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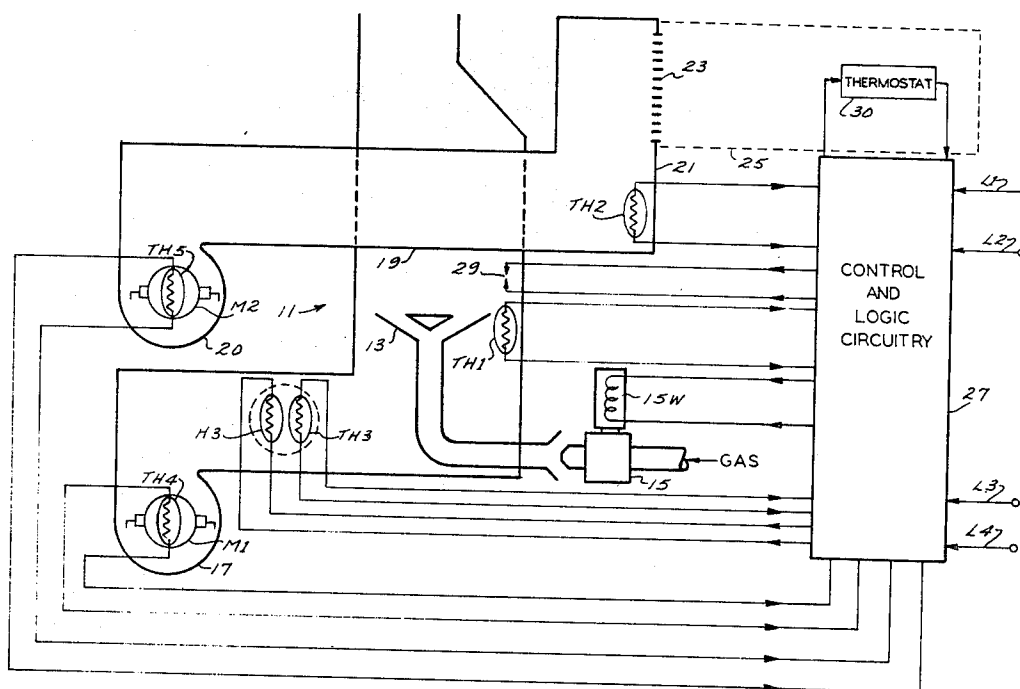
[54] ELECTROTHERMAL FURNACE CONTROL
28 Claims, 2 Drawing Figs.

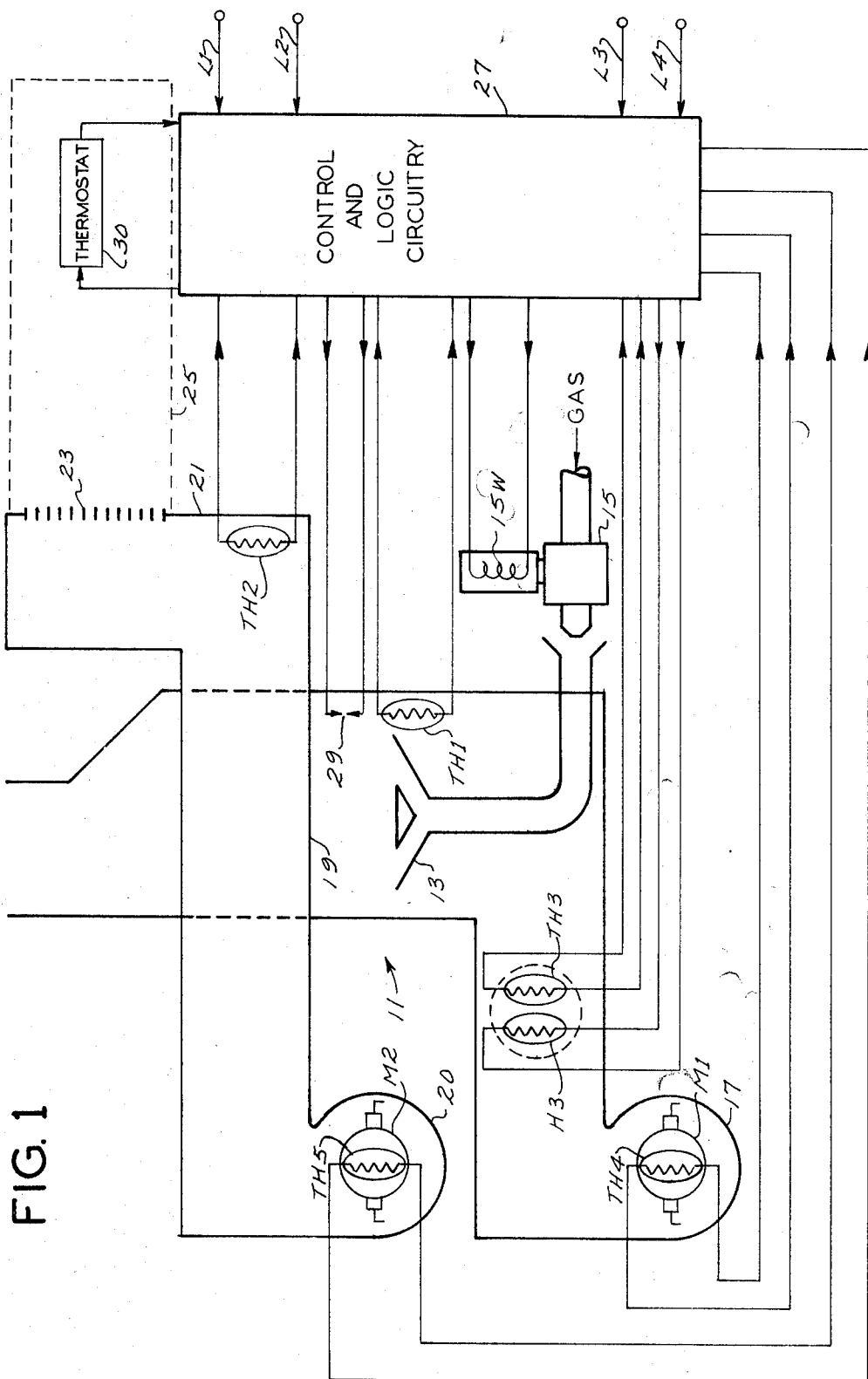
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ABSTRACT: Apparatus for controlling the operation of a furnace in response to the demand of a thermostat. The furnace has an electrically energizable fuel valve which, when energized, supplies fuel to the furnace burner. A triggerable semiconductor current-switching device is conductive, when triggered, to supply power for energizing the fuel valve when the thermostat demands heat. Means is provided for normally supplying triggering current to cause triggering of the switching device. An ignition circuit is provided for igniting the fuel, this circuit being energized to cause ignition when the thermostat demands heat. A thermistor is connected in a circuit with the switching device for preventing energization of the fuel valve when the thermistor is heated above a predetermined threshold temperature. Means is provided for heating the thermistor, this means being connected with the ignition circuit and being energized to cause heating of the thermistor only when the ignition circuit is energized. When heated, the thermistor requires a predetermined heating time interval to reach the threshold temperature. Accordingly, if the fuel is not ignited within this predetermined interval, further energization of the fuel valve is prevented, thereby shutting off the supply of fuel.





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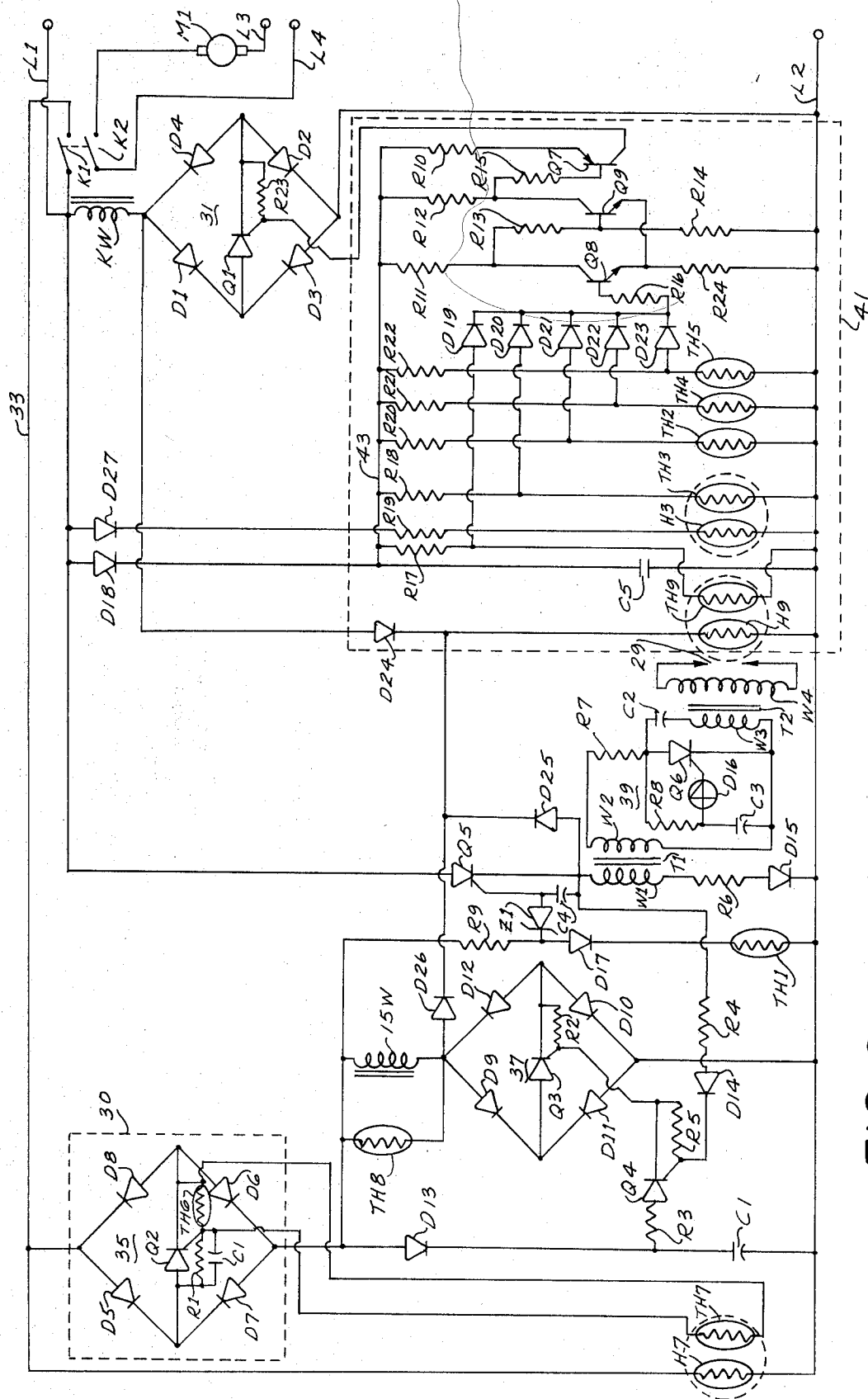


FIG. 2

ELECTROTHERMAL FURNACE CONTROL

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

In furnace control applications, electromechanical apparatus including, inter alia, cumbersome mechanical temperature-sensing elements, electromagnetic devices and the like, have traditionally been employed for carrying out the control and protective functions which are typically required for furnace control. Such an electromechanical approach, as contrasted with essentially wholly electronic methodology, appears to have been dictated by the requirements of safety, economics and the available state of the technological art. However, the development of low-cost solid-state electronic and electrothermal devices, such as semiconductor switching devices, transistors, and thermistors having high reliability, simplicity, and small size, has provided incentive for the utilization of such devices in satisfying furnace control requirements with the promise of safety, economy and superior performance.

Among the several objects of the present invention may be noted the provision of 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 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 delaying the supply of fuel to the burner for a predetermined time interval following initiation of a heating cycle sufficient to allow purging of any dangerous accumulation of fuel at the burner; 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 for controlling a furnace with a high degree of safety, reliability and with fail-safe operation; the provision of such apparatus employing no mechanical thermostatic sensors; the provision of such apparatus having relative insensitivity to variations in ambient temperature and supply voltage; and the provision of such apparatus which is relatively inexpensive. Other objects and features will be in part apparent and in part pointed out hereinafter.

Briefly, according to one important aspect of the invention, 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 has a burner and an electrically energizable valve which, when energized, supplies fuel, e.g., gas, to the burner. The apparatus includes a triggerable semiconductor current-switching device. When triggered, the device is conductive to supply power for energizing the fuel valve when the thermostat demands heat. Means is provided for normally supplying triggering current to cause triggering of the switching device. An ignition circuit is provided which is energized to generate recurrent sparking for igniting the fuel when the thermostat demands heat. A thermistor is connected with the means for supplying triggering current to the switching device and is adapted to cause cessation of the triggering current when the thermistor is heated above a predetermined threshold temperature. A means for heating the thermistor is connected with the ignition means so that the heating means is energized to cause heating of the first thermistor only when the ignition circuit generates sparking. Upon being heated, the thermistor requires a predetermined heating time interval to reach its threshold temperature. If the fuel is not ignited within this predetermined interval, triggering of the switching device ceases, deenergizing the fuel valve and preventing fuel from being further supplied to the burner.

In other aspects of the invention, the apparatus includes means for deenergizing the fuel valve if a plenum temperature

exceeds a predetermined maximum, if there is insufficient forced-air draft being supplied to the burner, or if the temperature of a motor utilized for driving a blower for the furnace exceeds a predetermined maximum. In another aspect, means is provided for preventing the gas valve from being energized for a predetermined interval following a demand for heat sufficient to allow purging of any dangerous accumulation of fuel at the burner.

In the accompanying drawings in which is illustrated one of various possible embodiments of the invention,

FIG. 1 is a block diagram of furnace control apparatus of this invention pictorially represented as controlling the operation of a gas-fired hot-air furnace; and

FIG. 2 is a schematic circuit diagram of a furnace control apparatus of the present invention.

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

Referring now to FIG. 1, illustrated generally at 11 is a gas-fired, forced hot-air furnace which may, for example, comprise a conventional residential heating unit which includes a burner 13 to which gas is supplied for combustion when a solenoid-operated gas valve 15 is opened by energization of its winding 15W. A draft blower 17, normally continuously driven by a motor M1, supplies the burner with a forced-air draft. The furnace includes a heat exchanger 19 and a second blower 20 driven by a motor M2 for forcing air through the heat exchanger to pick up heat from the burner flame. After leaving the heat exchanger, the heated air passes through the plenum 21 of the furnace and then out through duct work 23 into the zone which is to be heated. This zone is indicated generally at 25 and may, for example, comprise the interior of a residential structure.

In accordance with this invention, control and logic circuitry indicated generally at 27 is provided for controlling the operation of the furnace. A pair of electrodes 29 is provided for igniting the gas at the burner 13 when the circuitry 27 supplies a high voltage for causing recurrent sparking across the electrodes. A flame sensing thermistor TH1 is mounted so as to be heated by combustion of the fuel. Another sensing thermistor TH2 is located in plenum 21 for sensing the temperature therein. Positioned in the forced-air draft is a draft sensing thermistor TH3. Thermally coupled to thermistor TH3 to provide means for heating the latter is a heater thermistor H3. Thermistor TH3 is adapted to be cooled by the forced-air draft as long as there is sufficient forced draft and thus thermistors TH3 and H3 together function as an air flow sensor. Mounted for sensing the temperature of motors M1 and M2 are respective PTC thermistors TH4 and TH5. A thermostat 30 is positioned in the zone 25 heated by the furnace. Pairs of conductors L1 and L2 and L3 and L4 are provided for connection of the control and logic circuitry 27 to sources of AC power.

Referring now to the schematic circuit diagram of FIG. 2, conductors L1 and L2 provide means for connection of the apparatus to a conventional source of AC power of a voltage suitable for semiconductor circuitry, e.g., 24 VAC. An SCR (silicon controlled rectifier) Q1 is connected in a full-wave SCR bridge 31 including diodes D1-D4, and the bridge is connected in series with the winding KW of a contactor across lines L1 and L2. As will be appreciated by those skilled in the art, an SCR is a triggerable semiconductor current-switching device which is conductive if triggered while forward biased by voltage across its cathode and anode terminals. SCR Q1 is connected across the opposed legs of the full-wave bridge 31 so that SCR Q1 is always forward biased and therefore conductive, when triggered, on successive half cycles of the applied AC waveform. Current may therefore flow in both directions through the bridge to energize the winding KW of the contactor and thereby close a pair of normally open contacts K1 and K2 of the contactor upon triggering of SCR Q1. When contacts K1 are closed, power is supplied to thermostat 30 by means of a conductor 33 connected from line L1 to the thermostat. Contacts K2 are adapted to complete, when

closed, a circuit for energization of fan motor M1 including a pair of conductors L3 and L4 for connection across a source of AC power of a voltage suitable for operating the fan motor, e.g., 117 VAC. Motor M2 is interconnected with a conventional circuit (not shown) for energizing the motor either continuously, or when the temperature in plenum 21 reaches a certain level.

Thermostat 30 comprises a full-wave SCR bridge 35 constituted by an SCR Q2 and diodes D5-D8. SCR Q2 is connected across opposite legs of the bridge whereby SCR Q2, when triggered, is conductive on successive half cycles so that power may flow in both directions through the bridge. SCR Q2 is provided with a triggering circuit including a resistor R1 and a capacitor C1 connected in parallel between the cathode and the gate or triggering terminal of this SCR. A thermistor TH6 having a negative thermal coefficient (NTC) of resistivity is connected between the gate terminal and the cathode terminal of the SCR. Thermistor TH6 is mounted for sensing the temperature in the zone 25 to be heated by the furnace and is preferably of the type having a transition temperature above which its resistance decreases relatively abruptly, thereby providing a well-defined temperature at which a demand for heat is made by the thermostat. Thermistor TH6 may be variably thermally coupled to a selfregulating thermistor heater of the type disclosed in application Ser. No. 653,469, filed July 14, 1967, so that thermistor TH6 will, when heated, assume a temperature which is different from the environmental temperature in zone 25 so that the switching point may be varied.

Connected in parallel with thermistor TH6 is a thermistor TH7 exhibiting a positive temperature coefficient (PTC) of resistivity and preferably of the type having a transition temperature, e.g., 80° C., above which the resistance of the thermistor increases relatively abruptly. Thermally coupled to thermistor TH7 to provide means for heating the thermistor is a PTC heater thermistor H7 having a transition temperature somewhat higher, e.g., 120° C., than that of thermistor TH7 and above which the resistance of the heater thermistor H7 increases relatively abruptly. Heater thermistor H7 is also supplied with AC power by means of connection 33 upon closing of contacts K1.

If sufficient voltage is applied across a thermistor such as thermistor H7, the thermistor material therein selfheats due to internal resistive consumption of power until it reaches the transition temperature, whereupon the resulting increase in the material's resistance causes a decrease in the power consumed. Thus, the thermistor is maintained substantially at the transition temperature. As will be explained, thermistor TH7 and the heater thermistor H7 together constitute an electrothermal "purge delay" timer for delaying energization of the ignition means of the present apparatus for a predetermined time interval following the demand of the thermostat for heat sufficient to allow purging by the forced draft of any dangerous accumulation of fuel.

Since thermistors TH6 and TH7 are connected in parallel, if either exhibits a low resistance, SCR Q2 is prevented from being triggered. If bridge 35 is conductive, indicating a demand by the thermostat for heat, power is supplied to the gas valve circuit including gas valve winding 15W and an SCR full-wave bridge 37 constituted by an SCR Q3 and diodes D9-D12, SCR Q3 being connected across the legs of the bridge in the manner of SCR's Q2 and Q1. A PTC thermistor TH8 is connected across the gas valve winding 15W for a purpose which will be explained. A triggering circuit for SCR Q3 includes a resistor R2 connected between its gate and cathode terminals and another SCR Q4 connected with a resistor R3 and a diode D13 so that a forward biasing voltage is applied across SCR Q4 when bridge 35 is conductive. The latter circuit includes also a capacitor C1 connected from the cathode of diode D13 to line L2. Triggering for SCR Q4 is provided by a triggering circuit including a diode D14 and a current-limiting resistor R4 connected to the gate terminal of SCR Q4. A resistor R5 interconnects the gate and cathode terminals of the SCR Q4.

An ignition circuit indicated generally at 39 is provided for generating a recurrent sparking across electrodes 29, when the circuit is energized, to cause ignition of the gas. An SCR Q5 is provided for energizing the ignition circuit and is connected in a circuit across lines L1 and L2 in series with the primary winding W1 of a step-up transformer T1, a limiting resistor R6 and a diode D15. The secondary winding W2 of transformer T1 provides stepped-up voltage, e.g., about 120 volts, through a resistor R7 to a capacitor discharge circuit which includes an SCR Q6 having its cathode and anode terminals connected with a capacitor C2 across the primary winding W3 of a spark transformer T2. The spark electrodes 29 are connected across the secondary high voltage winding W4 of transformer T2. A triggering circuit for SCR Q6 includes a resistor R8 and a capacitor C3 connected across the main terminals of the SCR and a unilateral switch (or Shockley avalanche diode) D16 connected between the triggering or gate terminal to the junction of resistor R8 and capacitor C3. Capacitor C2 is adapted to quickly charge to a maximum voltage when power is supplied through resistor R7. Resistor R8 is provided for limiting the current which can flow to capacitor C3 so that it charges in somewhat more time than is required for capacitor C2. When the voltage across capacitor C3 reaches a predetermined level, unilateral switch D16 is conductive for discharging capacitor C3 to respectively trigger SCR Q6. When triggered, SCR Q6 discharges capacitor C2 through primary winding W3 of transformer T2, causing a strong high-voltage sparking across electrodes 29.

Until SCR Q5 is triggered and thereby rendered conductive, the ignition circuit 39 is not energized. SCR Q5 is normally triggered when thermostat 30 demands heat by a triggering circuit connected for simultaneous energization with the gas valve circuit. This triggering circuit includes a resistor R9 and a Zener diode Z1 connected between bridge 35 and the gate terminal of SCR Q5. The circuit also includes a capacitor C4 connected between the gate and cathode terminals of SCR Q5. Connected between the cathode of Zener diode Z1 and line L2 is a circuit including a diode D17 and the flame sensing thermistor TH1. This thermistor is an NTC type preferably having a transition temperature above which its resistance decreases relatively abruptly. As will appear, when thermistor TH1 is heated above its transition temperature by combustion of the gas at burner 13, SCR Q5 is prevented from being triggered and thus this circuit provides means for causing the ignition circuit to cease generating sparking when the gas ignites.

Indicated generally at 41 is a circuit including means for normally supplying triggering current to SCR Q1. The circuit is supplied with power by means of a diode D18 connected between line L1 and a conductor 43. A capacitor C5 is connected between conductor 43 and line L2 for smoothing the pulsating DC supplied by diode D18. A PNP transistor Q7 has its emitter connected through a load resistor R10 to conductor 43 and its collector is connected to the gate of SCR Q1. A resistor R23 is connected between the gate and cathode of the SCR. The state of conduction of transistor Q7 is controlled by a Schmitt trigger circuit comprising a pair of transistors Q8 and Q9. Transistor Q8 is provided with a collector load resistor R11 and the collector of transistor Q9 is provided with a load resistor R12. The collector of transistor Q8 is connected to the base of transistor Q9 by a resistor R13 to provide coupling between the two transistors, and the emitters of the two transistors are connected together and to line L2 through a common resistor R24 which provides the regenerative feedback which gives the Schmitt trigger circuit its typical two-state characteristics. Transistor Q9 is provided with a biasing resistor R14 connected between its base and line L2. The base of transistor Q7 is connected through a resistor R15 to the collector of transistor Q9. As will be understood by those skilled in the art, this Schmitt trigger circuit switches abruptly from a normal state in which transistor Q8 is nonconductive and transistor Q9 is conductive to a state in which the opposite is true when a voltage of a predetermined level sufficient for causing transistor Q8 to be biased into conduction is applied to the base thereof. The state of conduction of transistor Q8 is

controlled by a logic OR gate comprising diodes D19-D23, the cathode of which are commonly interconnected with the base of transistor Q8 through a resistor R16. Each of the diodes has its anode connected to a respective voltage divider circuit comprising a reference resistor connected in series with a thermistor across conductor 43 and line L2.

Diode D19 is connected to a junction between a reference resistor R17 and a PTC thermistor TH9 preferably having a transition temperature, e.g., 80° C., above which its resistance increases relatively abruptly with continued heating. Thermally coupled to thermistor TH9 to provide means for heating it is a PTC heater thermistor preferably having a transition temperature somewhat higher, e.g., 120° C., than that of thermistor TH9 and above which its resistance increases relatively abruptly such that, when energized, thermistor H9 self-heats substantially to its transition temperature in the same fashion as the heater H7 for thermistor TH7. Thermistor TH9 and heater thermistor H9 together comprise an electrothermal delay timer adapted to cause the circuit 41 to cease supplying triggering current to SCR Q1 in the event that thermistor TH9 is heated substantially above its transition temperature. Heater thermistor H9 is adapted for being energized by means of a diode D24 connected to a point between the contactor winding KW and SCR bridge 31, by means of a diode D25 connected to a point between the cathode of SCR Q5 and winding W1 of transformer T1, or by means of a diode D26 connected to a point between gas valve winding 15W and SCR bridge 37.

Similarly, diode D20 is connected to the junction between a reference resistor R18 and the thermistor TH3 mounted for being cooled by the air draft supplied to burner 13 by blower 17. Thermally coupled to thermistor TH3 to provide means for heating the latter is a heater thermistor H3. Each of thermistors TH3 and H3 is a PTC type and each preferably has a transition temperature above which the resistance thereof rises relatively abruptly, the transition temperature of thermistor H3 being somewhat higher than that of thermistor TH3. These transition temperatures may, for example, be 120° C. and 80° C., respectively. Heater thermistor H3 is connected through a resistor R19 and a diode D27 across lines L1 and L2 for energization when lines L1 and L2 are connected to a source of power.

Diode D21 is connected to the junction of a reference resistor R20 and the plenum temperature sensing thermistor TH2. Thermistor TH2 is a PTC type preferably having a transition temperature above which its resistance increases relatively abruptly, the transition temperature being chosen to correspond with a maximum permissible temperature in plenum 21. Diode D22 is connected to the junction of a reference resistor R21 and thermistor TH4. Thermistor TH4, which is thermally coupled to motor M1 for sensing its temperature, is a PTC type and preferably has a transition temperature corresponding with the maximum permissible temperature of the motor M1 and above which its resistance increases relatively abruptly. Similarly, diode D23 is connected between a reference resistor R22 and the other motor temperature sensing PTC thermistor TH5, also preferably having a transition temperature above which its resistance increases relatively abruptly upon further heating and which corresponds to the maximum permissible temperature of motor M2 (not shown in FIG. 2).

In the operation of the present furnace control apparatus, it is assumed that initially the pairs of lines L1, L2 and L3, L4 are not connected to the sources of AC power and that none of the thermistors of the apparatus is heated or selfheating. Since motor M1 of the draft blower 17 is therefore deenergized, no forced-air draft is supplied to burner 13. Upon the connection of lines L1, L2 and L3, L4 to appropriate sources of AC power, a voltage is applied across lines L1 and L2. Diode D18 accordingly provides a DC voltage between conductor 43 and line L2. Since each of the thermistors TH2-TH5 and TH9 is relatively cool, each exhibits a relatively low resistance. Therefore, only a relatively low voltage is thereby ap-

plied to any one of the anodes of the respective diodes D19-D23. Accordingly, the voltage applied to the base of transistor Q8 is insufficient to cause the transistor to be biased into conduction. Since the voltage at the collector of transistor Q8 is thereby relatively high, transistor Q9 is biased into conduction. Thus, the voltage at the base of transistor Q7 is such that the latter is rendered conductive and a positive triggering current is supplied to the gate of SCR Q1. Because of the voltage appearing across the circuit including contactor winding KW and SCR bridge 31, SCR Q1 is forward biased and thus is triggered on successive half cycles. Contactor winding KW is thereby energized, closing the sets of contacts K1 and K2. The closing of contacts K2 supplies power to energize the motor M1 of draft blower 17 to supply a forced-air draft for burner 13.

When contacts K1 close, power is supplied by means of the conductor 33 to thermostat 30 and to purge delay heater thermistor H7. Initially, thermistor TH7 is cool and thereby exhibits a relatively low resistance, shunting the NTC thermistor TH6 connected in the triggering circuit of SCR Q2 of thermostat 30. This low resistance prevents SCR Q2 from being triggered in spite of the temperature of NTC thermistor TH6. After a predetermined purge delay interval followed by energization of thermistor heater H7 sufficient to allow purging of any dangerous accumulation of gas by the forced-air draft of draft blower 17, thermistor TH7 reaches a threshold temperature (corresponding with its transition temperature), so that the resistance of thermistor TH7 is sufficiently great to allow triggering of SCR Q2 to be determined by the resistance of zone temperature sensing thermistor TH6. Assuming then that the temperature in zone 25 is such that thermistor TH6 is below its threshold temperature and therefore has relatively high resistance, triggering current is supplied through resistor R1 to the gate terminal of SCR Q2. Bridge 35 thereby becomes conductive, indicating a demand by the thermostat for heat and initiating a furnace heating cycle. Once triggered, SCR Q2 continues to be triggered on successive half cycles of the supplied AC waveform until heat supplied by the furnace raises the temperature in zone 25 and therefore the temperature of thermistor TH6 above its transition temperature. At some predetermined temperature of thermistor TH6, its resistance is sufficiently low that SCR Q1 ceases to be triggered and conduction of bridge 35 thereby ceases.

When bridge 35 thus becomes conductive, current is supplied through resistor R9 and Zener diode Z1 to the gate terminal of SCR Q5 for triggering this SCR. Flame sensor thermistor TH1 is cold and therefore exhibits a relatively high resistance through diode D17, thus permitting SCR Q5 to be triggered. However, if for some reason there should be flame or excessive heat present at the burner, thermistor TH1 will exhibit a low resistance and will shunt the triggering current to prevent triggering of SCR Q5. As will be explained, this will prevent energization of the gas valve. When thus triggered, SCR Q5 is conductive on alternate half cycles of the applied AC waveform and supplies current through winding W1 of transformer T1, thus energizing the ignition circuit. Secondary winding W2 applies voltage across SCR Q6 which is then triggered each time the voltage across capacitor C3 increases to a level sufficient to cause breakdown of unilateral switch or Shockley diode D16. When thus repetitively triggered, SCR Q6 discharges capacitor C2 through the primary winding W3 of spark transformer T2 to cause recurrent sparking across electrodes 29. It should be noted that capacitor C2 recharges more quickly than capacitor C3 and is thus ready for discharge each time SCR Q6 is triggered.

When SCR Q5 is triggered, a pulse from the top of primary winding W1 is applied through resistor R4 and diode D14 to the gate terminal of SCR Q4. SCR Q4 is thereby triggered and conducts because it is forward biased by the voltage applied through diode D13 and resistor R3. Triggering of SCR Q4 in turn supplies a triggering current to the gate terminal of SCR Q3 so that it, too, is triggered. By virtue of diodes D9-D12, SCR Q3 is always forward biased and, when triggered, is

therefore conductive on successive half cycles to energize gas valve winding 15W thereby opening gas valve 15 to begin supplying gas to burner 13. SCR Q4 provides a latching circuit for triggering of SCR Q3, permitting continued energization of gas valve winding 15W so that gas continues to be supplied. SCR Q4 is maintained in its conductive state by virtue of diode D13 and capacitor C1 until thermistor TH6 causes SCR Q2 to cease being triggered, thus indicating no further demand for heating of zone 25.

From the foregoing, it may be seen that the apparatus provides an important safety feature in that, unless SCR Q5 is successfully triggered to supply current for energization of the ignition circuit 39, SCR Q3 is prevented from initially being triggered. In other words, means is provided for proving energization of the ignition means and therefore insuring that gas will be supplied to burner 13 only after initial energization of ignition circuit 39. Such an arrangement provides for fail-safe operation of the apparatus.

Assuming that the gas supplied to burner 13 is ignited by the sparking across electrodes 29, flame sensing thermistor TH1 is quickly heated above its transition temperature. When this occurs, its low resistance drops and shunts triggering current away from the gate terminal of SCR Q5, preventing further triggering of the SCR and thus deenergizing the ignition circuit and causing it to cease spark generation.

If, however, ignition is not successful, SCR Q5 continues to be triggered. As long as SCR Q5 is conductive, current is supplied through diode D25 to heater thermistor H9. As noted previously, heater thermistor H9 and thermistor TH9 together constitute an electrothermal timer. Upon being heated by thermistor H9, thermistor TH9 requires a predetermined heating time interval, e.g., 4—10 seconds, to reach its threshold temperature. Of course, if ignition occurs within this predetermined interval, thermistor H9 is deenergized and the heated thermistor TH9 will not reach its threshold temperature. However, if it does, it causes a voltage to be applied through diode D19 to transistor Q8 which is sufficiently great enough to cause this transistor to be biased into conduction. When this occurs, the Schmitt trigger circuit quickly changes states and normally conductive transistor Q9 then becomes nonconductive. This causes a rise in the voltage at the base of transistor Q7 which cuts off transistor Q7 and thereby prevents further current from being supplied to the gate terminal of SCR Q1. This deenergizes contactor winding KW and contacts K1 and K2 are thereby opened. The opening of contacts K1 breaks the connection through conductor 33 to thermostat 30 and thereby deenergizes the fuel valve circuit, closing the fuel valve and preventing fuel from being further supplied to burner 13. The apparatus may then be said to be "locked out" of operation. It will be appreciated that the ignition circuit is also deenergized when such a "lockout" occurs.

When SCR Q1 becomes nonconductive, current is supplied through diode D24 to maintain heater H9 and thereby thermistor TH9 in heated condition. As long as thermistor TH9 remains heated, transistor Q8 remains biased in its conductive state. It will thus be seen that diode D24 provides means for automatically preventing further energization of gas valve 15 in the event that ignition is unsuccessful. Diode D24 thus causes the apparatus to remain locked out of operation until lines L1 and L2 are manually disconnected from the source of AC power for a period sufficient to permit heater H9 and thermistor TH9 to cool. In other words, if a lockout occurs, the apparatus is, by virtue of diode D24, manually resettable. If diode D24 were removed, the present apparatus would, in effect, automatically reset after a lockout which caused triggering of the Schmitt trigger circuit and deenergization of the contactor winding KW, since opening of contacts K1 would deenergize the heater thermistor H9, permitting thermistor TH9 to cool and allowing transistor Q8 to return to its normally nonconductive state. It should be noted that diode D26 provides means for energizing heater H9 in the event that SCR Q5 malfunctioned or was never triggered. By varying the thermal coupling between heater H9 and

thermistor TH9 or the thermal characteristics of the thermistors, the time interval required for thermistor TH9 to reach the lockout threshold temperature may be conveniently predetermined.

It should be noted that, by virtue of the circuit including diode D26 connecting heater thermistor H9 to a point between gas valve winding 15W and SCR bridge 37, if for some reason either SCR Q5 or SCR Q3 were not triggered, or failed, then the heating means constituted by thermistor H9 will be energized upon a demand for heat by thermostat 30. After the predetermined heating time interval required for thermistor TH9 to reach its threshold temperature, the Schmitt trigger circuit will be triggered and contactor winding KW will accordingly be deenergized to lock out the apparatus, thus providing fail-safe operation.

The purpose for which thermistor TH8 is provided across gas valve winding 15W can now be made clear. Heater thermistor H9 is, in effect, connected in a series circuit with the gas valve winding. Thus when power is initially supplied to the gas valve circuitry upon a demand by the thermostat for heat, thermistor H9 is cool and has a quite low resistance. Accordingly, the current drawn by thermistor H9 is great enough so that it could energize the gas valve winding to open the valve. To prevent this unintended energization of the gas valve winding, thermistor TH8 is provided. Initially, its resistance is also low and thus effectively shunts the gas valve winding until, after a few cycles of the AC waveform, thermistor H9 has heated somewhat such that it has an increased resistance and the current therethrough is therefore diminished. Current flowing through thermistor TH8 also causes it to heat and thus it, too, increases in resistance until it shunts only an insignificant amount of current and thus no longer appreciably affects the circuit.

As previously noted, thermistor TH3 and heater thermistor H3, together with the Schmitt trigger circuit, provide means for preventing energization of fuel valve 15 if there is insufficient forced-air draft supplied to burner 13 by draft blower 17. Heater thermistor H3 is adapted to be continuously energized by means of its connection through resistor R19 and diode D27 across lines L1 and L2 to supply heat to thermistor TH3. Thermistor TH3 is mounted for being cooled by the forced draft and is prevented from heating to a threshold temperature at which its resistance would rise sufficiently to cause transistor Q8 to be biased into a conductive state as long as there is sufficient forced draft. Thus, if for some reason the forced draft should cease or be insufficient, thermistor TH3 will heat and cause a cessation of the supply of triggering current to SCR Q1. The opening of contacts K1 will deenergize the fuel valve circuit and thereby prevent further energization of the fuel valve. If SCR Q1 ceases to be conductive, current is supplied through diode D24 to cause heating of heater thermistor H9 and thereby causes heating of thermistor TH9 above its threshold temperature to maintain transistor Q8 in a conductive state, thereby maintaining the gas valve in its deenergized or locked-out condition. Until lines L1 and L2 are manually disconnected, the system will remain in this disabled condition.

Plenum temperature sensing thermistor TH2 located in plenum 21 similarly causes the fuel valve to be deenergized and locked out if heated above a predetermined threshold chosen to correspond with a predetermined maximum permissible plenum temperature. At this threshold temperature, the resistance of thermistor TH3 is sufficiently large to cause transistor Q8 to be biased into conduction, and triggering of SCR Q1 to cease. Thus the gas valve is deenergized. When this occurs, diode D24 provides means for energizing thermistor H9 and thus maintains the thermistor TH9 above its threshold temperature so that the gas valve remains, in effect, locked out and deenergized until lines L1 and L2 are manually disconnected such that the various thermistors of the furnace may cool and permit restart of a heating cycle. In similar fashion, heating of thermistors TH4 or TH5, as a result of excessive heating of either of motors M1 or M2, will cause a

lockout to occur, the gas valve 15 being deenergized and then remaining deenergized by heating of thermistor heater H9 by virtue of the connection through diode D24 to the source of power.

Assuming that operation of the furnace proceeds normally, heat is supplied to zone 25 until thermistors TH6 is heated above its transition temperature. Its lowered resistance will prevent further triggering of SCR Q2 and thus deenergize the gas valve circuit, thereby terminating the heating cycle.

It may be appreciated that apparatus of the present invention is provided with relative insensitivity to variations in line voltage or ambient temperature through the extensive use for both heating and temperature sensing of thermistors having sharply defined transition temperatures. In heating applications, such thermistors are selfregulating in character substantially without regard to variations in line voltage and ambient temperature. In sensing applications, such thermistors, because of their "switching" resistance characteristics, greatly minimize the effects of voltage and temperature variation.

While a gas-fired, forced hot-air furnace has been illustrated, it should be understood that the present invention may be applied to other types of furnaces or heating system, e.g., a furnace having an oil-fed burner or a hot-water heating system.

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.

We claim:

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:

a triggerable semiconductor current-switching device which, when triggered, is conductive to supply power for energizing the fuel valve when the thermostat demands heat;

means for normally supplying triggering current to cause triggering of said switching device;

ignition means for igniting the fuel, said ignition means being energized to cause ignition of the fuel when the thermostat demands heat;

a first thermistor connected in a circuit with said switching device for preventing energization of the fuel valve when said thermistor is heated above a predetermined threshold temperature; and

means for heating said first thermistor, said heating means being connected with said ignition means and being energized to cause heating of said first thermistor only when said ignition means is energized, said first thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby, if the fuel is not ignited within said predetermined interval, further energization of the fuel valve is prevented thereby preventing fuel from being further supplied to the burner.

2. Furnace control apparatus as set forth in claim 1 wherein said means for heating said first thermistor comprises a second thermistor thermally coupled to said first thermistor.

3. Furnace control apparatus as set forth in claim 1 further comprising means for deenergizing said ignition means when the fuel ignites.

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:

a triggerable semiconductor current-switching device which, when triggered, is conductive to supply power for energizing the fuel valve when the thermostat demands heat;

means for normally supplying triggering current to cause triggering of said switching device;

ignition means which, when energized, generates a recurrent sparking for igniting the fuel, said ignition means being energized when the thermostat demands heat;

means for causing said ignition means to cease generating sparking when the fuel ignites;

a first thermistor connected with said means for supplying triggering current to said switching device and adapted to cause the last said means to cease supplying said triggering current when said thermistor is heated above a predetermined threshold temperature; and

means for heating said first thermistor, said heating means being connected with said ignition means and being energized when said ignition means generates sparking to cause heating of said first thermistor, said first thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby, if the fuel is not ignited within said predetermined interval, triggering of said switching device ceases and the fuel valve is thereby deenergized to prevent fuel from being further supplied to the burner.

5. Furnace control apparatus as set forth in claim 4 wherein said means for heating said first thermistor comprises a second thermistor thermally coupled to said first thermistor.

6. Furnace control apparatus as set forth in claim 5 wherein each of said first and second thermistors has a positive temperature coefficient and a transition temperature above which the resistance thereof increases relatively abruptly, said second thermistor having a higher transition temperature than that of said first thermistor, said thermistors together constituting an electrothermal timer.

7. Furnace control apparatus as set forth in claim 5 further comprising a third thermistor, said thermistor being mounted for sensing the temperature in a plenum of the furnace and being also connected with said means for supplying triggering current to said switching device and adapted to cause the last said means to cease supplying said triggering current when said third thermistor is heated above a predetermined threshold temperature corresponding to a predetermined maximum permissible temperature in said plenum.

8. Furnace control apparatus as set forth in claim 7 wherein said third thermistor has a positive temperature coefficient and a transition temperature above which the resistance thereof increases relatively abruptly.

9. Furnace control apparatus as set forth in claim 7 for controlling the operation of a furnace normally having a forced-air draft supplying the burner, further comprising:

a fourth thermistor, said thermistor being also connected with said means for supplying triggering current to said switching device and preventing triggering of said switching device when heated above a predetermined threshold temperature, said thermistor being mounted for being cooled by the forced draft; and

means for heating said fourth 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 fourth thermistor above said threshold temperature, thereby preventing energization of the fuel valve, if there is insufficient forced draft.

10. Furnace control apparatus as set forth in claim 9 wherein said fourth thermistor has a positive temperature coefficient and a transition temperature above which the resistance thereof increases relatively abruptly.

11. Furnace control apparatus as set forth in claim 9 wherein said means for heating said fourth thermistor comprises another thermistor having a positive temperature coefficient and a transition temperature higher than the transition

temperature of said fourth thermistor and above which the resistance thereof increases relatively abruptly.

12. Furnace control apparatus as set forth in claim 9 for controlling the operation of a furnace having a blower including an electric motor, further comprising a fifth thermistor mounted for sensing the temperature of the motor and being also connected with said means for supplying triggering current to said switching device and adapted to cause the last said means to cease supplying triggering current when said fifth thermistor is heated above a predetermined threshold temperature corresponding to a predetermined maximum permissible temperature of the motor.

13. Furnace control apparatus as set forth in claim 12 wherein said fifth thermistor has a positive temperature coefficient and a transition temperature above which the resistance thereof increases relatively abruptly.

14. 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, further comprising means for delaying energization of said ignition means for a predetermined time interval following the demand of the thermostat for heat sufficient to allow purging by the forced draft of any dangerous accumulation of fuel.

15. Furnace control apparatus as set forth in claim 14 wherein said means for delaying energization of said ignition means comprises:

a further thermistor having a positive temperature coefficient and connected for preventing energization of said ignition means until heated above a predetermined threshold temperature; and

means, when energized, for heating said further thermistor and being energized for causing heating of said further thermistor upon a demand by the thermostat for heat, said further thermistor requiring a predetermined heating time interval to reach said threshold temperature.

16. Furnace control apparatus as set forth in claim 7 wherein said means for normally supplying triggering current to cause triggering of said switching device includes a transistor having its collector-emitter circuit connected with said switching device for supplying triggering current thereto when said transistor is biased into conduction and further includes a transistor Schmitt trigger circuit connected for controlling the biasing of said transistor, said Schmitt trigger circuit normally having a first state biasing said transistor into conduction and a second state biasing said transistor out of conduction, said first and third thermistors each being connected for causing said Schmitt trigger circuit to switch from said first state to said second state when either of said first and second thermistors is heated above the predetermined threshold temperature thereof.

17. Furnace control apparatus as set forth in claim 16 wherein said first and third thermistors are each connected with a respective resistance to constitute respective voltage divider networks, each of said networks being connected to said Schmitt trigger circuit through a respective isolating diode.

18. Furnace control apparatus as set forth in claim 5 further comprising a magnetic contactor having contacts and a winding, said contacts closing upon energization of said winding, said winding being connected for energization by said triggerable switching device, said contacts being connected in a circuit with said gas valve, whereby power is supplied for energizing said gas valve when said switching device is triggered.

19. Furnace control apparatus as set forth in claim 5 further comprising a second triggerable semiconductor current-switching device, said second switching device being connected with said ignition means and being conductive, when triggered, for energizing said ignition means, said second switching device being triggered when the thermostat demands heat.

20. Furnace control apparatus as set forth in claim 19 further comprising:

a third triggerable semiconductor current-switching device connected with the fuel valve and being conductive when

triggered, the fuel valve being energized when said third switching device is conductive; and
means for triggering said third switching device after conduction of said second switching device, whereby the fuel valve is energized only after initial energization of said ignition means.

21. Furnace control apparatus as set forth in claim 20 wherein said means for causing said ignition means to cease generating sparking includes a further thermistor having a negative thermal coefficient and being mounted for being heated by combustion of the fuel, said second switching device including a triggering terminal, said second thermistor being connected thereto for preventing triggering of said second switching device when heated above a predetermined threshold temperature.

22. Furnace control apparatus as set forth in claim 5 including means for maintaining said first thermistor above said threshold temperature after triggering of said switching device ceases whereby the fuel valve remains deenergized following heating of said first thermistor above said threshold temperature.

23. Furnace control apparatus as set forth in claim 22 wherein said means for maintaining said first thermistor above said threshold temperature comprises circuit means, including a diode, for energization of said second thermistor when said triggering of said switching device ceases.

24. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature in 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, the burner being normally supplied with a forced-air draft, said apparatus comprising:

a triggerable semiconductor current-switching device including a triggering terminal and being conductive, when triggered, to supply power for energizing the fuel valve when the thermostat demands heat;

means, interconnected with the triggering terminal of said switching device, for normally supplying triggering current to cause triggering of said switching device;

a thermistor connected with said means for supplying triggering current to the switching device, and preventing triggering of said switching device when heated above a predetermined threshold temperature, said thermistor being mounted for being cooled by the forced draft; and

means for heating said thermistor, said heating means being continuously energized to supply heat to the first said thermistor, said heat normally being insufficient to cause heating of said thermistor above said threshold temperature as long as there is sufficient forced draft, but causing heating of said thermistor above said threshold temperature if there is insufficient forced draft, thereby preventing energization of the fuel valve.

25. Furnace control apparatus as set forth in claim 24 wherein said means for heating said thermistor comprises an additional thermistor thermally coupled to the first said thermistor.

26. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature in 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, the burner being normally supplied with a forced-air draft, said apparatus comprising:

circuit means connecting said apparatus to a source of power by means of the thermostat;

ignition means which, when energized, ignites the fuel;

a semiconductor current-switching device including a triggering terminal and being conductive, when triggered, to connect the source of power for energization of said ignition means;

means, interconnected with the triggering terminal of said switching-device, for supplying triggering current for

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causing triggering of said switching device when the thermostat demands heat;

a thermistor connected with said means for supplying triggering current, said thermistor preventing triggering of said switching device until heated above a predetermined threshold temperature; and
 means for heating said thermistor, said heating means being energized by the source of power to cause heating of the first said thermistor, said thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby, when the thermostat demands heat, energization of said ignition means is delayed until after said predetermined interval following energization of said heating means by the source of power sufficient to allow purging by the forced draft of any dangerous accumulation of fuel.

27. Furnace control apparatus as set forth in claim 26 wherein said means for heating said thermistor comprises an additional thermistor thermally coupled to the first said thermistor.

28. Apparatus for controlling the operation of a furnace in response to the demand of a thermostat sensing the temperature in a zone heated by the furnace, the thermostat including a semiconductor current-switching device and a triggering circuit for the switching device, the switching device being triggered into conduction to indicate a demand for heat, the furnace having a burner and an electrically energizable fuel valve which, when energized, supplies fuel to the burner, the burner

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being normally supplied with a forced-air draft, the thermostat normally being connected to a source of power but subject to disconnection therefrom, said apparatus comprising:

means for energizing the fuel valve and for igniting the fuel operable in response to triggering of the switching device;
 a thermistor having a positive temperature coefficient and a transition temperature above which the resistance thereof rises relatively abruptly, said thermistor being connected to the triggering circuit of the switching device to prevent triggering thereof until said thermistor is heated above a predetermined threshold temperature; and an additional thermistor thermally coupled to the first said thermistor and having a positive temperature coefficient and a transition temperature above which the resistance thereof rises relatively abruptly, said transition temperature being higher than that of the first said thermistor, the additional thermistor being connected to the source of power when the thermostat is connected thereto to cause heating of the first said thermistor, the first said thermistor requiring a predetermined heating time interval to reach said threshold temperature, whereby operation of said means for energizing the fuel valve and for igniting the fuel is delayed until after said predetermined interval following connection of the thermostat to the source of power sufficient to allow purging by the forced draft of any dangerous accumulation of fuel.

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