly deteriorate. Each electrode should also be provided with a water cooled electrode block which is gas purged to further preserve the electrode. The electrodes may be made of molybdenum, graphite, or other suitable materials, but molybdenum is preferred.

Each circuit for a pair of electrodes must contain a voltage source and a means for controlling the current, or more exactly, the average value of the square of the current.

The voltage source in each circuit is of a constant voltage. If a transformer is used the same core should not be used for the secondary windings of other circuits since variations in the current of one circuit would then affect the current available to other circuits.

The current-control means is any means which can control the average value of the square of the current by maintaining it at a desired level in spite of changes in the resistance of the melt. This average value may be controlled in at least two ways—by introducing a resistance into the circuit and by breaking the circuit.

A resistance may be introduced into the circuit, for example, by using a saturable core reactor as a current-control device, but such a reactor displaces the current vectorially which can mean a low power factor. Moreover, any resistance introduced into the circuit generates heat which is a waste of current and must be dissipated by some means.

The preferred method of controlling the average value of the square of the current which avoids the difficulties encountered by introducing a resistance into the circuit, is to break the circuit for short periods of time (the average is a continuous average over a period of time which is substantially longer than the time that the circuit is broken). Thus, the average value of the square of the current can be maintained at a constant level even though a greater current may flow during the time that the circuit is closed.

There are at least two methods of controlling the current by breaking the circuit—phase angle control and time proportioned cycle control; other methods may appear with advances in electronics.

In phase angle control the current is permitted to flow from phase angles separated by 180° until the end of each half cycle (180° and 360°). For example, a current could flow from every 30° to 180° and every 210° to 360°. However, due to limitations in present-day electronics, it is very difficult to separate by exactly 180° the two phase angles at which the current begins to flow. If the phase angles are not separated by exactly 180°, small amounts of direct current will be generated, creating electrolytic reactions in the furnace which wear the electrodes and blister and seed the melt. At some future time this method of control may become sufficiently precise so that no significant amount of direct current is generated; this method of control will then be more suitable for purposes of this invention.

Control of the current by breaking the circuit may also be obtained by breaking the circuit for an equal number of positive half-cycles and negative half-cycles, a procedure known as time proportioned cycle control. That is, for example, the circuit can be opened for one entire cycle and closed for the next entire cycle. I have found that present-day electronics are sufficiently precise so that the current may be controlled by this method without generating direct current.

One means for breaking the circuit for short periods using time proportioned cycle control is to use solid state gated switch controls in cooperation with control circuits. Such controls include water-cooled germanium rectifiers and silicon controlled rectifiers (SCR's); SCR's are preferred. Gated switch controls do not pass any current unless they are gated, and when gated each control will pass current in only one direction. Thus, by connecting two or more controls back-to-back in parallel, a current having a complete cycle will flow only when the controls are gated. The gate control is so precise that the gate may be opened and closed in millionths of a second. Although at least two controls are needed to pass a complete cycle, almost any number may be used; the number will depend upon the rating of the control and the power requirements of the furnace.

In cooperation with the gated switch control is a control circuit which activates the control. The resistance of the melt at different temperatures is predetermined. The control circuit is then set to activate the gated switch control when the resistance of the melt falls to level indicative of an excessive temperature. The resistance of the melt is indicated by the current flow in the electrode circuit since $E=IR$ and E is constant. Therefore, essentially the control circuit requires a means for measuring the current in the electrode circuit and a means for actuating the gated switch control in accordance with current in the electrode circuit. In a similar manner, the current flow in the electrode circuit is increased again when safe temperatures are indicated.

A more complete understanding of my invention may be obtained by consulting the accompanying drawings.

In FIGURE 1 an electric furnace container **1** is provided with a batch charger **2** for feeding charge materials and a throat **3** for tapping the melt. Sixteen electrodes **4** extend vertically from the base of the furnace. Each pair of electrodes is in an independent circuit formed with wires **5**, the secondary windings of transformers **6**, and current-control devices **7**. The primary windings of transformers **6** are wired in three different ways to the three lead wires **8**, the currents of which are 120° out of phase. Thus, there will be a total of three phases among the eight independent electrode circuits; an attempt should be made to equalize the number of electrodes on each phase.

In FIGURE 2, cuurrent flows from transformer **9** through cable **10** to electrode **11**. Interposed between the other electrode **12** in the electrode circuit and transformer **9** is a means for controlling the current in the circuit using time proportioned cycle control. This means is two SCR's **13** and **14** wired back-to-back in parallel and a control circuit for activating the SCR's.

Auto manual control **15** is set for the current desired in the electrode circuit. A signal proportional to the setting is sent to time proportioning amplifier **16** via mixer amplifier **17**. Time proportioning amplifier **16** sends pulses back to the mixer amplifier, the number of pulses per second being proportional to the signal from the auto manual control. The mixer amplifier also receives a signal from current transformer **18** which is first rectified by current feedback amplifier **19**; this signal is proportional to the current flowing in the electrode circuit. The mixer amplifier mixes the signal from the time proportioning amplifier and the rectified signal from the current transformer using the magnetic flux in the core of a transformer. The resultant signal is then sent to pulse circuit amplifier **20** which splits the signal into two pulsed signals 180° out of phase. These two pulsed signals are sent to two pulse amplifiers **21** and **22** which supply the gate voltage and current to SCR's **13** and **14** in the proper time sequence for controlling conduction through the SCR's. Circuits for controlling gated switch controls are well-known in the art and the circuitry of FIGURE 2 is only illustrative of many possible control circuits.

As the following example illustrates, industrial-sized furnaces using my invention have been constructed and successfully operated.

Example

A furnace of the design shown in FIGURE 1 and having the basic circuitry illustrated by FIGURE 2 was constructed for use with a 2300 volt delta primary three phase voltage source. Eight transformers supplied 120 volts to each independent circuit and the current was controlled with eight pairs of SCR's per circuit. The furnace melted 51½ tons of soda-lime container glass every 24 hours. The production was uneventful and melt was unblistered, unseeded, and of good quality.

From the foregoing it may be seen that this invention is for an electric resistance furnace having an even number of vertical electrodes where each pair of electrodes is in an independent circuit which includes a means for controlling the current.

While I have described my invention in terms of the presently preferred embodiment, it may be otherwise embodied within the scope of the following claims.

I claim:

1. An electric resistance furnace comprising:

(A) a heat-resistant container provided with means for feeding charge materials into said container and means for tapping a melt from said container;

(B) an even number of electrodes, at least four, positioned vertically within said furnace and fixed relative thereto;

(C) an independent electrical circuit for each pair of electrodes, each circuit including a substantially constant voltage source; and

(D) means for controlling the current in each circuit.

2. The furnace described in claim **1** wherein said means for controlling the current includes at least two solid state gated switch controls wired back-to-back in parallel.

3. The furnace described in claim **1** wherein said means for controlling the current includes at least two silicon controlled rectifiers wired back-to-back in parallel.

4. The furnace described in claim **1** wherein said means for controlling the current includes a saturable core reactor.

5. The furnace described in claim **1** wherein said current is controlled by means of time proportioned cycle control.

6. An electric resistance furnace comprising:

(A) a heat-resistant container with means for feeding charge materials into said container and means for tapping a melt from said container;

(B) an even number of electrodes, at least four, positioned vertically with said furnace and fixed relative thereto, each electrode being at a substantially equal distance from at least two of the nearest electrodes;

(C) an independent electric circuit for each pair of electrodes, each circuit including a substantially constant voltage source whereby a current flows in said circuit and between paired electrodes; and

(D) electrical means for individually opening and closing each of said circuits whereby the average value of the square of the current in each circuit is controlled.

7. The furnace described in claim **6** wherein said means for opening and closing said circuits includes at least two solid state gated switch controls wired back-to-back in parallel.

8. The furnace described in claim **6** wherein said means for opening and closing said circuits includes at least two silicon controlled rectifiers wired back-to-back in parallel.

9. The furnace described in claim **6** wherein said circuits are opened and closed using time proportioned cycle control.

10. An electric resistance furnace comprising:

(A) a heat-resistant container having a rectangular planar design and provided with means for feeding charge materials into said container and means for tapping a melt from said container;

(B) an even number, between six and twenty, of vertical electrodes positioned within said furnace and fixed relative thereto, each positioned so that substantially equal rectangles are formed by any electrode and three other suitably chosen electrodes;

(C) an independent electric circuit for each pair of electrodes, each circuit including a voltage source of substantially constant voltage whereby a current can flow between paired electrodes; and

(D) electrical means for each circuit for controlling the average value of the square of the current in each circuit using time proportioned cycle control.

11. The furnace described in claim **10** wherein said electrical means includes at least two solid state gated switch controls wired back-to-back in parallel.

12. The furnace described in claim **10** wherein said electrical means includes at least two silicon controlled rectifiers wired back-to-back in parallel.

13. The furnace described in claim **10** wherein the distance between said electrodes is about 3 feet to about 4 feet 6 inches and the distance between the walls of said container and the peripheral electrodes is about 2 feet to about 3 feet when said furnace is used to melt soda-lime glass.

14. An electric resistance furnace, including its electrical system, for use with a three phase power source of a substantially constant voltage comprising:

(A) a heat-resistant container provided with means for feeding charge materials into said container and means for tapping a melt from said container;

(B) an even number of electrodes, at least six, positioned vertically within said furnace and fixed relative thereto;

(C) an independent electrical circuit for each pair of electrodes, each circuit including the secondary windings of a transformer and a means for controlling the current in said circuit; and

(D) a second electrical circuit for each independent electrical circuit, each second electrical circuit including the primary windings of a transformer the secondary windings of which are a part of the corresponding independent electrical circuit, and electrical connections to a selected two of the three phases of said power source, said selected two phases being selected for different circuits in a total of three different ways.

15. The furnace described in claim **14** wherein said means for controlling said current is at least two solid state gated switch controls wired back-to-back in parallel.

16. The furnace described in claim **14** wherein said means for controlling said current is at least two silicon controlled rectifiers wired back-to-back in parallel.

17. The furnace described in claim **14** wherein said means for controlling the current includes a saturable core reactor.

18. The furnace described in claim **14** wherein said current is controlled by means of time proportioned cycle control.

19. An electric resistance furnace, including its electrical system, for use with a three phase power source of a substantially constant voltage comprising:

(A) a heat-resistant container provided with means for feeding charge materials into said container and means for tapping a melt from said container;

(B) an even number of electrodes, at least six, positioned vertically within said furnace and fixed relative thereto, each electrode being at a substantially equal distance from at least two of the nearest electrodes;

(C) an independent electric circuit for each pair of electrodes, each circuit including the secondary windings of a separate transformer and a means for opening and closing each of said circuits whereby the average value of the square of the current in each circuit is controlled; and

(D) a second electrical circuit for each independent electrical circuit, each second electrical circuit including the primary windings of a transformer the secondary windings of which are a part of a corresponding independent electrical circuit, and electrical connections to a selected two of the three phases of said power source, said selected two phases being selected for different circuits in a total of three different ways, each way being selected as nearly as possible the same number of times that each other way is selected.

20. The furnace described in claim **19** wherein said means for opening and closing said circuits includes at least two solid state gated switch controls wired back-to-back in parallel.

21. The furnace described in claim **19** wherein said means for opening and closing said circuits includes at least two silicon controlled rectifiers wired back-to-back in parallel.

22. The furnace described in claim **19** wherein said circuits are opened and closed using time proportioned cycle control.

23. An electric resistance furnace, including its electrical system, for use with a three phase power source of a substantially constant voltage comprising:

(A) a heat-resistant container having a rectangular planar design and provided with means for feeding charge materials into said container and means for tapping a melt from said container;

(B) an even number, between six and twenty, of vertical electrodes positioned within said furnace and fixed relative thereto, each positioned so that substantially equal rectangles are formed by any electrode and three other suitably chosen electrodes;

(C) an independent electrical circuit for each pair of electrodes, each circuit including the secondary windings of a different transformer and an electrical means for controlling the average value of the square of the current in each circuit using time proportioned cycle control; and

(D) a second electrical circuit for each independent electrical circuit, each second electrical circuit including the primary windings of a transformer the secondary windings of which are a part of a corresponding independent electrical circuit, and electrical connections to a selected two of the three phases of said power source, said selected two phases being selected for different circuits in a total of three different ways, each way being selected as nearly as possible the same number of times that each other way is selected.

24. The furnace described in claim **23** wherein said electrical means includes at least two solid state gated switch controls wired back-to-back in parallel.

25. The furnace described in claim **23** wherein said electrical means includes at least two silicon controlled rectifiers wired back-to-back in parallel.

26. The furnace described in claim **23** wherein the distance between said electrodes is about 3 feet to about 4 feet 6 inches and the distance between the walls of said container and the peripheral electrodes is about 2 feet to about 3 feet when said furnace is used to melt soda-lime glass.

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