

[72] Inventors **Hans G. Hirsbrunner;**
Lindsey M. Rice, both of Attleboro, Mass.
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[73] Assignee **Texas Instruments Incorporated**
Dallas, Tex.

Primary Examiner—Edward G. Favors

Attorneys—Harold Levine, Edward J. Connors, Jr., John A. Haug, James P. McAndrews and Gerald B. Epstein

ABSTRACT: Apparatus for controlling the operation of a furnace having an electrically energizable fuel valve, which, when energized, supplies fuel to the furnace burner. An ignition circuit generates recurrent sparking, when energized upon the demand of a thermostat, and ceases to regenerate sparking after ignition of the fuel. A triggerable semiconductor current-switching device is interconnected with the fuel valve. Upon generation of sparking by the ignition circuit the device is triggered and this initially energizes the valve. Means is included for maintaining energization of the fuel valve following initial energization thereof by the switching device. A power circuit supplies power to the switching device and the fuel valve when the thermostat demands heat. A thermistor is connected for causing interruption of this supply of power if the thermistor is heated above a predetermined threshold temperature. Means for heating the thermistor is interconnected with the ignition circuit to cause heating of the thermistor when sparking is generated. Upon heating, the thermistor requires a predetermined heating time interval to reach the threshold temperature and thus, if the fuel is not ignited in the predetermined interval, the supply of power to the fuel valve is interrupted, thereby shutting off the supply of fuel to the burner.

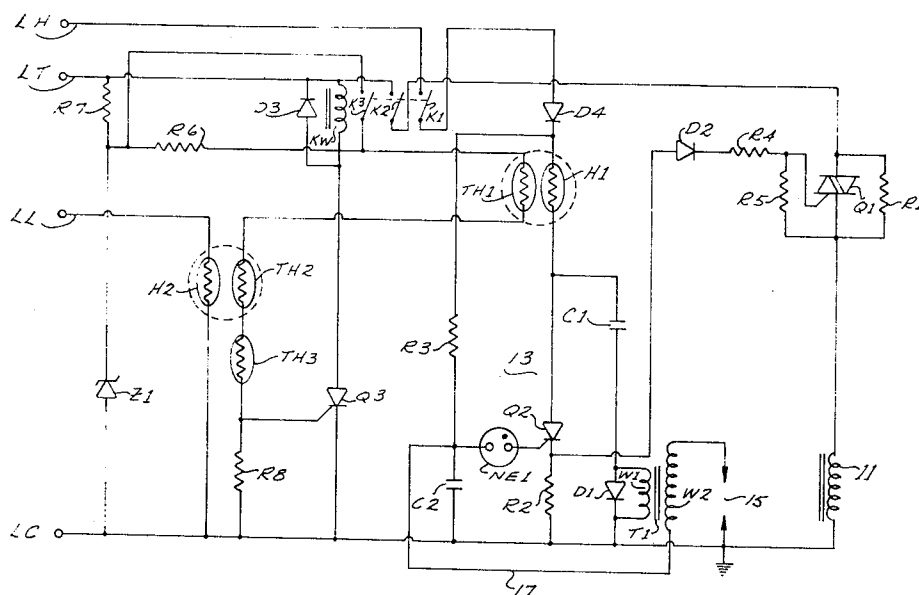
[54] ELECTROTHERMAL FURNACE CONTROL
16 Claims, 2 Drawing Figs.

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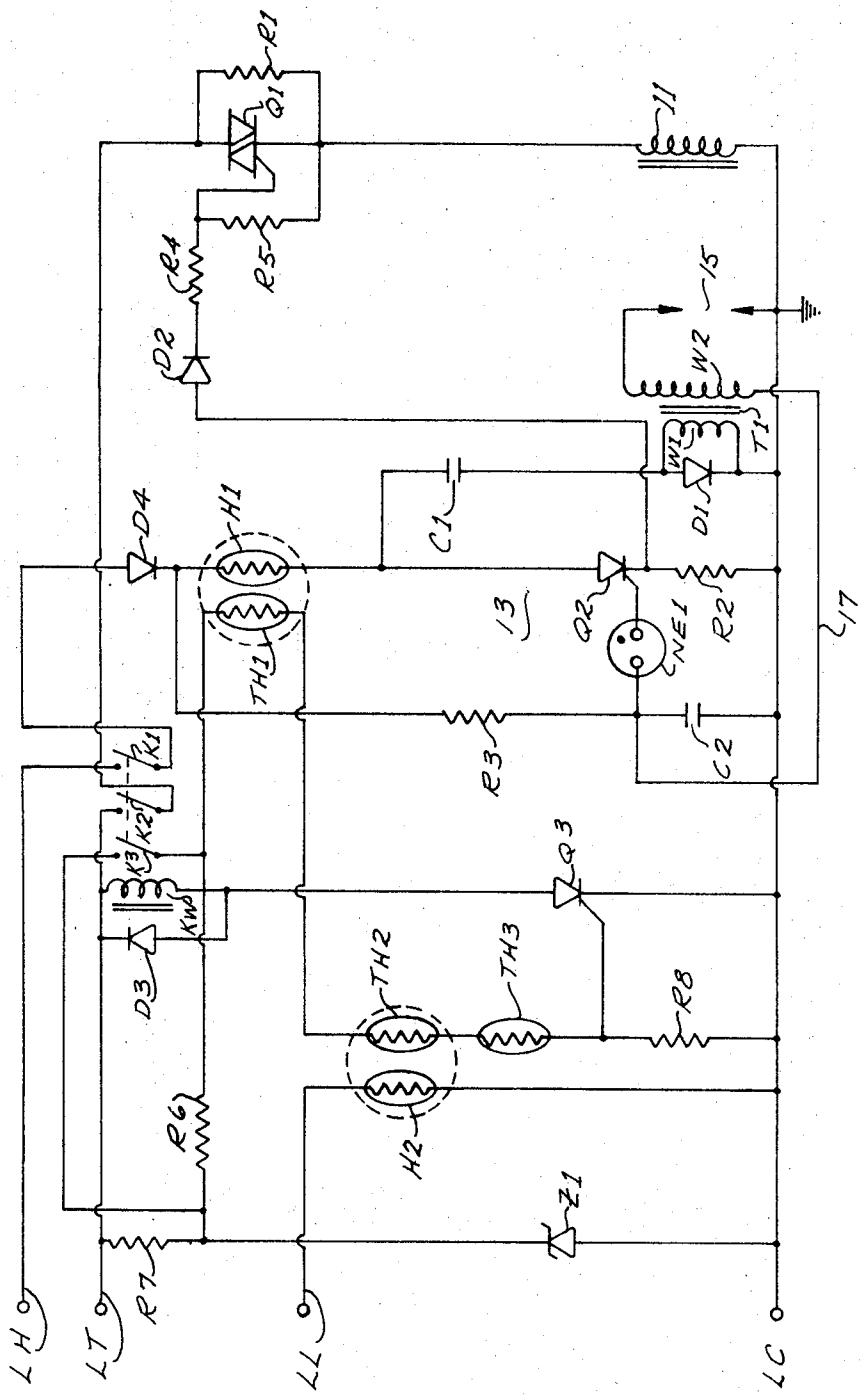


FIG. 1

HANS G. HIRSBRUNNER
LINDSEY M. RICE
INVENTORS

ELECTROTHERMAL FURNACE CONTROL

This invention relates to apparatus for controlling the operation of a furnace and, more particularly, to simple furnace control apparatus for carrying out various required furnace control and protective functions through the use of solid-state electrothermal circuitry.

This invention is an improvement of the electrothermal furnace control disclosed in application Ser. No. 822,901, filed May 8, 1969. That application disclosed a furnace control apparatus for carrying out furnace control and protective functions through the use of essentially wholly electronic circuitry, as contrasted with electromechanical apparatus, with a high degree of safety, reliability and with fail-safe operation. While entirely satisfactory in these respects, the circuit disclosed in that application can be simplified in certain desirable ways.

Accordingly, among the several objects of the present invention may be noted the provision of relatively simple apparatus for carrying out required furnace control and protective functions employing solid-state devices and electrothermal logic; the provision of such apparatus for terminating the supply of fuel to the burner of a furnace if the fuel does not ignite within a predetermined ignition trial time interval following initiation of a heating cycle; the provision of such apparatus for terminating the supply of fuel to the burner if the temperature in the plenum of the furnace exceeds a predetermined maximum; the provision of such apparatus for preventing supply of fuel to the burner upon initiation of a heating cycle if the furnace has insufficient draft; the provision of such apparatus which either automatically resets or is manually resettable for recycling if the fuel does not ignite with a predetermined time interval following initiation of a heating cycle; the provision of such manually resettable apparatus wherein an ignition means continues to be energized for generating sparking for attempting ignition of the fuel but at a reduced sparking rate; the provision of such automatically resettable apparatus wherein the recycling time interval is substantially greater than the ignition trial interval; the provision of such apparatus for controlling a furnace with a high degree of safety, reliability and with fail-safe operation; and the provision of such apparatus which is simple and is easily and economically manufactured. Other objects and features will be in part apparent and in part pointed out hereinafter.

Briefly, apparatus of the present invention controls the operation of a furnace in response to the demand of a thermostat sensing the temperature of a zone heated by the furnace. The furnace includes a burner and an electrically energizable fuel valve which, when energized, supplies fuel, e.g., gas, to the burner. The apparatus includes an ignition means which, upon energization, generates recurrent sparking to cause ignition of the fuel. The ignition means is energized when the thermostat demands heat and ceases to generate sparking after ignition of the fuel. A triggerable semiconductor current-switching device is interconnected with the fuel valve and, when triggered, is conductive to cause initial energization of the fuel valve. Means is provided for normally supplying triggering current to cause triggering of the switching device when the ignition means generates sparking and means is provided for maintaining the energization of the fuel valve following its initial energization by the switching device. Included in the apparatus is a power circuit for supplying power to the switching device and to the fuel valve when the thermostat demands heat. A thermistor is connected for causing interruption of the supply of power from the power circuit, thereby causing deenergization of the fuel valve, if the thermistor is heated above a predetermined threshold temperature. Finally, a means is provided for heating the thermistor and is interconnected with the ignition means so that it is energized to cause heating of the thermistor when the ignition means generates sparking. Upon heating, the thermistor requires a predetermined heating time interval to reach its threshold temperature. If the fuel is not ignited within the predetermined inter-

val, the thermistor causes interruption of the supply of power from the power circuit and thus deenergizes the fuel valve to prevent the fuel from being further supplied to the burner.

In the accompanying drawings, in which are illustrated two of various possible embodiments of the invention,

FIG. 1 is a circuit schematic diagram of a first embodiment of apparatus of this invention which automatically resets for recycling if fuel supplied to the burner of the furnace is not ignited within a predetermined time interval following initiation of a heating cycle; and

FIG. 2 is a schematic circuit diagram of a furnace control apparatus of the present invention which is manually resettable if the fuel supplied to the furnace burner is not ignited within the predetermined time interval.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

Referring now to FIG. 1, there is illustrated a first embodiment of an electrothermal furnace control of this invention which is adapted to control a furnace such as a gas-fired, forced hot-air furnace conventionally used for residential heating. The furnace is of the type having a burner to which gas is supplied for combustion when a solenoid operated fuel valve is opened by energization of its winding 11, all generally as described and illustrated in the aforesaid patent application. The apparatus controls the operation of the furnace in response to the demand of a conventional thermostat (not shown) which senses the temperature of a zone heated by the furnace. A line LT is provided for connection in conventional manner to a thermostat, the line being energized by a suitable low voltage, e.g., 24 v.a.c. with respect to common line LC, whenever the thermostat circuit closes thus indicating a demand for heating of the zone wherein the thermostat is located. A line LL is provided for connection of the apparatus to a continuous source of AC power preferably of the same low AC voltage, i.e., 24 v.a.c. with respect to common line LC. A line LH is provided for connection of the apparatus to an AC source of a higher potential, e.g., line voltage at 115 v.a.c. with respect to common line LC.

The fuel valve is of the type requiring a predetermined higher level of energization for initially opening to supply fuel to the burner and requiring a predetermined lesser level of energization for continuing to supply fuel. Connected in a series circuit with fuel valve winding 11 are the main terminals of a triac Q1 which, as will be appreciated by those skilled in the art, is a triggerable semiconductor current-switching device which is rendered conductive between the main terminals thereof when a triggering current is supplied to its triggering terminal. A resistor R1 is connected across the main terminals of triac Q1 for a purpose which will be explained.

Indicated generally at 13 is an ignition circuit which, upon energization, generates recurrent sparking for igniting the fuel supplied to the burner of the furnace. The circuit includes a triggerable semiconductor switching device constituted by a silicon controlled rectifier (SCR) Q2 having its anode and cathode terminals connected in a circuit with a capacitor C1, a resistor R2 and the primary winding W1 of a conventional spark transformer T1. The winding W1 is shunted by a so-called halfback diode D1 for suppressing inductively induced voltage thereacross on deenergization of the winding. Spark transformer T1 includes a high voltage winding W2 connected with a pair of electrodes located at the burner for causing ignition of the fuel by recurrent sparking thereacross. Interconnected with the gate or triggering terminal of the SCR Q2 are a neon bulb NE1 and a capacitor C2, one side of the capacitor being connected to the common lead LC. A connection 17 is provided from the junction of capacitor C2 and neon bulb NE1 to one side of high voltage winding W2 for a purpose to be explained. The capacitor is adapted to be charged through a resistor R3. A triggering circuit for supplying a triggering current to the triggering terminal of triac Q1 includes a diode D2 and a resistor R4 in a series circuit connecting the triggering terminal of triac Q1 and the cathode terminal of SCR Q2, and a resistor R5 interconnecting the triggering terminal of triac Q1 and the adjacent main terminal thereof.

Another SCR Q3 is connected in a series circuit across lines LT and LC with the winding KW of a conventional magnetic contactor having pairs of normally open contacts K1, K2 and K3 which are closed by energization of winding KW, the latter being energized by triggering of SCR Q3. SCR Q3 and the contactor together constitute a power circuit for supplying power to ignition circuit 13 and the fuel valve circuit. A half-back diode D3 is connected across winding KW for suppressing any inductively induced voltage on deenergization of the winding. Contacts K1 are adapted, when closed, to complete a series circuit including a diode D4 and a thermistor H1 for energization of ignition circuit 13. When contacts K2 are closed, a series circuit is completed to supply power from thermostat line LT to triac Q1 and fuel valve winding 11 when the thermostat demands heat. When closed, contacts K3 shunt a resistor R6 which is part of a triggering circuit interconnected with the triggering terminal of SCR Q3. This triggering circuit is connected to supply triggering current from line LT to SCR Q3 and includes a resistor R7, resistor R6 and thermistors TH1, TH2 and TH3. A resistor R8 interconnects the triggering terminal of triac Q3 and common line LC. A Zener diode Z1 is connected from the junction of resistors R6 and R7 to common line LC for regulating the voltage provided to this triggering circuit.

Thermistor TH1 has a positive temperature coefficient of resistivity (PTC) and a well-defined transition temperature, e.g., 80° C., above which the resistance thereof increases relatively abruptly. Thermistor H1 is a heater thermistor which is thermally coupled to thermistor TH1 to provide means, when energized, for heating the latter. Preferably thermistor H1 is also a PTC type of thermistor and also has a well-defined transition temperature above which its resistance increases relatively abruptly, its transition temperature being somewhat higher, e.g., 120° C., that of thermistor TH1. As will be explained, if thermistor TH1 is heated above a predetermined threshold temperature, corresponding with its transition temperature, triggering of SCR Q3 will be prevented. Upon being heated by thermistor H1, thermistor TH1 requires a predetermined heating time interval, e.g., 4—10 seconds, to reach this threshold temperature and thus thermistors TH1 and H1 together constitute an electrothermal timer.

Thermistor TH2 is provided with a heater thermistor H2 interconnecting lines LL and LC. Thermistor H2 is thermally coupled to thermistor TH2 to provide means for heating the latter. Thermistors TH2 and H2 are both PTC types having well-defined transition temperatures above which the resistance thereof increases relatively abruptly, thermistor TH2 having a transition temperature, for example, of 80° C. and that of thermistor H2 being, for example, 120° C. Thermistor TH2 and H2 together constitute a draft sensor or air flow sensor and are suitably mounted in a furnace air draft duct or in conjunction with a draft blower of the furnace for causing thermistor TH2 to be cooled by the forced air draft as long as there is sufficient forced draft provided to the burner. Thermistor TH2 is, like thermistor TH1, adapted to prevent triggering current from being supplied to the gate terminal of SCR Q3 when thermistor TH2 is heated above a predetermined threshold temperature corresponding to its transition temperature. The thermal coupling between thermistors H2 and TH2 is such that thermistor H2 normally supplies insufficient heat to cause thermistor TH2 to be heated above its transition temperature as long as there is sufficient forced draft for cooling it, but causes heating of the thermistor above its threshold temperature if there is insufficient forced draft.

Thermistor TH3 is a plenum temperature sensing thermistor and is located in the plenum of the furnace for sensing the temperature therein. Like thermistors TH1 and TH2, thermistor TH3 is also a PTC thermistor preferably having a well-defined transition temperature above which the resistance thereof increases relatively abruptly. When heated above a predetermined threshold temperature corresponding to a maximum permissible temperature in the plenum, thermistor TH3 also prevents triggering of SCR Q3.

In the operation of the control, it is assumed that lines LL and LH are connected to appropriate sources of power, e.g., 24 and 115 v.a.c., respectively, that a sufficient forced air draft is being satisfactorily provided to the burner and that the plenum of the furnace is cool. Thus, thermistors TH2 and TH3 are relatively cool and, accordingly, exhibit a low resistance.

With regard to the draft sensor or air flow sensor constituted by thermistors TH2 and H2, it will be appreciated that, when line LL is connected to a low voltage a.c. source, heater thermistor H2 self-heats due to internal resistive consumption of power until it reaches the transition temperature of the thermistor material therein, whereupon the resulting increase of its resistance causes a decrease in the power consumed to maintain the thermistor substantially at the transition temperature. However, as long as there is a sufficient forced air draft, thermistor TH2 remains relatively cool. Since contacts K1 are opened, no power is supplied to heater thermistor H1 and accordingly, thermistor TH1 is also relatively cool.

When the thermostat in the zone which is heated by operation of the furnace demands heat, the thermostat supplies AC voltage, i.e., 24 v.a.c., to line LT, such as by closing a pair of contacts in the thermostat, as is conventional. Since thermistors TH1, TH2 and TH3 each exhibits a relatively low resistance, a triggering current is supplied to the gate or triggering terminal of SCR Q3, which is forward biased on alternate half cycles of the waveform of the AC voltage applied across its main terminals through the contactor winding KW. SCR Q3 is accordingly triggered to energize contactor winding KW.

Energization of winding KW closes the normally open contacts K1, K2 and K3. The closing of contacts K1 completes a circuit from line LH through diode D4 and heater thermistor H1 to energize ignition circuit 13, the voltage appearing between lines LH and LC forward biasing SCR Q2 on alternate half cycles of the applied AC waveform. The power supplied through thermistor H1 also causes capacitor C1 to quickly charge to peak voltage. Simultaneously, current is supplied through resistor R3 to charge capacitor C2. When the voltage across capacitor C2 reaches a sufficient level, neon bulb NE1 breaks down or conducts to supply a triggering current to the gate terminal of SCR Q2. SCR Q2 is thereby triggered and becomes conductive, discharging capacitor C1 through the primary winding W1 of transformer T1. Secondary winding W2 steps up the voltage across winding W1 to cause sparking across electrodes 15. Resistor R3 limits the current which can flow to charge capacitor C2 so that it charges in somewhat more time than capacitor C1 and thus capacitor C1 is ready for discharge when capacitor C2 reaches the breakdown voltage of neon bulb NE1. Capacitor C2 reaches this breakdown voltage many times per second, causing repetitive triggering of SCR Q2 and thus providing recurrent sparking across electrodes 15.

Upon triggering of SCR Q2, the voltage drop across resistor R2 is supplied through the connection including diode D2 and resistor R4 to the triggering terminal of triac Q1. The closed contacts K2 provide triac Q1 with voltage across its main terminals and thus triac Q1 is triggered and conducts to initially energize fuel valve winding 11 at the level of energization required for initially supplying fuel to the burner. Diode D2 and resistor R4 thus provide means for supplying triggering current to the triggering terminal of triac Q1 for initially energizing the fuel valve, with resistors R4 and R5 together constituting a voltage divider for applying the triggering current at the proper voltage.

The recurrent sparking across electrodes 15 ignites the gas. When ignition occurs, the presence of flame at electrodes 15 provides a conductive path thereacross. By virtue of a conductor 17 connecting the lower side of a winding W2 to the top of capacitor C2, the resultant conductive path across electrodes 15 causes capacitor C2 to be discharged and to remain discharged so long as combustion continues. When capacitor C2 is discharged, SCR Q2 ceases to be triggered and thus igni-

tion circuit 13 ceases to generate sparking after ignition of the fuel. When triggering of SCR Q2 ceases, triggering current ceases to be supplied through diode D2 and resistor R4 to triac Q1 and thus it, too, ceases to conduct. However, and in accordance with this invention, resistor R1 provides means for maintaining energization of the fuel valve following initial energization thereof by triac Q1. Resistor R1 provides a power connection from line LT to winding 11 and thus energizes the winding at the predetermined lesser level required for continuing to supply fuel to the burner. If, while the thermostat continues to demand heat, combustion at the burner should cease, capacitor C2 will be permitted to charge and SCR Q2 will thus once more be repetitively triggered to generate sparking across electrodes 15. It will also be appreciated that, with such a fuel valve energizing circuit, should power to the fuel valve winding be momentarily interrupted, the valve will close and terminate the supply of fuel to the burner until such time as ignition circuit 13 once more generates sparking and thereby again triggers triac Q1. Operation is thus fail-safe if either the ignition circuit or fuel valve circuit should fail.

With the ignition circuit 13 thus deenergized but with combustion continuing at the burner, the furnace supplies heat to the zone in which the thermostat is located until the thermostat circuit between LT and LC opens thereby indicating no further demand for heat. When this occurs, the thermostat ceases to supply voltage to line LT and thus triggering current ceases to be supplied to SCR Q3, thereby deenergizing contactor winding KW and opening contacts K1, K2 and K3.

It should be noted that so long as SCR Q2 is triggered to generate sparking across electrodes 15, thermistor H1 is concomitantly energized with ignition circuit 13 by the power drawn thereby and thus self-heats to cause heating of thermistor TH1. Upon being heated by heater thermistor H1, thermistor TH1 requires a predetermined heating time interval, i.e., 4-10 seconds, to reach the predetermined threshold temperature at which it will prevent further triggering of SCR Q3. Thus, if ignition circuit 13 does not cease generating sparking as a result of the discharge of capacitor C2 by conduction across electrodes 15 caused by fuel combustion, thermistor TH1 will be heated sufficiently to cause triggering of SCR Q3 to cease. When this occurs, contactor winding KW is deenergized and contacts K1, K2 and K3 are permitted to open. In other words, if ignition does not occur within this predetermined ignition trial time interval, thermistor TH1 acts to interrupt the supply of power from the power circuit, since the opening of contacts K2 deenergizes the circuit including triac Q1 and fuel valve winding 11 to prevent fuel from being further supplied to the burner.

Such a deenergization of contactor winding KW also opens contacts K1 to deenergize ignition circuit 13. This permits heater thermistor H1, and thus thermistor TH1, to cool. If the thermostat continues to demand heat, line LT will remain energized with AC voltage so that, when thermistor TH1 has cooled sufficiently, SCR Q3 is retriggered to cause automatic resetting for recycling of the control and thus reenergizes ignition circuit 13 and fuel valve winding 11 to cause a new ignition attempt. If ignition of the fuel still fails to occur, thermistor TH1 is again heated and causes triggering of SCR Q3 to cease. Such recycling continues indefinitely as long as the thermostat continues to demand heat.

It will be noted that resistor R6 is shunted by contacts K3 as long as contactor winding KW is energized to cause these contacts to be closed, but that resistor R6 is, in effect, switched into the triggering circuit for SCR Q3 whenever contacts K3 open. Thus SCR Q3 is initially triggered at a first voltage for initial triggering thereof when contacts K3 are open, but is triggered at a higher voltage for continuing triggering thereof when contacts K3 close and shunt resistor R6. This has the effect of altering the response of thermistor TH1 to cause the interval during which it is cooled from the predetermined threshold temperature at which triggering of SCR Q3 ceases to the temperature at which SCR Q3 is once more triggered to be substantially greater than its heating interval. In other

words, the recycling time interval of the control is substantially greater than the ignition trial interval and thus desirably permits purging of any accumulated gas between ignition attempts. The effect of switching resistor R6 into the triggering circuit for SCR Q3 upon heating of thermistor TH1 to its threshold temperature is to provide an interval in which thermistor TH1 requires, for example, from 20-40 seconds to recool for causing a new ignition attempt.

In a manner similar to the operation of thermistor TH1, if either of thermistors TH2 or TH3 is heated above the threshold temperature thereof, triggering of SCR Q3 ceases. Thus, if insufficient draft is supplied to the burner, heating of thermistor TH2 by thermistor H2 causes thermistor TH2 to exceed a threshold temperature at which insufficient current will be supplied to the triggering terminal of SCR Q3 to cause triggering thereof. Similarly, if the temperature in the furnace plenum should be excessive, plenum temperature sensing thermistor TH3 will be heated above its threshold level, causing triggering of SCR Q3 to cease.

FIG. 2 illustrates a second embodiment of this invention which is manually resettable in the event that the fuel supplied to the furnace burner is not ignited within the predetermined time interval.

A thermistor TH1' heated by H1 is connected in a series circuit with fuel valve winding 11 and thus, when heated above its predetermined threshold, substantially prevents the gas valve from being energized for supplying fuel to the burner. More specifically, if so heated, thermistor TH1' prevents energization of the fuel valve at the level of energization required for continuing to supply fuel. As in the embodiment for FIG. 1, heater thermistor H1 is connected for concomitant energization of ignition circuit 13 when the latter generates sparking. The triggering circuit for SCR Q3 includes only resistors R7, R6 and R8, and thermistors TH2 and TH3. Thus, on a demand for heat by the thermostat, energization of line LT causes triggering of SCR Q3 to energize contactor winding KW. Its energization closes contacts K1 and K2 and power is thereby supplied to ignition circuit 13 and to the circuit including triac Q1, thermistor TH1' and fuel valve winding 11. Ignition circuit 13 operates in the same manner as in the embodiment of FIG. 1 and when SCR Q2 is triggered, triggering current is supplied through diode D2 and resistor R4 for triggering of triac Q1, energizing gas valve winding 11 to supply fuel to the burner. If the fuel is successfully ignited, the conductive path provided by the flame across electrodes 15 causes ignition circuit 13 to cease generating sparking. This deenergizes thermistor H1 and terminates further heating of thermistor TH1'.

However, if ignition should not be successful, continued energization of thermistor H1 causes heating of thermistor TH1' so that, within a predetermined time interval, it reaches the threshold temperature at which fuel valve winding 11 will be insufficiently energized to continue supplying fuel to the burner. When this occurs, triggering of SCR Q3 does not cease. Accordingly, power continues to be supplied to the circuit including triac Q1, thermistor TH1' and gas valve winding 11 and to ignition circuit 13. The ignition circuit thereby remains energized. However, continued energization of thermistor H1 causes its resistance to increase until it is maintained substantially at the transition temperature. This increased resistance reduces the level of energization of the ignition circuit and causes capacitor C1 to charge at a somewhat lower rate. Accordingly, SCR Q2 is triggered less frequently and thus sparking across electrodes 15 is generated at a reduced sparking rate. This has the advantages of reducing erosion of the electrodes and yet permitting thermistor TH1 to remain heated for preventing fuel from being supplied to the burner. The control accordingly remains in this condition with the fuel valve deenergized for preventing fuel from being further supplied to the burner and with the ignition circuit remaining energized but generating sparking at a reduced rate. In other words, the control remains "locked out" of operation. However, it may be manually reset for a new igni-

tion attempt by disconnecting lines LH or LT from their respective sources of power, as by opening the thermostat circuit to interrupt the supply of power to line LT, or by breaking the circuit to line LH (as by opening the usual furnace main power switch).

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What I claim is:

1. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature of a zone heated by the furnace, the furnace having a burner and an electrically energizable fuel valve which, when energized, supplies fuel to the burner, said apparatus comprising:

ignition means which, upon energization, generates recurrent sparking for igniting the fuel, said ignition means being energized when the thermostat demands heat and ceasing to generate sparking after ignition of the fuel;

a triggerable semiconductor current-switching device interconnected with the fuel valve and, when triggered, being conductive for initially energizing the fuel valve;

means for normally supplying triggering current to cause triggering of said switching device when said ignition means generates sparking;

means for maintaining energization of the fuel valve following initial energization thereof by said switching device;

a power circuit for supplying power to said switching device and the fuel valve when the thermostat demands heat;

a thermistor connected in a series circuit with the fuel valve for causing interruption of the supply of power from said power circuit thereby deenergizing the gas valve when said thermistor is heated above a predetermined threshold temperature;

means for heating said thermistor comprising a further thermistor thermally coupled to the first said thermistor, connected in series with said ignition means for concomitant energization therewith and being energized to cause heating of said thermistor when said ignition means generates sparking, said further thermistor being deenergized when said ignition means ceases to generate sparking, said thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby if the fuel is not ignited within said predetermined interval, the supply of power to the fuel valve is interrupted to prevent fuel from being further supplied to the burner; and

the resistance of said further thermistor is increased by energization thereof for said predetermined time interval whereby energization of said ignition means is reduced for causing sparking to be generated at a reduced rate.

2. Furnace control apparatus as set forth in claim 1 wherein each of said thermistors has a positive temperature coefficient and a transition temperature above which the resistance thereof increases relatively abruptly, said further thermistor having a higher transition temperature than that of the first said thermistor, said thermistors together constituting an electrothermal timer.

3. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature of a zone heated by the furnace, the furnace having a burner and an electrically energizable fuel valve which, when energized, supplies fuel to the burner, said apparatus comprising:

ignition means which, upon energization, generates recurrent sparking for igniting the fuel, said ignition means being energized when the thermostat demands heat and ceasing to generate sparking after ignition of the fuel;

a triggerable semiconductor current-switching device interconnected with the fuel valve and, when triggered, being conductive for initially energizing the fuel valve;

means for normally supplying triggering current to cause triggering of said switching device when said ignition means generates sparking;

means for maintaining energization of the fuel valve following initial energization thereof by said switching device;

a power circuit including a second triggerable current-switching device which is conductive, when triggered, for causing power to be supplied to the first said switching device and the fuel valve, said second switching device normally being triggered when the thermostat demands heat;

a thermistor connected for causing interruption of the supply of power from said power circuit thereby deenergizing the gas valve when said thermistor is heated above a predetermined threshold temperature, said thermistor being connected in the triggering circuit of said second switching device for preventing triggering thereof when heated above said predetermined threshold temperature; means for heating said thermistor interconnected with said ignition means and being energized to cause heating of said thermistor when said ignition means generates sparking, said thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby if the fuel is not ignited within said predetermined interval, the supply of power to the fuel valve is interrupted to prevent fuel from being further supplied to the burner; and

said power circuit also supplies power to said ignition means and further comprising means, interconnected with said thermistor, for supplying triggering current to said second switching device at a first voltage for initial triggering thereof and at a higher voltage for continued triggering thereof whereby if said thermistor is heated above said predetermined threshold temperature within said predetermined heating interval thereby preventing triggering of said second switching device, said means for heating said thermistor is deenergized and said thermistor cools for a cooling time interval substantially greater than said heating interval, thereby permitting retriggering of said second switching device.

4. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature of a zone heated by the furnace, the furnace having a burner and an electrically energizable fuel valve which, when energized, supplies fuel to the burner, said apparatus comprising:

ignition means which, upon energization, generates recurrent sparking for igniting the fuel, said ignition means being energized when the thermostat demands heat and ceasing to generate sparking after ignition of the fuel;

a triggerable semiconductor current-switching device interconnected with the fuel valve and, when triggered, being conductive for initially energizing the fuel valve;

means for normally supplying triggering current to cause triggering of said switching device when said ignition means generates sparking;

means for maintaining energization of the fuel valve following initial energization thereof by said switching device;

a power circuit including a second triggerable current-switching device which is conductive, when triggered, for causing power to be supplied to the first said switching device and the fuel valve, said second switching device normally being triggered when the thermostat demands heat;

a thermistor connected in a series circuit with the fuel valve for causing interruption of the supply of power from said power circuit thereby deenergizing the gas valve when said thermistor is heated above a predetermined threshold temperature;

means for heating said thermistor interconnected with said ignition means and being energized to cause heating of said thermistor when said ignition means generates sparking, said thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby if the fuel is not ignited within said predetermined interval, the supply of power to the fuel valve is interrupted to prevent fuel from being further supplied to the burner; and

said power circuit includes a magnetic contactor having a winding and respective pairs of contacts connected, when closed, for energizing the first said switching device and the gas valve and for energizing the ignition means, said winding being connected with said second switching device and being energized by triggering thereof for causing said contacts to close.

5. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature of a zone heated by the furnace, the furnace having a burner and an electrically energizable fuel valve which, when energized, supplies fuel to the burner, said apparatus comprising:

ignition means which, upon energization, generates recurrent sparking for igniting the fuel, said ignition means being energized when the thermostat demands heat and ceasing to generate sparking after ignition of the fuel;

a triggerable semiconductor current-switching device interconnected with the fuel valve and, when triggered, being conductive for initially energizing the fuel valve;

means for normally supply triggering current to cause triggering of said switching device when said ignition means generates sparking;

means for maintaining energization of the fuel valve following initial energization thereof by said switching device;

a power circuit including a second triggerable current-switching device which is conductive, when triggered, for causing power to be supplied to the first said switching device and the fuel valve, said second switching device normally being triggered when the thermostat demands heat;

a thermistor connected in a series circuit with the fuel valve for causing interruption of the supply of power from said power circuit thereby deenergizing the gas valve when said thermistor is heated above a predetermined threshold temperature;

means for heating said thermistor interconnected with said ignition means and being energized to cause heating of said thermistor when said ignition means generates sparking, said thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby if the fuel is not ignited within said predetermined interval, the supply of power to the fuel valve is interrupted to prevent fuel from being further supplied to the burner; and

a second thermistor mounted for sensing the temperature in a plenum of the furnace and connected in the triggering circuit of said second switching device for preventing further triggering thereof, thereby preventing further energization of the fuel valve, when heated above a predetermined threshold temperature corresponding to a predetermined maximum permissible temperature in said plenum.

6. Furnace control apparatus as set forth in claim 5 wherein said second thermistor has a positive temperature coefficient of resistivity and a transition temperature above which the resistance thereof increases relatively abruptly.

7. Furnace control apparatus as set forth in claim 5 for controlling the operation of a furnace normally having a forced-air draft supplying the burner, wherein said second switching device includes a triggering terminal and further comprising:

an additional thermistor mounted for being cooled by the forced draft and connected in a series circuit with said second thermistor and said triggering terminal for

preventing triggering of said second switching device when said additional thermistor is heated above a predetermined threshold temperature; and

means for heating said additional thermistor, said means normally supplying insufficient heat to cause said fourth thermistor to be heated above said threshold temperature as long as there is sufficient forced draft, but causing heating of said additional thermistor above said threshold temperatures thereby preventing energization of the fuel valve if there is insufficient forced draft.

8. Furnace control apparatus as set forth in claim 7 wherein said additional thermistor has a positive temperature coefficient of resistivity and a transition temperature above which the resistance thereof increases relatively abruptly, and said means for heating said additional thermistor comprises another thermistor having a positive temperature coefficient of resistivity and a transition temperature higher than that of said additional thermistor and above which the resistance thereof increases relatively abruptly.

9. Furnace control apparatus as set forth in claim 7 wherein said second switching device comprises a silicon controlled rectifier.

10. Furnace control apparatus as set forth in claim 1 wherein said switching device comprises a triac.

11. Furnace control apparatus as set forth in claim 1 wherein said ignition means includes a further triggerable semiconductor current-switching device and generates sparking when said further switching device is triggered.

12. Furnace control apparatus as set forth in claim 11 wherein the first said switching device includes a pair of main terminals and a triggering terminal for controlling conduction between said main terminals, said main terminals being connected in a series circuit with the fuel valve, and said means for normally supplying triggering current comprises circuit means interconnecting said further switching device and said triggering terminal.

13. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature of a zone heated by the furnace, the furnace having a burner and an electrically energizable fuel valve which, when energized, supplies fuel to the burner, said apparatus comprising:

ignition means which, upon energization, generates recurrent sparking for igniting the fuel, said ignition means being energized when the thermostat demands heat and ceasing to generate sparking after ignition of the fuel;

a triggerable semiconductor current-switching device interconnected with the fuel valve and, when triggered, being conductive for initially energizing the fuel valve;

means for normally supplying triggering current to cause triggering of said switching device when said ignition means generates sparking;

means for maintaining energization of the fuel valve following initial energization thereof by said switching device;

a power circuit including a second triggerable current-switching device which is conductive, when triggered, for causing power to be supplied to the first said switching device and the fuel valve, said second switching device normally being triggered when the thermostat demands heat;

a thermistor connected for causing interruption of the supply of power from said power circuit thereby deenergizing the gas valve when said thermistor is heated above a predetermined threshold temperature, said thermistor being connected in the triggering circuit of said second switching device for preventing triggering thereof when heated above said predetermined threshold temperature;

means for heating said thermistor interconnected with said ignition means and being energized to cause heating of said thermistor when said means generates sparking, said thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby if the fuel is not ignited within said predetermined interval, the

supply of power to the fuel valve is interrupted to prevent fuel from being further supplied to the burner; and said power circuit includes a magnetic contactor having a winding and respective pairs of contacts connected, when closed, for energizing the first said switching device and the gas valve and for energizing the ignition means, said winding being connected with said second switching device and being energized by triggering thereof for causing said contacts to close.

14. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature of a zone heated by the furnace, the furnace having a burner and an electrically energizable fuel valve which, when energized, supplies fuel to the burner, said apparatus comprising:

ignition means which, upon energization, generates recurrent sparking for igniting the fuel, said ignition means being energized when the thermostat demands heat and ceasing to generate sparking after ignition of the fuel;

a triggerable semiconductor current-switching device interconnected with the fuel valve and, when triggered, being conductive for initially energizing the fuel valve;

means for normally supplying triggering current to cause triggering of said switching device when said ignition means generates sparking;

means for maintaining energization of the fuel valve following initial energization thereof by said switching device;

a power circuit including a second triggerable current-switching device which is conductive, when triggered, for causing power to be supplied to the first said switching device and the fuel valve, said second switching device normally being triggered when the thermostat demands heat;

a thermistor connected for causing interruption of the supply of power from said power circuit thereby deenergizing the gas valve when said thermistor is heated above a predetermined threshold temperature, said thermistor being connected in the triggering circuit of said second switching device for preventing triggering thereof when heated above said predetermined threshold temperature; means for heating said thermistor interconnected with said ignition means and being energized to cause heating of

said thermistor when said ignition means generates sparking, said thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby if the fuel is not ignited within said predetermined interval, the supply of power to the fuel valve is interrupted to prevent fuel from being further supplied to the burner; and

a second thermistor mounted for sensing the temperature in a plenum of the furnace and connected in the triggering circuit of said second switching device for preventing further triggering thereof, thereby preventing further energization of the fuel valve, when heated above a predetermined threshold temperature corresponding to a predetermined maximum permissible temperature in said plenum.

15. Furnace control apparatus as set forth in claim 14 for controlling the operation of a furnace normally having a forced-air draft supplying the burner, wherein said second switching device includes a triggering terminal and further comprising:

an additional thermistor mounted for being cooled by the forced draft and connected in a series circuit with said second thermistor and said triggering terminal for preventing triggering of said second switching device when said additional thermistor is heated above a predetermined threshold temperature;

means for heating said additional thermistor, said means normally supplying insufficient heat to cause said fourth thermistor to be heated above said threshold temperature as long as there is sufficient forced draft, but causing heating of said additional thermistor above said threshold temperatures thereby preventing energization of the fuel valve if there is insufficient forced draft.

16. Furnace control apparatus as set forth in claim 15 wherein said additional thermistor has a positive temperature coefficient of resistivity and a transition temperature above which the resistance thereof increases relatively abruptly, and said means for heating said additional thermistor comprises another thermistor having a positive temperature coefficient of resistivity and a transition temperature higher than that of said additional thermistor and above which the resistance thereof increases relatively abruptly.

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