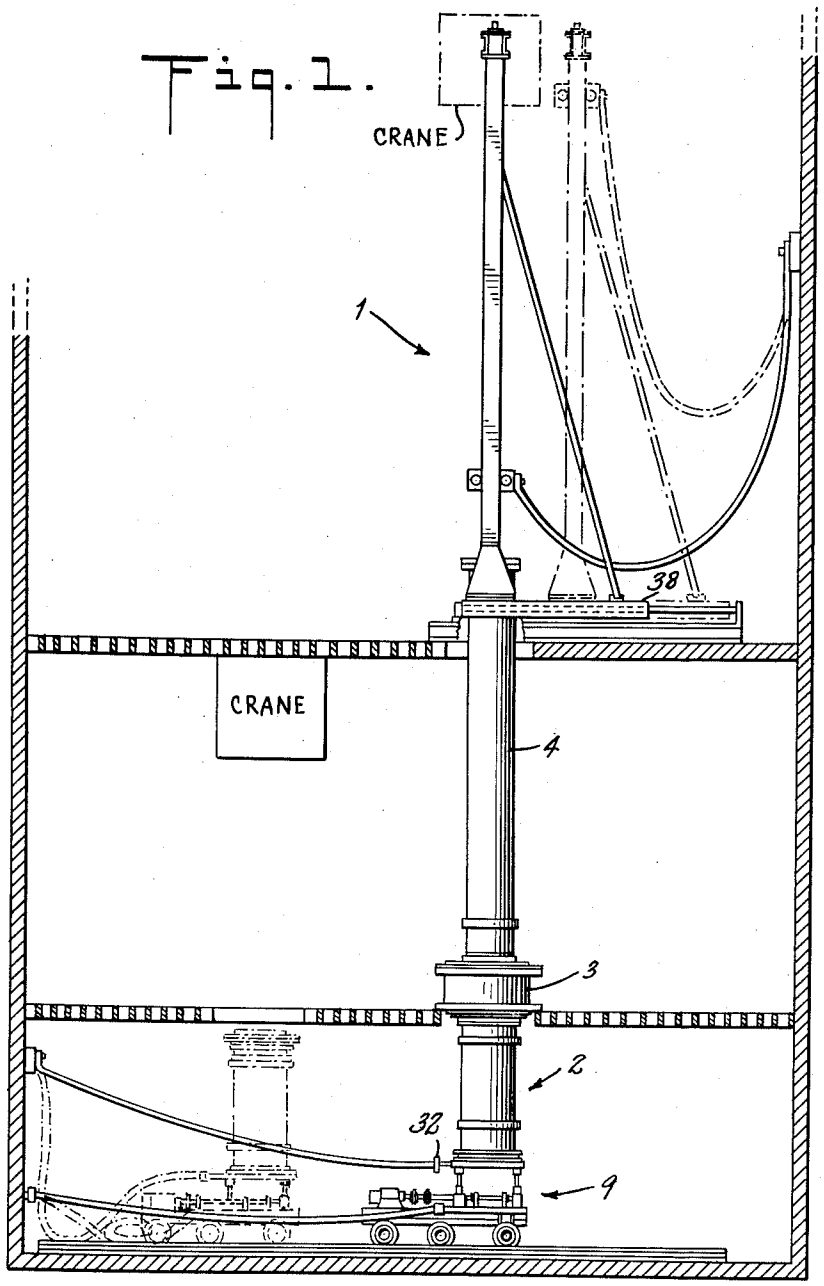
Jan. 14, 1964 R. J. GARMY 3,118,013

SAFETY CONTROLS FOR ELECTRIC FURNACES

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Fig. 1.



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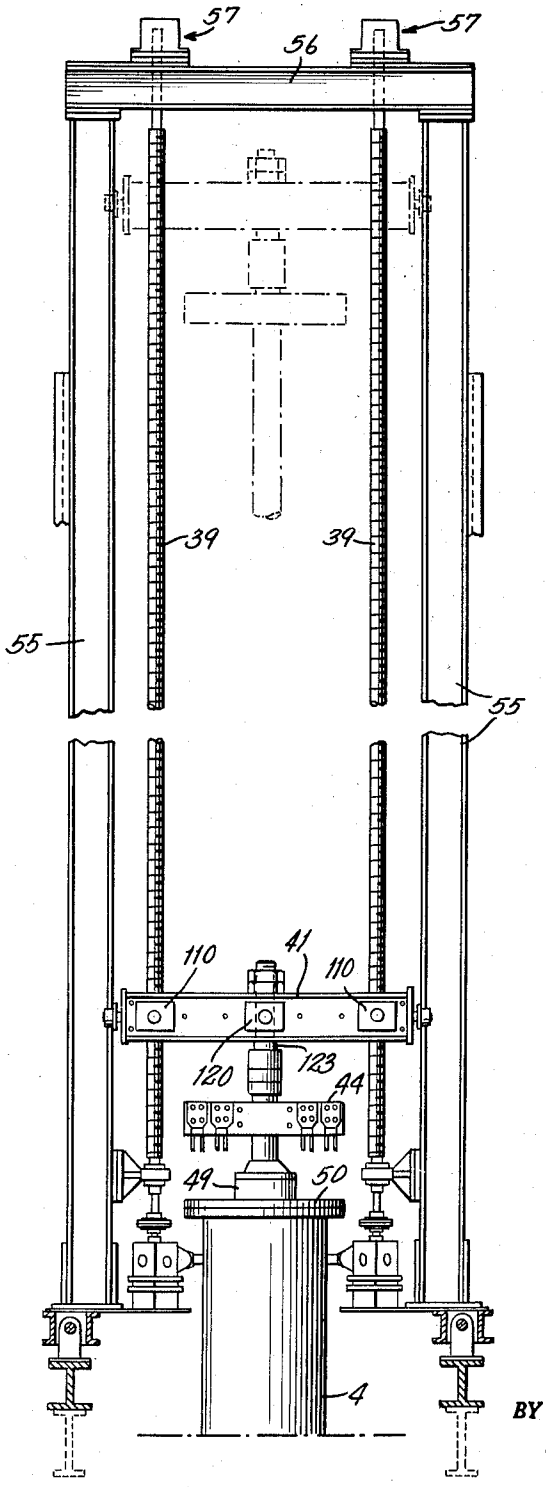


Fig. 2.

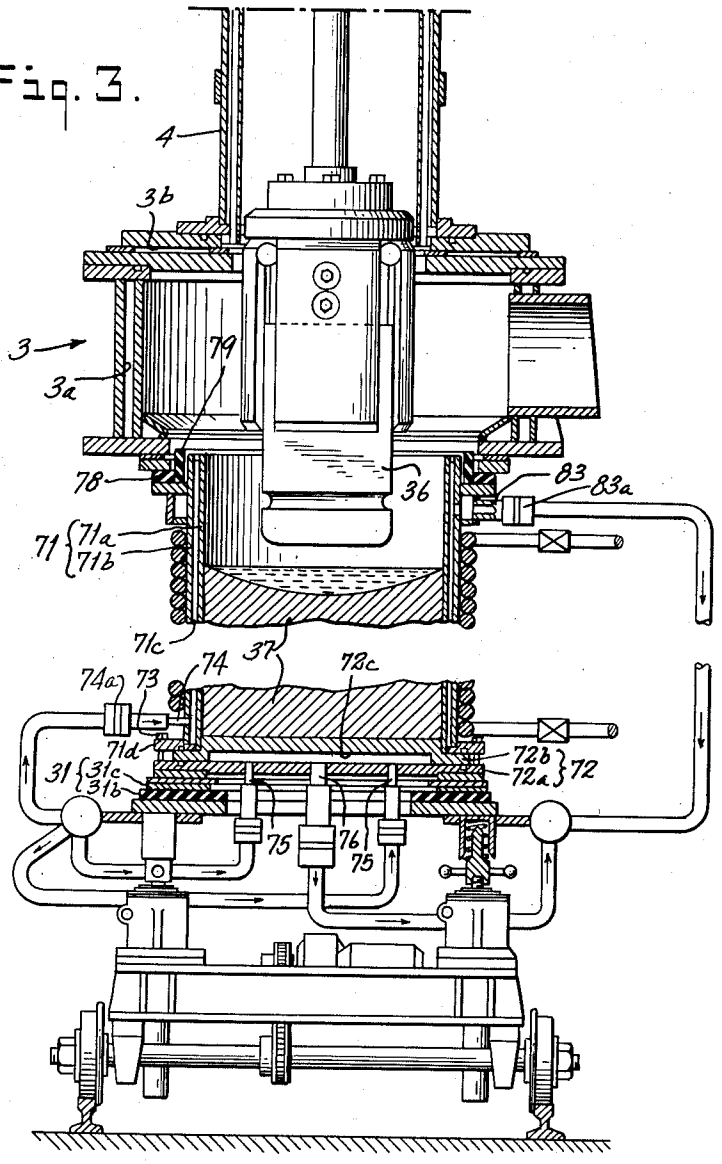
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SAFETY CONTROLS FOR ELECTRIC FURNACES

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Fig. 3.



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Fig 4

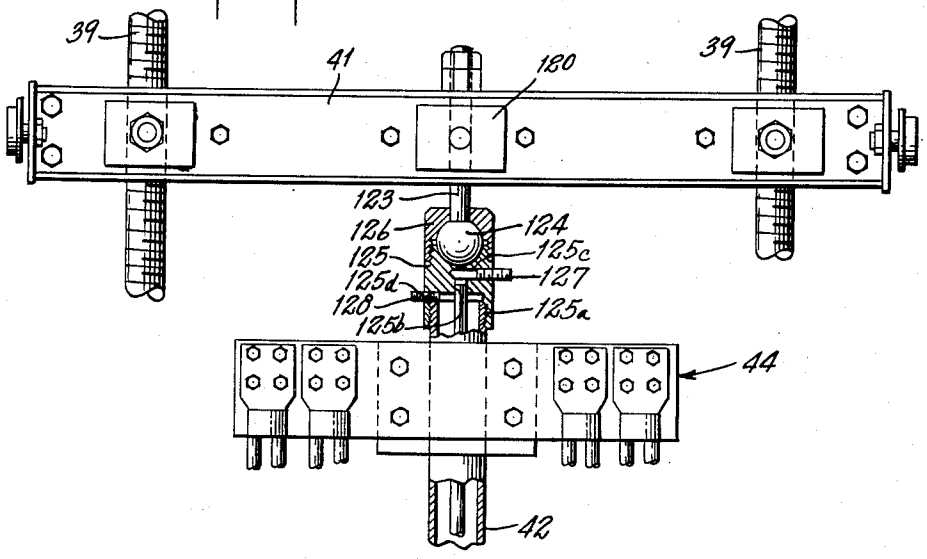


Fig. 5

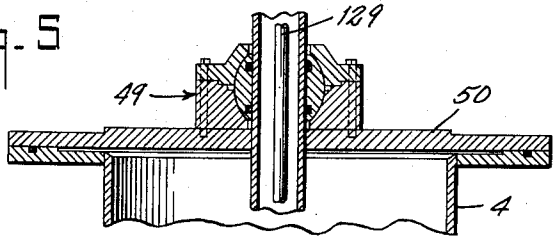
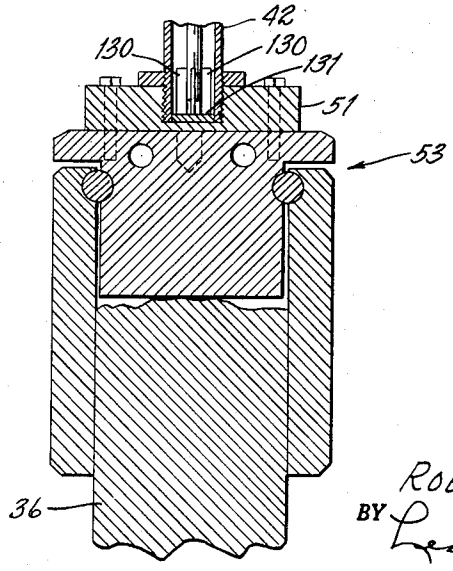


Fig. 6



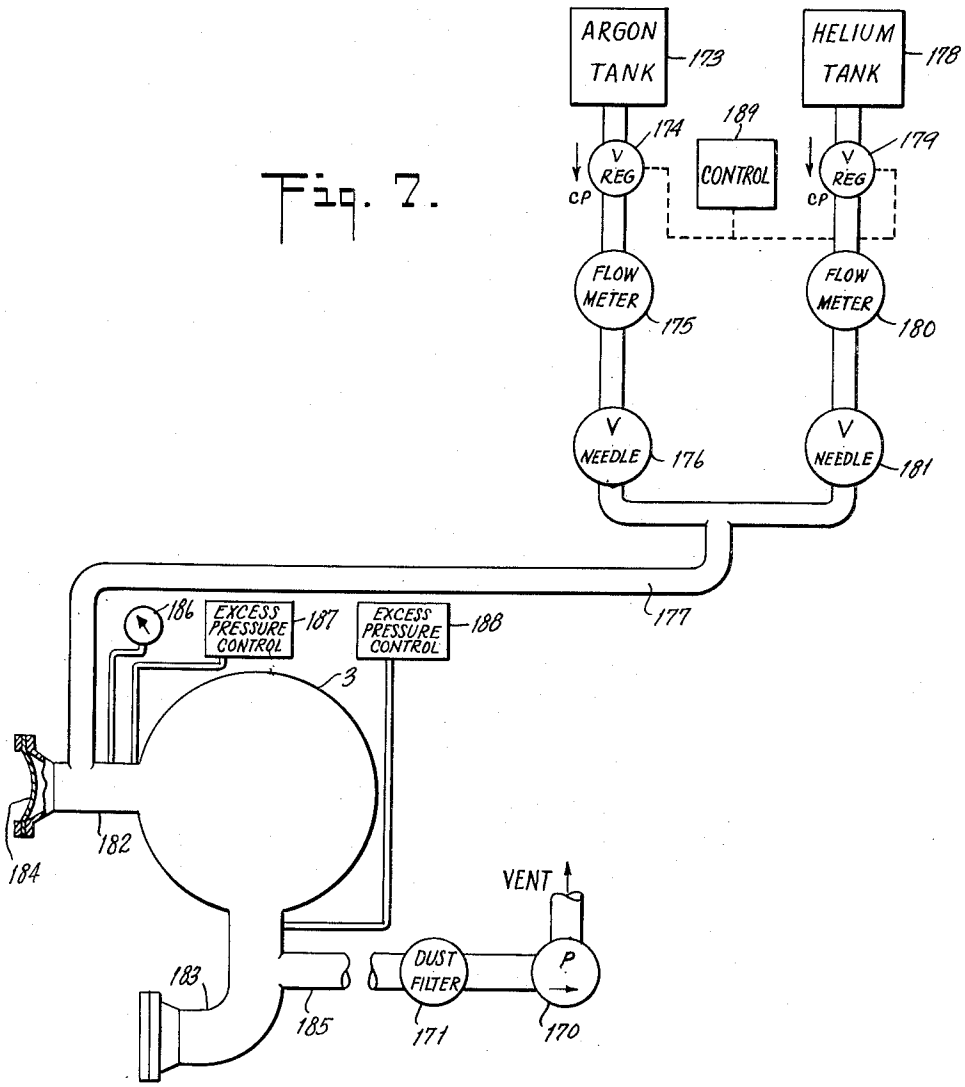
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SAFETY CONTROLS FOR ELECTRIC FURNACES

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Fig. 7.



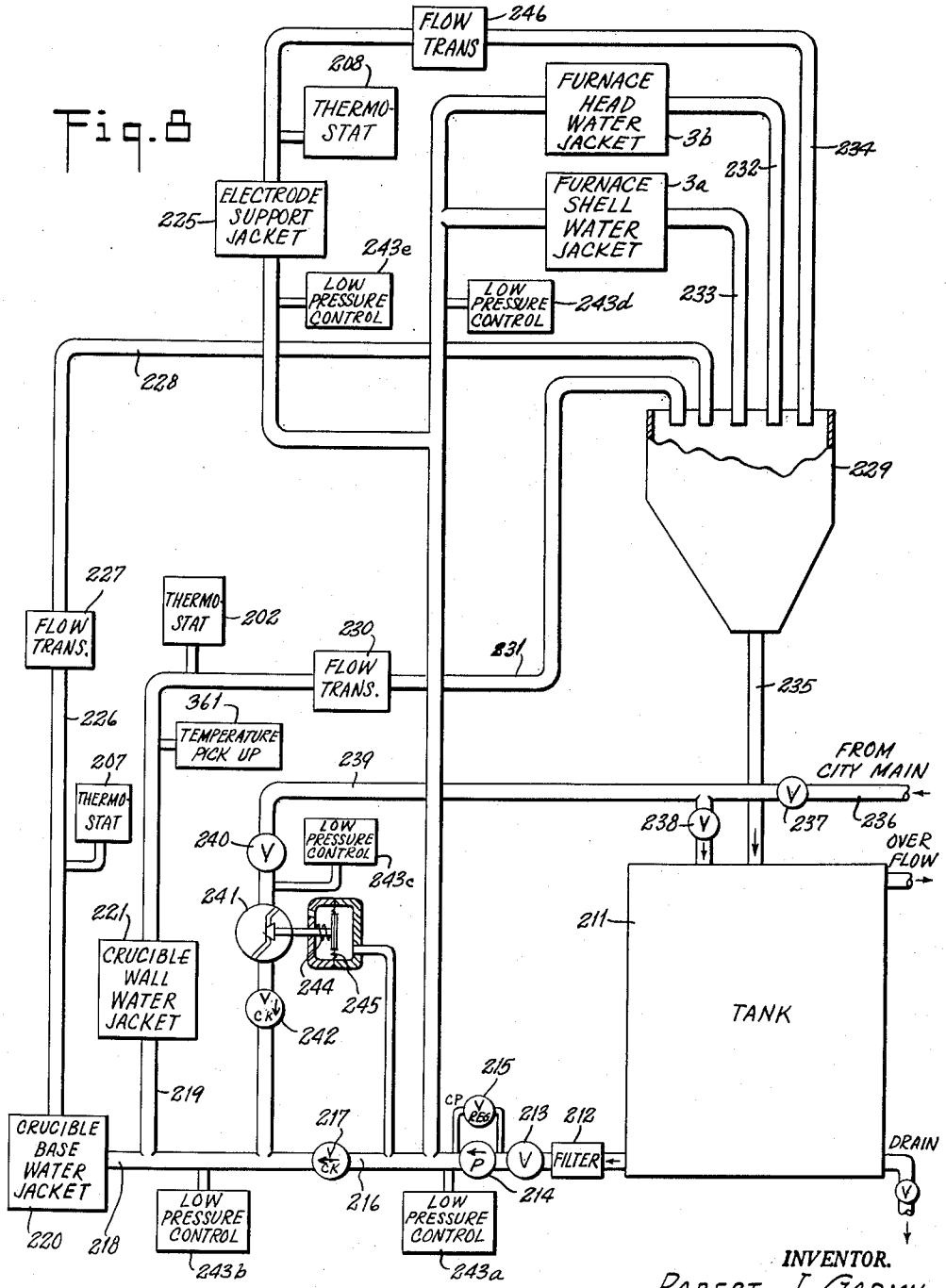
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SAFETY CONTROLS FOR ELECTRIC FURNACES

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Fig. 6



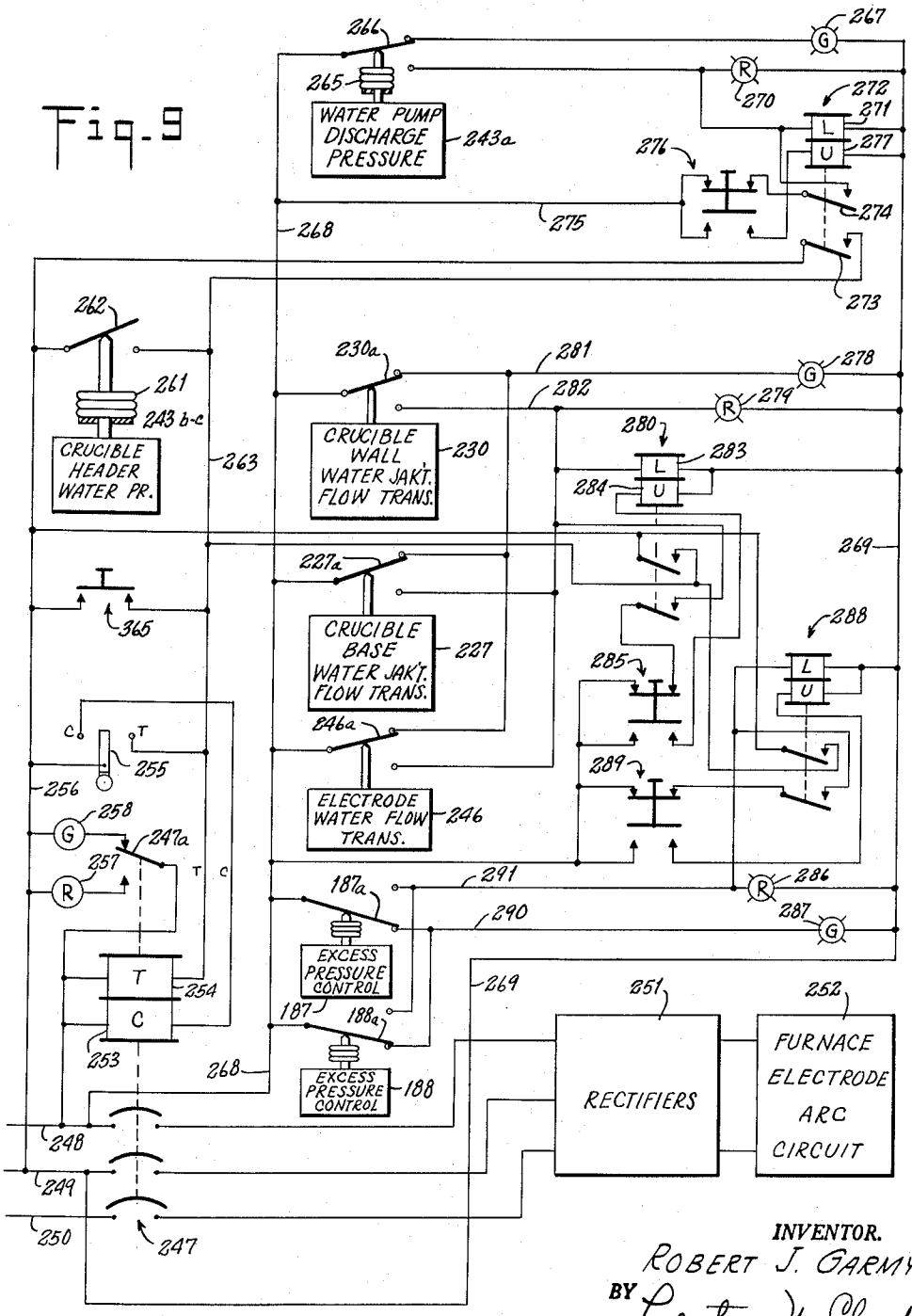
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SAFETY CONTROLS FOR ELECTRIC FURNACES

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Fig. 9



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United States Patent Office 3,118,013 Patented Jan. 14, 1964

3,118,013

SAFETY CONTROLS FOR ELECTRIC FURNACES

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Original application Nov. 22, 1957, Ser. No. 698,256, now Patent No. 2,973,452, dated Feb. 28, 1961. Divided and this application Feb. 27, 1961, Ser. No. 91,771

3 Claims. (Cl. 13—9)

This application is a division of my copending application Ser. No. 698,256, filed November 22, 1957, now Patent No. 2,973,452, granted February 28, 1961, entitled "Electric Furnace Utilizing Consumable Electrodes and Method of Operating Same."

This invention relates to electric furnaces and particularly to furnaces for producing metallic ingots of high purity. The furnace described herein was designed especially for use with and has successfully been used with metals such as titanium, zirconium and the like, which are difficult to melt because of their high melting points and also because of their high chemical activity at their melting points. This furnace has also been successfully used with other metals, e.g., steel, where an ingot of high purity was desired.

A problem of particular difficulty in connection with furnaces for use in the melting of titanium and the like is the problem of safety with respect to the persons controlling the operation of the furnace and loading and unloading it. The extremely high operating temperatures involved, in the neighborhood of 3140° F. (the melting point of titanium) and the great chemical activity of metals such as titanium and zirconium at their melting points make the probability of an explosion extremely high if oxygen, air or water is allowed to leak into the furnace. Furthermore, if the structural parts of the furnace (which are commonly made of other metals having lower melting points) become overheated, those parts are likely to be destroyed, with resultant contact between the molten titanium and air or water.

An object of the present invention is to provide an electric furnace of the type described which is considerably improved from the standpoint of safety.

Another object is to provide an electric furnace including improved safety control means for cutting off the source of heat whenever a condition affecting the safety of the furnace passes beyond a predetermined limiting value.

A further object is to provide an electric furnace including safety control means of the type described in which the controlling condition is the rate of flow of coolant in a cooling jacket of the furnace, and the heat is cut off whenever the rate of flow falls below a predetermined value.

A further object is to provide an electric furnace including safety control means of the type described in which the controlling condition is the pressure of coolant in a cooling jacket of the furnace, and the heat is cut off whenever the pressure falls below a predetermined value.

A further object is to provide an electric furnace including safety control means of the type described in which the furnace includes an enclosed chamber provided with an inert gas atmosphere, the controlling condition is the pressure within the chamber, and the heat is cut off whenever the pressure exceeds a predetermined value.

The foregoing and other objects of the invention are attained in the furnace described herein. That furnace is an electric arc furnace including an electrically conductive crucible which holds the charge of material being melted and which conducts electricity to the charge. The charge serves as one electrode of the arc. The material

is fed into the furnace by means of a consumable billet, or electrode, of material to be melted, which is fed into the top of the crucible, and which serves as the other electrode of the arc. The crucible is conveniently made of a material having high electrical conductivity, e.g., copper, but having a melting point which may be lower than that of the material being treated. Consequently, the crucible must be cooled to keep the furnace operating. For that purpose, the crucible is provided with cooling jackets through which a suitable coolant, e.g., water, is circulated. Certain of the current carrying structures which support the consumable electrode are also provided with cooling jackets. The interior of the crucible is supplied with an inert gas and the pressure of the inert gas atmosphere is maintained at a value determined by the arc characteristics desired.

The present invention concerns safety controls for shutting down the furnace, i.e., cutting off the arc current, in response to a condition indicative that the furnace operation might become dangerous.

Safety controls are provided for cutting off the arc current when the rate of flow of coolant in the jackets falls below a predetermined value. Other controls cut off the arc current if the pressure of the coolant at certain points in the coolant system falls below a predetermined value. Other controls cut off the arc current if the pressure in the arc chamber exceeds a certain value.

In the event of failure of the coolant supply pressure, the safety control system operates to cut off the supply of the arc current and simultaneously to transfer the cooling jackets from the normal coolant supply to a standby coolant supply system which has sufficient capacity to cool the furnace when the arc current is cut off as during a cooling down period of furnace operation.

Other objects and advantages of the invention will become apparent from the following description and claims, taken together with the accompanying drawings.

In the drawings:

FIG. 1 is an overall elevational view of a furnace embodying the invention, and showing the parts in full lines in their operating positions and in their loading and unloading positions in dotted lines;

FIG. 2 shows an elevational view of the upper part of the furnace taken from the left as viewed in FIG. 1;

FIG. 3 is a cross-sectional view of the crucible and related parts;

FIG. 4 is a detailed view showing the crosshead and its related parts, similar to a portion of FIG. 2 but on a larger scale;

FIG. 5 is a detailed view on the same scale as FIG. 4, showing the power tube and its sealing connection through the cover of the electrode receiving tube;

FIG. 6 is a view on the same scale as FIG. 4, showing in section the lower end of the power tube and its connection to the electrode clamp;

FIG. 7 is a somewhat diagrammatic illustration of the inert gas supply system and the pressure control system for the interior of the furnace;

FIG. 8 is a somewhat diagrammatic illustration of the water supply system for the cooling jackets of the furnace; and

FIG. 9 is an electrical wiring diagram showing the arc current supply system with the various safety controls for cutting off that current supply.

General Furnace Structure—FIGS. 1 to 6

These figures illustrate an electric furnace which is generally indicated by the reference numeral 1. Many details of the furnace structure have been omitted from FIG. 1 for purposes of clarification. The furnace 1 comprises a crucible 2 in which an ingot is formed during operation of the furnace, a generally cylindrical shell or

housing 3 above the crucible 2, and an electrode receiving tube 4 which projects upwardly from the shell 3. A truck 9 carries the crucible 2 and is movable between an operating position shown in full lines in FIG. 1 and a loading and unloading position shown in dotted lines. (See Ser. No. 698,256, filed November 22, 1957, now Patent No. 2,973,452 granted February 28, 1961, for a more complete description of the construction and operation of the furnace.)

Various instrumentalities having to do with the control of the atmosphere inside the furnace are connected to the shell 3, as illustrated diagrammatically in FIG. 7. The shell wall is made double to provide a water jacket 3*a* (FIG. 3), and its top or head is also double walled to provide a head water jacket 3*b*.

The electrode tube 4 is mounted on the head of the shell 3 and extends upwardly therefrom a substantial distance, e.g., 12 to 15 feet. The electrode tube 4 is provided to enclose a consumable electrode such as shown at 36 in FIG. 3, which is being fed to the furnace to form an ingot 37 in the bottom of the crucible 2.

The electrode 36 may be of compressed titanium sponge as shown and claimed in detail in the U.S. patent of Thomas A. Sindelar, No. 2,925,619, granted February 23, 1960, entitled "Apparatus for Pressing Consumable Electrode Billets."

It has become conventional in the making of titanium ingots to run the titanium through a two-step process. In the first step, an electrode of compressed titanium sponge, as just described, is formed into an ingot having a somewhat larger diameter than the original electrode. This ingot, which has been considerably purified by the elimination of the impurities during its formation, is then passed through a repetition of the ingot forming step. In this second step, the first ingot is used as an electrode and is melted down again in an arc and forms a second ingot of larger diameter. The purpose of the two ingot forming operations is to increase the purity and homogeneity of the final product. The melting down of the material in the arc is very effective to remove those impurities which are gaseous or volatile at the temperature employed. Since these temperatures are in the neighborhood of the melting point of titanium, namely 3140° F., it may be seen that most impurities are thereby removed. The double operation results in an ingot of high purity and homogeneity. Since titanium is still quite an expensive metal, it is commonly used only where its peculiar heat resistant properties and high strength to weight ratio are of great advantage. Such properties are at their best when the metal or alloy is most nearly free of undesirable contaminants. Consequently, practically all the present demand for titanium and its alloys is for the highly purified forms which may best be manufactured by repeating the melting step.

The crucible structure, the truck and the related mechanisms concerned with the loading and unloading of the crucible on the truck, and the unloading of the ingot from the crucible, are not part of the present invention, but are shown and described more completely and claimed in my copending application Serial No. 672,603, filed July 18, 1957, now Patent No. 2,984,876, granted May 23, 1961, entitled "Electric Furnace Crucible."

Furthermore, the specific water jacket structures of the crucible form no part of the present invention, being described more completely and claimed in my U.S. Patent No. 2,950,094, granted August 23, 1960. However, an understanding of the crucible structure and its related parts are necessary to a complete understanding of certain features of the present invention relating to safety controls. For that reason, a brief description of the crucible is supplied herein, as follows.

As seen in FIG. 3, the crucible 2 comprises a generally cylindrical wall section 71 and a base plate 72. The wall section 71 comprises a copper inner shell 71*a* and a steel outer shell 71*b* defining between them a water jacket 71*c* supplied through a series of inlets, one of which is shown at 74, spaced around the bottom of the jacket. The water jacket 71*c* has a plurality of outlets 83 peripherally spaced around its upper end. The wall sections 71 is provided at its lower end with an outwardly extending flange 71*d* which is attached by means of a plurality of peripherally spaced bolts 73 to the peripheral edge of the base plate 72.

The base plate 72 comprises a lower plate 72*a* and an upper plate 72*b* defining between them a water jacket 72*c* supplied through a number of spaced inlets 75 and having a central outlet 76.

When a crucible is in place on the platform 31 it rests on the conductive plate 31*c*, which conducts the electric arc current from the crucible to the terminals 32 (FIG. 1).

In the electric circuit of the arc, the electrode and its supporting parts are all operated at ground potential, while the crucible and ingot are at a different potential, usually positive. The plate 31*b* and the rings 78 and 79 insulate the crucible from the other parts of the furnace.

The inlets 74 for the crucible wall water jacket and the outlets 83 for those jackets, as well as the inlets and outlets for the base plate water jackets, are provided with quick-disconnect couplings 74*a*, 83*a* which may be readily removed when preparing to unload the crucible.

The electrode supporting mechanism is mounted on carriage 38 (FIG. 1) which moves horizontally between the operating position shown in full lines in FIG. 1 and the loading position shown in dotted lines. The details of the electrode supporting mechanism are described more completely and claimed in my copending application Serial No. 827,960 filed July 17, 1959, entitled "Supporting and Current Supplying Means for Consumable Electrodes in Electric Furnaces."

The supporting mechanism includes two upwardly extending masts 55 connected at their upper ends by a crossbar 56 (FIG. 2). Two vertical lead screws 39 are supported on the crossbar 56 by means of two combined thrust and guide bearings generally indicated at 57. The lead screws 39 turn in nuts generally indicated at 110 which are fixed against rotation on a crosshead 41.

At its center, the crosshead 41 pivotally supports a bearing block, generally indicated at 120. An electrode supporting pin 123 extends downwardly from block 120. On the lower end of pin 123 there is integrally formed a ball 124 (FIG. 4) which is received in a spherical socket formed in a socket base 125 and a cap 126 threaded onto the base 125. The base 125 is provided on its lower end with an internally threaded socket 125*a* to receive the threaded upper end of a power tube 42. Concentric with the socket 125*a*, and opening into the upper end thereof, there is provided a central passage 125*b* which communicates with a laterally extending passage 125*c* adapted to receive an external water supply coupling member 127. Another passage 125*d* is provided to receive another coupling member 128 and to provide communication with the socket 125*a*. A water pipe 129 is concentric with the power tube 42 and has its upper end received in the opening 125*b*. The lower end of the water pipe 129 is provided with a plurality of wings 130 which support its lower end above a plug 131 which closes the lower end of the power tube 42. The couplings 127, 128, the various passages in the socket base 125 and the water pipe 129 cooperate to provide a path for circulating coolant, e.g., water, from coupling 127 through central pipe 129, out through its lower end, up through the power tube 42 and out the coupling 128. The coolant is necessary because the power tube 42 carries heavy electrical currents and tends to become overheated due to the power loss in the resistance of the tube 42.

Just below the socket base 125 there is mounted on the power tube 42 a terminal block generally indicated by the reference numeral 44. The power tube 42 extends downwardly through a sealing mechanism 49 located on a cover 50 at the top of the electrode receiving tube 4.

Below the cover 50, the power tube 42 carries at its lower end the contact plate 51 attached by means of bolts to an electrode clamp, generally designated at 53, and described in more detail in U.S. Patent No. 2,964,580, issued to Arthur F. Jones and Donald A. Rice on December 13, 1960 and entitled, "Apparatus for Supporting and Conducting Electric Current to a Load." The electrode clamp 53 engages the upper end of the electrode 36 and not only supports it but serves as a path for conducting electricity to it.

Atmosphere Control System—FIG. 7

This figure illustrates diagrammatically the system for controlling the pressure of the atmosphere inside the furnace. A vacuum pump 170 is connected through a dust filter 171 to the furnace shell 3, and discharges to the atmosphere, preferably outside the building. An inert gas supply system, including an argon tank 173 and a helium tank 178, supplies to the furnace a mixture of those gases (or either gas alone, as preferred in a particular situation). The gas flows from the argon tank 173 through a pressure regulating valve 174, a flow meter 175, a needle valve 176 and a conduit 177 to the furnace shell 3. Similarly, helium flows from the tank 178 through a pressure regulating valve 179, a flow meter 180 and a needle valve 181 and the conduit 177 to the shell 3.

The furnace shell 3 is provided with two large outwardly extending conduits 182 and 183. At the outer end of each of the latter conduits there is provided a large rupture disc 184, only the one on the conduit 182 being shown. These discs are set to rupture at a predetermined pressure (commonly 18 pounds per square inch gage for a furnace adapted to operate with an internal atmospheric pressure of 50 to 100 microns). The purpose of the rupture disc is to relieve internal pressures which may be developed, due to faulty operation or structural failure within the furnace. The conduit 177 supplies gas to the conduit 182. The conduit 185 leading to the vacuum pump 170 is connected to the conduit 183. The connection of the conduits in this manner maintains a flow through the conduits leading to the rupture discs and tends to minimize the deposit of dust or foreign materials in those conduits. Furthermore, the conduits 182 and 183 run cooler than the shell 3. A gage 186, which may be located remotely from a furnace, for example in a control room such as described in Ser. No. 698,256, filed November 22, 1957, now Patent No. 2,973,452, granted February 28, 1961, is connected to the conduit 182 so that the furnace operator has constantly available a measure of the pressure in the furnace. An excess pressure control device 187 is connected to the conduit 182. Another excess pressure control device 188 is connected to the conduit 183. As explained below in connection with the safety control system, the control devices 187 and 188 operate to cut off the supply of electrode current in the event of excessive pressures being established inside the furnace shell 3.

The pressure regulator valves 174 and 179 associated respectively with the argon and helium tanks are all connected to a common control device 189, located preferably in the control room. The regulators 174 and 179 should also be independently operable from the control room. The device 189 may operate through a pneumatic line or any other suitable remote control system.

Coolant Supply System for Cooling—FIG. 8

This figure illustrates diagrammatically the system for supplying water to the various cooling jackets associated with the furnace. The system illustrated is a recirculating system and depends upon the city main or other primary supply only for makeup water or for emergency use in case the recirculating system fails. If a coolant other than water is used, a standby supply is employed in place of the primary supply mentioned above. The system includes a tank 211. Water flows from the tank 211 through a filter 212 and a valve 213 to the recirculating pump 214 provided with a regulating valve 215 which maintains a nominally constant discharge pressure. Water flows from the pump 214 through a manifold 216 and a check valve 217 to a conduit or manifold 218 leading to crucible base water jacket 220 and a conduit or manifold 219 leading to the crucible wall water jacket 221. Each of these water jackets actually has multiple inlets which are supplied from a manifold structure. In the diagrammatic FIGURE 8, the manifolds are shown as single conduits, for the sake of simplicity. A branch conduit 222 leads to the furnace head water jacket 3*b* and the furnace shell water jacket 3*a*. The branch conduit 222 also supplies the electrode support or power tube jacket 225.

Water discharged from the crucible base water jacket 220 passes through a conduit 226, a rate of flow responsive telemetric transmitter 227 and a discharge conduit 228 into a sink 229. Water discharged from the crucible wall water jacket passes through a rate of flow responsive telemetric transmitter 230 and a conduit 231 to the sink 229. The furnace head water jacket 3*b*, furnace shell water jacket 3*a* and the electrode support jacket 225 discharge through conduits 232, 233 and 234 respectively to the sink 229. The sink 229 is open at the top, and is located where it is visible to the operator. It therefore provides the operator with a direct visible check on the fact that water is flowing through all the cooling jackets. The operator also receives from his observation of that sink a rough indication of the presence of any excessive temperature in any cooling jacket. This indication is a change from the normal condition of the vapor rising from the sink. The sink 229 discharges back into the tank 211 through a conduit 235.

The location of the flow responsive transducers 227, 230 and 246 downstream from the respective water jackets which they protect, as shown in FIG. 8, is effective to enhance the safety of operation of the furnace. When the flow transducers are so located, they detect a flow stoppage from any cause. For example, a flow stoppage might be caused either by a leak, by the clogging of a conduit, or by the failure of the pump. If any one of these occurs, the resultant decrease in flow is detected by the transducers located as shown. If, on the other hand, the flow detecting transducer were located upstream from the water jacket, it might not detect a decrease in the rate of flow through the water jacket due to a leak between the transducer and the water jacket.

Makeup water is received from the city main or other suitable source through a conduit 236, a valve 237 and a valve 238 in a conduit leading directly into the tank. Water may also flow from the valve 237 through a bypass conduit 239 controlled by a manual valve 240 and an automatic valve 241. A check valve 242 is located downstream from the valve 241 in order to prevent reverse flow through the bypass line.

Five low pressure control devices identified by the reference numerals 243*a*, 243*b*, 243*c*, 243*d* and 243*e* are connected at individual points in the water supply system, as described in detail below. The function of all these low pressure control devices is generally the same, i.e., to cut off the supply of electric current to the arc in the event that the pressure at its particular control locality falls below a desired minimum. The electric circuit by which these low pressure control devices operate is described below in connection with the safety control system of FIG. 9. The use of a multiplicity of such devices increases the safety of the system, since it increases the number of localities where pressure drops may be detected and also increases the rapidity with which a pressure drop may be detected. Such pressure drops are indicative of either leaks, water supply failures, or pump failures.

Control device 243*a* responds to the pressure at the outlet of the pump 214. Control device 243*b* responds to the pressure at the inlet of the manifolds leading to the crucible water jackets. Control device 243*c* responds

to the city main pressure, measured between the manifold valve 240 and bypass valve 241. Control device 243*d* responds to the pressure at the inlet to the furnace head and shell water jackets. Control device 243*e* responds to the pressure at the inlet to the electrode support or power tube cooling jacket.

The valve 241 is biased to open position by a spring 244, and is normally held closed against that spring by a diaphragm 245 subject on its right-hand side, as it appears in the drawing, to the pressure at the discharge side of the main pump 214 and subject on its left-hand side to atmospheric pressure. When the discharge pressure of pump 214 falls below a predetermined value established by the strength of the spring 244, then the valve 241 moves to open position, allowing the water to flow from the city main or other standby supply, direct into the crucible water jackets. The check valve 217 then prevents backflow from the city main through the pump 214 or through the other jackets.

It should be borne in mind that if the discharge pressure of pump 214 fails, the low pressure control 243*a* immediately operates to shut down the arc current, thereby terminating the heating in the furnace. The valve 241 operates at the same time to switch the water jackets to the city main, so that the cooling of those jackets may continue for the time necessary to cool the crucible, to avoid an explosion which might occur if the water in the jackets were allowed to stop flowing. Such a termination of flow might result in development of steam pressure in the jackets.

Safety Control System—FIG. 9

This figure illustrates diagrammatically the wiring diagram for the power supply system for the arc circuit. The system includes a circuit breaker 247, manual controls for operating the circuit breaker and automatic controls for tripping the circuit breaker upon the occurrence of any of several potentially dangerous conditions in the furnace.

The power supply for the electrode circuit of the furnace comes from a three-phase A.C. power line 248, 249, 250. The current flows from these lines through the contacts of the circuit breaker 247 to a bank of rectifiers schematically indicated at 251 which supply the electrode circuit of the furnace, which is schematically indicated at 252. The circuit breaker 247 is provided with a closing coil 253 and a tripping coil 254. The circuit breaker is of the type which latches in either of its closed or tripped positions by mechanical means. In order to transfer it from one of its positions to the other, it is necessary to energize the proper coil for a short interval.

The closing coil is energized from a single circuit which may be traced from the line 248 through coil 253, a contact C of a manual switch 255 and thence through a wire 256 to supply line 249. The tripping coil 254 also has an energizing circuit controlled by switch 255, which may be traced from line 248 through coil 254, contact T of switch 255 and line 256 to power supply line 249.

The circuit breaker 247 operates a contact 247*a* which controls the energization of red and green signal lights 257 and 258. Red signal light 257 is energized through an obvious circuit when the main contacts of the breaker are closed, and green signal light 258 is energized when the main breaker contacts are open.

An emergency circuit for energizing the tripping coil 254 extends through that coil and a push button switch 365, located at the principal control station. Other emergency controls for manual operation at other localities may be provided if desirable.

A group of automatic controls is provided for energizing the tripping coil in response to the various low water pressure controls 243*b* to 243*e* inclusive. Only one such control is shown in the wiring diagram, for purposes of simplification. As there shown, the water pressure control operates an expansible bellows 261 connected to a switch finger 262. The switch finger 262 is normally open but if the pressure in the bellows 261 drops below a predetermined value, the switch 262 closes, completing an energizing circuit between conductor 256 and a conductor 263 which is connected in series with the tripping coil.

Another safety control operates in response to the water pump discharge pressure and is provided with a latching relay and with signals. The pump discharge pressure responsive control device 243*a* is connected to an expansible bellows 265 which operates a switch finger 266 movable between two stationary contacts. In the normal position shown, the switch 266 completes an energizing circuit for a green signal light 267. This circuit may be traced from power supply line 248 through a conductor 268, switch 266, signal light 267 and a conductor 269 back to power supply line 249. If the pump discharge pressure falls below a predetermined value, the switch 266 moves to its opposite circuit closing position, where it completes an obvious circuit for a red signal light 270 and for the latching winding 271 of a latching relay generally indicated at 272. The latching relay has a contact 273 connected between the conductors 256, 263, so that when the relay is latched it completes a circuit for the tripping coil 254 of circuit breaker 247. The latching relay has a holding contact 274. When the relay is latched, contact 274 completes a circuit for the winding 271 which may be traced from power supply line 248 through wires 268 and 275, normally closed contacts of a manually operable push-button switch 276, the contact 274 and latching winding 271 to wire 269 and thence to power supply line 249.

Energization of the latching winding 271 results in closing of contact 273, thereby energizing the tripping coil 254 of the circuit breaker 247, cutting off the supply of current to the furnace arc and shutting the furnace down. The latching relay 272 may be reset manually by operating the push-button switch 276, which has a set of normally open contacts controlling an obvious energizing circuit for the unlatching winding 277 of the relay 272.

The three control devices 227, 230 and 246 of FIG. 8, which respond to the rate of water flow through the various cooling jackets, cooperate to control a green signal light 278, a red signal light 279, and a latching relay 280. The rate of flow responsive control devices may be simple flow responsive switches including an orifice or Venturi in the line whose flow is to be measured and a diaphragm subject to the pressure drop across the orifice or between the entrance and the throat of Venturi. The diaphragm or other control device is connected to a switch finger. The several switch fingers are respectively identified as 227*a*, 230*a* and 246*a*. These switch fingers are connected in parallel. Each of the three switch fingers is movable between a normal position in which it connects conductor 268 to a conductor 281 in series with the green signal lamp 278 and an emergency position in which it connects conductor 268 to a conductor 282 which is connected in parallel to the red signal lamp 279 and the latching winding 283 of latching relay 280. The latching relay 280 also has an unlatching winding 284 controlled by a manually operable reset switch 285. The operation of the latching relay and the reset switch 285 is entirely analogous to the operation of the latching relay 272 and reset switch 276 described above. A detailed description of latching relay 280 and reset switch 285 is therefore considered to be unnecessary.

The excess pressure control devices 187 and 188 of FIG. 7 are shown in FIG. 9 to control a red signal lamp 286, a green signal lamp 287 and a latching relay 288. The latching relay 288 is provided with a manual reset switch 289. The pressure controls 187 and 188 operate switches 187*a* and 188*a* between normal positions shown in the drawing in which they connect conductor 268 to a conductor 290 connected in series with the green signal lamp 287, and an emergency position in which they connect conductor 268 to a conductor 291 which supplies the

red signal lamp 286 and the latching relay 288 in parallel. The switches 137*a* and 138*a* are moved to their emergency positions whenever the pressure inside the furnace exceeds a predetermined value. The operation of the latching relay 288 and the reset switch 289 is analogous to that of relay 272 and reset switch 276, and will not be repeated in detail.

While I have shown and described a preferred embodiment of my invention, other modifications thereof will readily occur to those skilled in the art and I therefore intend my invention to be limited only by the appended claims.

I claim:

1. A furnace for melting a substance having at its melting point a chemical affinity for an atmospheric gas, comprising a crucible, means for producing heat in said crucible sufficient to melt a charge of said substance therein, means for controlling said heat producing means, means sealing said crucible against the entry of atmospheric gases, means for supplying an inert gas to the interior of said crucible, means for controlling the pressure of the gas in the crucible, and means responsive to the pressure of the gas in the crucible and operatively connected to said controlling means, said pressure responsive means being effective when the gas pressure in said crucible exceeds a predetermined value to cut off the supply of heat to said crucible.

2. A furnace as defined in claim 1, in which said means for controlling the gas pressure in the crucible comprises a vacuum pump and pressure regulating means for maintaining the inlet pressure at the pump at a value substantially below atmospheric pressure, and said pressure responsive means is effective to cut off the supply of heat when the pressure exceeds a value higher than that maintained by the regulating means but also substantially below atmospheric pressure.

3. A furnace comprising means for producing heat therein, means for controlling said heat producing means, cooling jacket means on said furnace, means for producing a flow of coolant through said cooling jacket means, and means responsive to the rate of flow of coolant, located downstream from the cooling jacket means and operatively connected to said controlling means, said rate of flow responsive means being effective when said rate of coolant flow falls below a predetermined value to operate said controlling means to cut off the supply of heat to said furnace.

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