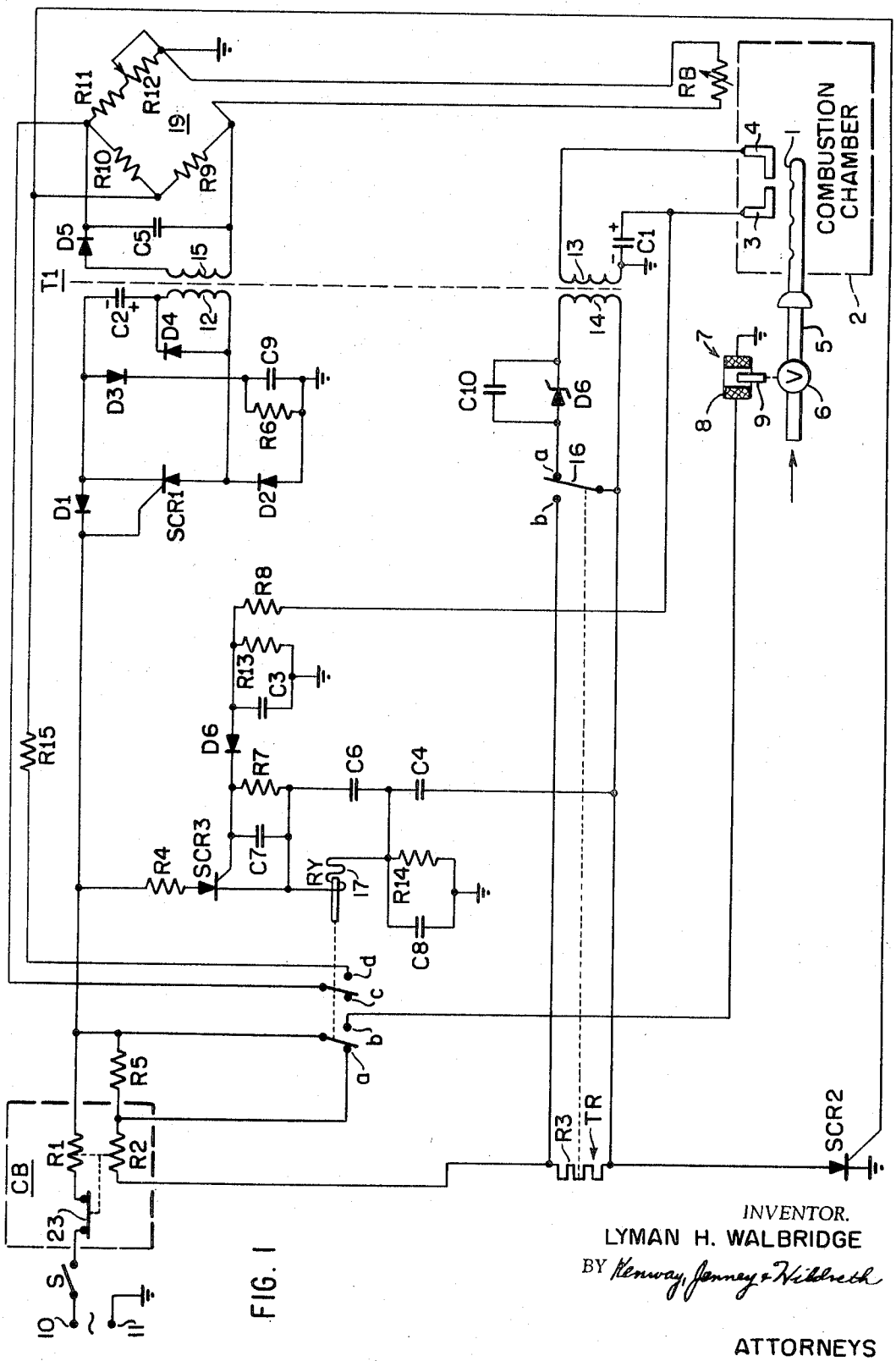
May 13, 1969 L. H. WALBRIDGE 3,443,752

CONTROL SYSTEM FOR GAS-FIRED HEATING APPARATUS

Filed July 29, 1966 Sheet 1 of 2



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Filed July 29, 1966 Sheet 2 of 2

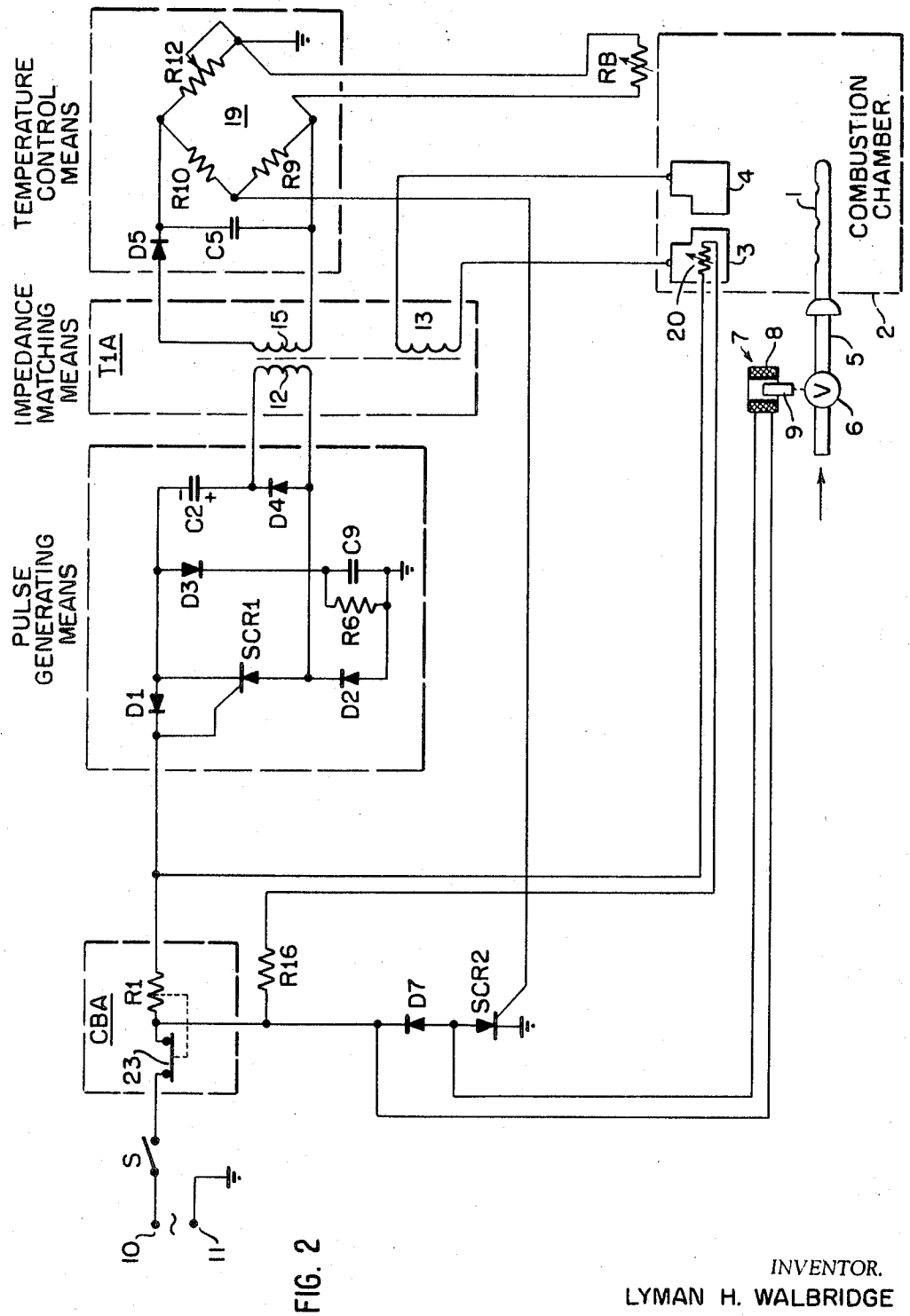


FIG. 2

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CONTROL SYSTEM FOR GAS-FIRED HEATING APPARATUS

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ABSTRACT OF THE DISCLOSURE

The invention relates to apparatus for gas ignition which includes a pair of electrodes to provide an ignition spark and a gas valve operated by a solenoid which is opened when an appropriate electrical signal is applied to it. Sparks are produced at the electrodes by supplying high voltage pulses to them and the gas valve is held open provided flame is present. The pulses which supply the electrodes are also supplied to a temperature-sensitive circuit and the output signal from this circuit, which is typically a bridge circuit, is used to initially operate the gas valve. The uses of pulses as opposed to continuous energization of the temperature measuring circuit reduces self heating and temperature offset, while yet providing a substantial output signal.

My invention relates to the control of gas burners, and particularly to a novel pulse ignited gas fired heating system.

The safe operation of fuel burners such as gas burners and the like requires a fuel supply and ignition control system of great reliability. But, however reliable, such a system must be designed with the possibility of failure in mind, and it is highly desirable that the system be arranged so that any failure which can occur will result only in an interruption of service, and not in an unsafe condition. Considerations of both safety and economy also require that failures which can occur do not result in the escape of fuel, and that maintenance should not be frequently required. For these reasons, it is desired to have the fuel supply arranged so that fuel will be supplied only when the ignition system is in operation, and that the fuel will be cut off if the flame, once established, is extinguished. Finally, it is desired in many instances to control the temperature in the combustion chamber or other region heated by the flame. Prior attempts made to meet all of these requirements have led in general to apparatus that sacrificed something in convenience, cost, reliability, or all of those qualities. It is the primary object of my invention to facilitate the safe, reliable and economical control of the ignition and combustion of gaseous fuel, as well as to simplify the control of the temperature of a heated region.

Briefly, the apparatus of my invention comprises an electrical ignition and fuel supply control system for a gas burner utilizing a set of relatively widely spaced electrodes. The electrodes are supplied with periodic pulses of very short duration and high peak voltage to cause ignition, and to monitor the resulting flame, with a very low average rate of current flow. Wide spacing of the electrodes makes the system reliable, because small changes in spacing that may occur due to erosion have little effect on the total spacing, and because the low average value of current flowing results in less erosion of the electrodes.

Pulses for exciting the electrodes are supplied by pulse generating means energized by a source of alternating voltage and arranged to produce a high intensity pulse of short duration once every other half-cycle of the source voltage. A solenoid valve is provided for admitting gas

to the burner when energized. Means are provided for energizing the solenoid valve only when ignition sparks are being produced across the electrodes, and for causing it to be deenergized after ignition of the fuel should the flame become extinguished.

The energizing circuit for the solenoid valve is controlled by an electronic switch, and means are provided for closing the switch only when the temperature of the region heated by the flame is below a predetermined maximum value. The control apparatus for the switch includes a temperature responsive impedance, such as a resistance bulb or the like, located in the region to be controlled, and the resistance bulb is connected as one arm of a bridge circuit. Power for exciting the bridge circuit is taken from the pulse generating means. As very little average energy is used by this circuit, self-heating and temperature offset of the bridge is avoided even though at the same time the bridge is providing a high level of output signal. By this arrangement, it is also made unnecessary to provide a separate power supply for the bridge. Moreover, the apparatus is so arranged that failure of the pulse generating means to deliver energy to the bridge will result in opening the switch to the solenoid valve, contributing to the fail-safe operation of the apparatus. Preferably, all energy is supplied to the system through a common circuit including a circuit breaker arranged to open the circuit, and thereby close the fuel supply valve, should any short circuit exist anywhere in the system.

The preferred construction of the apparatus of my invention, and its mode of operation, will best be understood in the light of the following detailed description, together with the accompanying drawings in which:

FIGURE 1 is a schematic wiring diagram of a circuit providing the combined functions of ignition, flame monitoring and temperature control in accordance with my invention; and

FIGURE 2 is a schematic wiring diagram of a simplified embodiment of my invention.

In FIGURE 1, I have shown a conventional gas burner **1** located in a combustion chamber **2** adjacent a pair of relatively widely spaced electrodes **3** and **4**. The burner **1** is arranged to be supplied with gas by a gas line **5** when an electromagnetically operated valve **6** is opened. The valve is arranged to be normally closed, as by a spring, and to be opened when an associated solenoid **7** is energized. As schematically indicated, the solenoid **7** is provided with a winding **8** and an armature **9** connected to the valve **6**.

Power for operating the apparatus to be described is supplied by an alternating voltage source connected between an input terminal **10** and a grounded input terminal **11** when a switch S is closed. While terminal **11** is shown as at ground potential for purposes of simplifying the drawing, in practice, terminal **11** may be ungrounded and all connections shown grounded made directly thereto. The switch S may be manually operated, or may be under the control of automatic apparatus, such as a thermostat or even another pulsed bridge temperature controller of the type to be described, particularly where the temperature control apparatus, the ignition apparatus and the flame monitoring apparatus are all dependent on a single pulse generator.

Ignition pulses are at times supplied to the electrodes **3** and **4** by a pulse transformer **T1**. The pulse transformer **T1** is provided with a primary winding **12** and three secondary windings **13**, **14** and **15**. The windings **12** and **15** are preferably bifilar, but in any event are relatively closely coupled. The secondary windings **13** and **14** are preferably more loosely coupled to the primary winding **12**, for reasons to appear.

The secondary winding **13** is connected to the elec-

trodes 3 and 4 in series with a capacitor C1, the latter serving to sense current flowing through the electrodes in a manner to appear below. The secondary winding 14 forms a part of a circuit for controlling the voltage of pulses coupled to the secondary winding 13 by the primary windings 12, to be described below. The secondary winding 15 forms a part of a temperature control circuit, to be described below.

One terminal of the primary winding 12 is connected to the anode of a silicon controlled rectifier SCR1. The cathode of the silicon controlled rectifier is connected through a capacitor C2 to the other terminal of the primary winding 12. As will appear, during normal operation of the apparatus the capacitor C2 is charged with the polarity indicated in the drawing on half cycles of the source voltage applied to terminals 10 and 11 during which terminal 10 is negative with respect to ground, and the capacitor is discharged through the primary winding 12 by gating the silicon-controlled rectifier SCR1 "on" during alternate half cycles. As shown, a diode D4 is connected across the primary winding 12, to limit voltage excursions in the undesired direction that might be caused by inductive energy storage in the transformer.

The controlled rectifier SCR1 is provided with a gate circuit controlled by the switch S and by a circuit breaker CB. The circuit breaker CB may be of any conventional construction, provided with two heating elements R1 and R2, either of which will respond to excessive current flow heating the element, or sufficient externally applied heat, to open contacts 23 of the circuit breaker. With the contacts of switch S closed and the contacts 23 of the circuit breaker CB closed, on positive half cycles of the source voltage with respect to ground, current gating the silicon controlled rectifier SCR1 into conduction is supplied from terminal 10, over the switch S and the contacts 23 of the circuit breaker CB, through the heating element R1 of the circuit breaker, from the gate terminal to the cathode of the silicon controlled rectifier SCR1, through a diode D3, and thence to ground through a resistor R6 and a capacitor C9 in parallel. The resistor R6 and the capacitor C9 are provided to control the magnitude and waveform of the gate current to the controlled rectifier SCR1.

A circuit for charging the capacitor C2 during half cycles of the source voltage in which the terminal 10 is negative with respect to ground extends from terminal 10 over the switch S in its closed position, contacts 23 of the circuit breaker CB when closed, the heating element R1 of the circuit breaker, a diode D1 connected between the gate of the controlled rectifier SCR1 and its cathode, and thence through the capacitor C2 and the diode D4 in series with a diode D2 to ground. During half cycles in which the capacitor C2 is being charged by this circuit, the anode of the controlled rectifier SCR1 is positive with respect to its cathode. However, the controlled rectifier SCR1 is held in its blocking state at this time by the forward drop across the diode D1.

It will be apparent that the circuit just described will provide a pulse of current to the primary winding 12 of the pulse transformer T1 every other half-cycle of the source voltage so long as the switch S and the contacts 23 of the circuit breaker CB remain closed. These pulses induce pulses across the secondary winding 13 of the transformer T1, having a magnitude dependent on the state of the voltage controlled circuit comprising the secondary winding 14 next to be described.

The circuit for controlling the voltage induced in the secondary winding 13 is governed by timing means here shown as a conventional thermal relay TR, having a resistive element R3, normally closed contacts 16*a* closed when the resistive element R3 is cold, and normally open contacts 16*b* closed when the resistive element R3 is heated. When the contacts 16*a* are closed, the secondary winding 14 of the pulse transformer T1 is connected across the parallel combination of a capacitor C10 and a Zener diode D6. In that state of the circuit, the voltage pulses induced in the secondary winding 13 are reduced because a substantial portion of the energy supplied to both windings 13 and 14 is absorbed by the circuit including the secondary winding 14. Because of the relatively loose coupling between the secondary windings 13 and 14 and the primary winding 12, the voltage induced in the secondary winding 13 when the switch contacts 16*a* are closed can be considerably below that of the voltage induced when the switch 16*a* is open. The reduced voltage is made sufficiently small to prevent arcing across the electrodes 3 and 4 in the absence of a flame bathing the electrodes. On the other hand, the tight coupling between the primary winding 12 and the secondary winding 15 causes the magnitude of the pulses induced in the secondary winding 15 to be essentially independent of the state of the thermal relay TR, for purposes to appear.

When the contacts 16*b* of the thermal relay TR close, the circuit for the secondary winding 14 is opened, allowing pulses of large magnitude to be induced across the secondary winding 13 sufficient to arc between the electrodes 3 and 4 even though the electrodes are cold. This voltage, for example, is typically of the order of 20,000 volts or more if not limited by breakdown of the gap. As will appear, the thermal relay TR is controlled to close the contacts 16*b* and open the contacts 16*a* during an ignition mode of operation of the apparatus, to allow large voltage pulses to appear across the electrodes 3 and 4 and produce arcs in the absence of a flame, to initially ignite the gas escaping from the burner 1. The thermal relay thereafter closes the contacts 16*a*, reducing the voltage applied to the electrodes and allowing arcing to continue only so long as the electrodes are bathed in flame. While the contacts 16*b* of the thermal relay are closed, the resistive element R3 of the relay is shunted to allow it to cool and prepare it for recycling if necessary, as will appear.

The thermal relay TR is controlled by the switch S, the circuit breaker CB, and an electronic switch here shown as a silicon-controlled rectifier SCR2. For that purpose, the resistive element R3 of the thermal relay TR is provided with an energizing circuit extending from input terminal 10 over the contacts of the switch S when closed, the contacts 23 of the circuit breaker CB, through the first heating element R1 of the circuit breaker CB, through a resistor R5, at times shunted by a normally closed contact *a* of a relay RY, to be described, through the second heating element R2 of the circuit breaker CB, through the resistive element R3 of the relay TR, and thence through the anode-to-cathode path of the controlled rectifier SCR2 to ground.

The silicon controlled rectifier SCR2 is controlled in accordance with the temperature of a region to be monitored, either in the combustion chamber 2 or in a region less directly heated by the burner 1 and external to the combustion chamber. The temperature sensing element is a thermally responsive resistance, preferably a resistance bulb RB located in position to sense the desired temperature. As is conventional, the resistance of the resistance bulb RB increases with increasing temperature.

The resistance bulb RB is connected in a bridge circuit 19 as one arm thereof. The other arms of the bridge comprise two fixed resistors R9 and R10, and a fixed resistor R11 in series with a variable temperature-setting resistor R12. An output circuit for the bridge extends from one output terminal at the junction of resistors R9 and R10 to the gate terminal of the controlled rectifier SCR2, and from the cathode of the controlled rectifier SCR2 to ground and the grounded terminal of the bridge 19. The fixed resistor R10 is at times shunted by a relatively large fixed resistor R15, for purposes to appear.

The bridge 19 is energized by a circuit extending from one terminal of the secondary winding 15 of the pulse transformer T1 through a diode D5 to one input terminal of the bridge at the junction of resistors R10 and R11, and from the second input terminal of the bridge, at the

junction of the resistors R9 and the resistance bulb RB, to the other end of the winding 15. The capacitor C5 is connected across the input terminals of the bridge to reduce the effects of unavoidable capacitance in the bridge circuit, without seriously affecting the amplitude of the pulses applied to the bridge, by attenuating high frequency components. Because of the close coupling of the windings 12 and 15, substantially constant amplitude pulses are supplied to the bridge once every other half-cycle of the source voltage applied between the input terminal 10 and ground.

With the sensed temperature below the point set by the adjustment of the resistor R12 (and the resistance bulb RB accordingly at a low value of resistance) positive gate pulses will be supplied to the gate terminal of the controlled rectifier SCR2 with respect to ground, gating the controlled rectifier into its conducting state. Should the temperature sensed by the resistance bulb RB rise, its resistance will increase and the pulses will decrease until, at some point determined by the setting of the resistor R12, the bridge will be balanced and the controlled rectifier SCR2 will go into its blocking state.

Since the bridge 19 is excited by the pulse transformer, it will be apparent that its output signal reflects both the temperature of the monitored space relative to the set point, and the integrity of the pulse generating means. The integrity of the ignition circuits to the electrodes 3 and 4 is checked separately, as will appear.

The control circuits for the valve control solenoid 7 will next be considered. The supply of energizing current for the solenoid winding 8 is directly controlled by the switch S, the circuit breaker CB, and a relay RY. The relay RY may be of any conventional construction, and is provided with a winding 17, back contacts *a* and *c* closed when the relay is deenergized, and front contacts *b* and *d* closed when the relay is energized. An energizing circuit for the winding 8 extends from terminal 10 over the contacts of the switch S, the contacts 23 of the circuit breaker CB, the heating element R1 of the circuit breaker CB, over front contacts *b* of the relay RY, and through the winding 8 to ground.

The relay RY is controlled by a first electronic switch comprising the silicon controlled rectifier SCR2, in dependence on the temperature of the space to be monitored, and also in dependence on the presence or absence of ignition current flowing between the electrodes 3 and 4, by means of another electronic switch here shown as a silicon controlled rectifier SCR3. For this purpose, an energizing circuit for the winding 17 of the relay RY extends from terminal 10 of the switch S, over the contacts 23 and the heating element R1 of the circuit breaker CB, through a current limiting resistor R4, from the anode to the cathode of the controlled rectifier SCR3, through the winding 17, and through the resistor R14 to ground. A storage capacitor C6 is connected across the winding of the relay RY to tend to maintain the flow of current in the relay winding between energizing pulses. The resistor R14 and a capacitor C8 are connected between ground and the junction of the relay winding 17 and the capacitor C4. The purpose of these two components is to control the magnitude and waveform of the pulses applied to the controlled rectifier SCR3 from the controlled rectifier SCR2, as will be discussed below.

It will be apparent that the relay winding RY can only be energized when the controlled rectifier SCR2 and the controlled rectifier SCR3 are both gated "on." In addition, the components are so selected that the capacitor C6 must first be charged, over several cycles of energization of conduction of the controlled rectifiers SCR2 and SCR3, in order to permit the relay to open its back contacts and close its front contacts.

Periodic gating "on" of the controlled rectifier SCR2 indicates both that the monitored temperature is below the set point and that the transformer T1 is receiving ignition pulses. The controlled rectifier SCR3 is gated "on" only when current flow is detected between the ignition electrodes 3 and 4, in a manner next to be described. Accordingly, the relay RY will be energized only when all these conditions prevail.

Operation of relay RY takes place in the following fashion. When the bridge 19 is unbalanced the controlled rectifier SCR2 will fire once every other half cycle and will therefore generate a negative going pulse at its anode terminal. The pulse is coupled through the capacitor C4 to the resistor R14 with the capacitor C8 in parallel. It is also supplied to both the cathode and gate of the controlled rectifier SCR3. If no voltage is present on capacitor C1, both cathode and gate go negative together and the controlled rectifier SCR3 does not fire. However, if, as a result of current flow through electrodes 3 and 4, the capacitor C1 is charged as shown, current will flow through the resistor R8 to replenish the charge on the capacitor C3 in relatively long intervals between pulses. Thereafter, when negative pulses are supplied from controlled rectifier SCR2 the cathode of SCR3 will go negative but not the gate with the result that the controlled rectifier SCR3 will fire, energizing the winding 17 of the relay RY.

When the relay RY picks up, it performs three functions. First, it energizes the solenoid winding 8 over its front contacts *b*. Second, when its back contacts *a* open, the resistor R5 is added to the energizing circuit for the thermal relay TR, reducing current flow to the thermal relay to prevent it from cycling while the valve 6 is open. Third, in accordance with the preferred embodiment of the invention illustrated, the relay RY connects the resistor R15 in parallel with the resistor R10 in the bridge 19 by completing a circuit for that purpose closed over its front contacts *d*.

The resistor R15 is relatively large with respect to the resistor R10, such that the equivalent resistance of the two in parallel is slightly less than the original resistance of the resistor R10. The result is that the effective set point of the bridge is raised when the relay is energized, so that once the valve 6 is open, allowing gas to flow to the burner 1, the bridge will be unbalanced and the temperature will be required to rise somewhat before it is again balanced to allow the relay RY to drop out and open the valve. The purpose is to prevent rapid on-off cycling of the apparatus about the set point, with attendant wear of the apparatus and erosion of the contacts. Once the relay RY is deenergized to open the valve, the resistor R15 will be disconnected and the set point will return to the original temperature, again requiring some time during which the temperature of the system cools to prevent the relay RY from being picked up again as soon as it has been dropped out. That arrangement is preferred because it imposes more severe ignition requirements on the system. Alternatively, however, it is possible to effect a more continuous control of temperature by control of the valve opening. To adapt the system for this mode of control, the resistor R15 would be connected across the arm of the resistor R9 in the bridge, producing an opposite effect from that shown, and effecting an average current flow to the solenoid 8 that will cause the valve 6 to assume a partly open position at which the flow of gas to the burner 1 maintains a temperature substantially at the set point.

Having described the construction of the apparatus of FIG. 1, its operation will next be described. It will be assumed for purposes of illustration that the apparatus is initially disconnected with the switch S open, contacts 23 of the circuit breaker CB closed, the thermal relay TR deenergized, the electronic switches SCR1, SCR2 and SCR3 in their blocking states, the relay RY and the solenoid 7 deenergized, and the valve 6 closed. It will be assumed that the resistance of the resistance bulb is initially at a low value representing a temperature well below the set point established by the setting of the resistor R12.

When the switch S is closed, current will be supplied

through the heating element R1 of the circuit breaker CB to the rest of the apparatus. Should there be any short circuits in the system, the element R1 will heat relatively rapidly, opening the contacts 23 of the circuit breaker CB and preventing further operation. Otherwise, during each negative half-cycle of the source voltage with respect to ground, the capacitor C2 will be charged, and during each next succeeding positive half-cycle, the controlled rectifier SCR1 will be gated "on" and the capacitor C2 will discharge through it to induce pulses in the secondary windings 13, 14 and 15. In the initial state of the apparatus, the contacts 16*a* of the thermal relay TR are closed, and the secondary winding 14, capacitor C10 and Zener diode D6 will reflect a low impedance to the transformer T1, causing the pulses induced across the secondary winding 13 to be at a relatively low value insufficient to cause arcing across the electrodes 3 and 4 with the system cold.

The pulses across the secondary winding 15 will excite the bridge 19 and cause unidirectional pulses of gating current to flow to the gate terminal of the controlled rectifier SCR2, during half cycles of the source voltage in which the terminal 10 is positive with respect to ground. At such times, the anode-to-cathode path of the controlled rectifier SCR2 will be forward-biased over the circuit extending from terminal 10 through the switch S, the circuit breaker CB, its heating element R1, over the closed back contacts *a* of the relay RY, through the resistor R2, through the resistive element R3 of the thermal relay TR, and through the anode-to-cathode path of the controlled rectifier SCR2 to ground. The current flowing through the controlled rectifier SCR2 at this time will heat the thermal relay TR. It will be noted that with the relay RY deenergized, and the resistor R5 shunted, a larger current will flow to the thermal relay TR than when the resistor R5 is in circuit. The purpose is to allow the thermal relay TR to cycle as the system is started up, until ignition has been established or until the circuit breaker CB is actuated by heating of the element R2. The latter action is controlled, by selecting the rating of the element R2, to take place after several cycles of operation of the thermal relay TR.

When the thermal relay TR is sufficiently heated, it will close its front contacts 16*b* and open its back contacts 16*a*. The secondary winding 14 will now reflect a very high impedance to the pulse transformer T1, and if the apparatus is operating properly, pulses of a sufficient magnitude to cause arcing across the electrodes 3 and 4 with the electrodes cold will be supplied by the secondary winding 13. The capacitor C1 will thereby be charged, and will supply current to maintain the charge on the capacitor C3, through resistor R8, so that the controlled rectifier SCR3 will fire as described above. The relay RY will then be energized, opening its back contacts *a* and *c* and closing its front contacts *b* and *d*.

The solenoid winding 8 will now be energized over the front contacts *b* of the relay RY, allowing the valve 6 to open and permitting gas to flow to the burner 1. At the same time the resistor R15 will be connected in the bridge 19 over the front contacts *d* of the relay RY, placing the set point of the bridge above the initial value for the reasons discussed above. There will then be present in the combustion chamber 2 both gas and arcs across the electrodes 3 and 4 to ignite the gas, and ignition should follow.

When the thermal relay TR is sufficiently heated to close its front contacts 16*b*, its winding is shunted and it will begin to cool. Thus, whether or not the relay RY is picked up and ignition is estabilshed, after a predetermined period the thermal relay TR will cool, open its contacts 16*b*, and again close its contacts 16*a*. The voltage across the electrodes 3 and 4 will be reduced to pulses which are sufficient to maintain current between the electrodes 3 and 4 when the electrodes are bathed in flame, but insufficient to arc across the electrodes when cold. If the electrodes are bathed in flame, current will continue to flow between them and the capacitor C1 will continually be charged to replenish the capacitor C3 and maintain the controlled rectifier SCR3 in its conducting state. The relay RY will thereby remain energized and keep the valve 6 open. At the same time, with the relay RY energized, the resistor R5 will be in series with the thermal relay TR, to reduce the flow of current to the thermal relay to a value that will prevent it from picking up again as long as the relay RY is energized.

If the apparatus is operating normally, with ignition established, the temperature in the heated space will continue to rise until the resistance of the resistance bulb RB increases sufficiently to balance the bridge. At that time, the controlled rectifier SCR2 will return to its blocking state. The relay RY will be deenergized after the charge across the capacitor C6 has decayed to a value inadequate to maintain sufficient flow of current through the winding 17 to keep the relay energized. The valve 6 will then be closed, and the temperature of the system will begin to drop. At some point shortly thereafter, the electrodes 3 and 4 will cool sufficiently so that the reduced voltage across the secondary winding 13 will no longer maintain current flow, and the charge across the capacitor C1 will begin to decay.

When the relay RY drops out, it will shunt the resistor R5. However the thermal relay TR will not again begin to heat until the controlled rectifier SCR2 begins again to conduct due to a command from the bridge. When relay RY drops out, it will also remove the resistor R15 from the bridge circuit, lowering the effective set point and thus requiring time to elapse before the system cools back to the point at which the bridge becomes unbalanced and again supplies gating pulses to the controlled rectifier SCR2. As the capacitor C1 has discharged, resumption of the cycle will await the heating of the thermal relay TR to again open its contacts 16*a* and permit larger pulses to be supplied at electrodes 3 and 4 to re-establish conduction.

It will be apparent that in the embodiment of my invention just described, the detection means comprising the electronic switch SCR3, its associated control circuit including the capacitor C1, and the voltage control circuit, comprising the thermal relay TR and the secondary winding 14 performs a dual function. In the ignition mode of operation, the detection means serves to detect the presence of ignition sparks, indicating that the gas may be turned on. In the flame monitoring and temperature control mode of operation, the detection means serves to detect the presence of flame, as the switch SCR3 will be opened if the flame is extinguished.

FIGURE 2 shows a simplified embodiment of my invention with which the essential functions of temperature control, flame monitoring, and interruption of operation in the event of circuit failure are attained with a smaller number of elements. Parts corresponding to parts in FIGURE 1 have been given the same designation, and will not be described again.

The circuit breaker CBA is simpler than the circuit breaker CB in FIGURE 1, in that it does not require the second heating element R2. The remaining heating element R1, operating the contacts 23 when sufficiently heated, has connected in parallel with it a circuit comprising in series a resistor R16 and a thermistor 20, the latter being located within or adjacent to one of the electrodes 3 and 4 as desired. The purpose of this circuit will be described below.

The portion of the circuit labeled "pulse generating means" and enclosed by the dotted line in FIGURE 2 is exactly the same as the corresponding portion of the apparatus in FIGURE 1, and operates in the same way to produce output pulses to the pulse transformer once every other cycle of the alternating source applied to the terminal 10 and 11 in a manner described in connection with FIGURE 1. The pulse transformer T1A, labeled "impedance matching means" in the circuit of FIGURE 2, may be the same as the pulse transformer T1 in FIG-

URE 1, except that it does not require the secondary winding 14. In addition, the circuit does not inherently require any different degree of coupling between the windings 12 and 15 than the coupling between the windings 12 and 13. However, tight coupling between the windings 12 and 15 would be preferred as reducing the effects of variations in circuit loading during arcing across the electrodes. The portion of the circuit labeled "temperature control means" may be the same as that described in FIGURE 1, and functions to produce positive output pulses when the temperature of the resistance bulb RB is below the desired value established by the setting of the adjustable resistor, here shown as a single adjustable resistor R12. The control valve 6 and its associated solenoid 7, the burner 1, and the arrangement of the electrodes 3 and 4 within the combustion chamber 2, may be the same as described in connection with FIGURE 1.

In this embodiment of my invention, the control circuit for the controlled rectifier SCR2 is the same as that described in connection with FIGURE 1, in that it is operated by the bridge 19, but it is used somewhat differently in the control of the solenoid 7. Specifically, the energizing circuit for the solenoid winding 8 extends from terminal 10 over the switch S, the contacts 23 of the circuit breaker CBA, through the winding 8 of the solenoid 7, and from the anode to the cathode of the controlled rectifier SCR2 to ground. A diode D7 is connected across the winding 8 to protect the circuit against transients when the winding is de-energized.

The thermistor 20 may be of any conventional type that decreases in resistance as the temperature is increased. It is selected in conjunction with the resistor R16 and the heating element R1 of the circuit breaker CBA such that when the electrodes are bathed in flame heating the thermistor, the current flow through the heating element R1 will be limited to a value that will prevent operation of the circuit breaker. However, when the thermistor 20 is cold, it is selected to present a sufficiently high resistance that the heating element R1 will operate the circuit breaker after a few seconds if the thermistor is not heated up in the meantime.

The purpose of the resistor R16 is to protect against shorting of the leads of the thermistor 20. Without the resistor R16, shorting of the leads to the thermistor 20 would completely defeat the purpose of the circuit breaker CBA. The resistor R16 is selected such that if connected alone in parallel with the heating element R1 of the circuit breaker CBA, the heating element R1 will eventually open the circuit breaker, though at a time beyond the time in which it would operate without the resistor R16.

The operation of the apparatus of FIGURE 2 will be described on the assumption that the switch S is initially open, the circuit breaker contacts 23 are closed, the valve 6 is closed, the electrodes 3 and 4 are cold, the temperature of the space monitored by the resistance bulb RB is well below the set point established by the resistor R12, and both of the electronic switches SCR1 and SCR2 are non-conducting. When the switch S is closed, during the first negative-going half-cycle of voltage applied to the terminal 10 with respect to ground, current will flow from ground through the diodes D2 and D4, through the capacitor C2, through the diode D1, through the circuit breaker CBA, and over the contacts of the switch S to terminal 10. During each such half-cycle, the capacitor C2 will be charged. On each next following positive going half-cycle, the controlled rectifier SCR1 will be gated "on" when the voltage at the terminal 10 exceeds the voltage on the capacitor C9, and the capacitor C2 will be discharged to produce a pulse of current in the primary winding 12 of the transformer T1A in the manner described in connection with FIGURE 1. Each such pulse will induce a pulse in the secondary winding 15 to excite the bridge 19, and will also induce a pulse in the secondary winding 13 to cause an arc between the electrodes 3 and 4, whether the electrodes are hot or cold. As the temperature of the resistance bulb is initially below the set point, the controlled rectifier SCR2 will be gated "on" and will conduct during the first or second positive half-cycle after the switch S is closed. The winding 8 will then be energized, and the valve 6 will be opened immediately, allowing gas to flow to burner 1. Ignition should follow immediately, and if it does the resistance of the thermistor 20 will drop to a value allowing the circuit breaker CBA to keep its contacts 23 closed. The valve 8 will then remain open until the temperature sensed by the resistance bulb RB reaches the set point, at which time the controlled rectifier SCR2 will be gated "off" and the valve will begin to close. As the set point is not changed in this embodiment of the invention when the valve 6 is open, after the controlled rectifier SCR2 is gated "off" it can be gated "on" again after a time dependent on the thermal inertia of the system and the sensitivity of the temperature detection and switching circuits. It will be apparent to those skilled in the art that the manner in which the apparatus cycles can be adjusted from relatively slow "on"-"off" action to essentially proportional control by appropriate selection of the components and their values in accordance with standard design practice.

While I have described the apparatus of my invention with respect to the details of specific embodiments thereof, many changes and variations will be suggested to those skilled in the art upon reading my description, and such can obviously be made without departing from my invention.

I claim:

1. In a pulsed spark gas ignition system, the combination comprising a pair of electrodes defining a spark gap, a pulse generating network connected to said electrodes and responsive to an applied voltage for supplying pulses of voltage to said electrodes to produce sparks across said gap, valve means actuable by an applied electrical signal to supply fuel to said gap, flame detecting means responsive to fuel burning adjacent said electrodes to produce a signal, a thermally responsive resistor located in position to be ignited by fuel ignited by said electrodes, a bridge circuit including said resistor, said bridge circuit being excited by pulses from said pulse generating network when said pulse generating network is supplying pulses, and switching means jointly controlled by said signal from said flame detecting means and the output signal of said bridge circuit for supplying a signal to maintain said valve in operated condition when flame is detected and the temperature of said region is below a predetermined value.

2. In combination with a gas burner adapted to be connected to a gas supply line by a valve, a solenoid connected to the valve and operable when energized to open the valve, a pair of spaced ignition electrodes located adjacent said burner, pulse generating means responsive to an applied alternating voltage for periodically applying pulses of voltage to said electrodes to produce ignition sparks, and a control circuit for energizing said solenoid, said control circuit comprising first and second switching means each actuable to a conducting and a non-conducting state means responsive to the average flow of current through said electrodes for actuating said first switching means to its conducting state when ignition sparks are produced, a thermally responsive impedance in position to respond to the temperature of a region heated by said burner, circuit means including said thermally responsive impedance and energized by alternating voltage supplied to said pulse generating means for actuating said second switching means to its conducting state when voltage is supplied to said pulsing means and the temperature of said impedance is below a pre-

determined value, and means controlled by both of said switching means in their conducting states for energizing said solenoid.

3. The apparatus of claim 2, in which said pulse generating means comprises a pulse transformer having a secondary winding connected to said electrodes and a primary winding, a capacitor connected in series with said primary winding, and switching means responsive to an applied alternating voltage for charging said capacitor through said primary winding on half-cycles of a first polarity and discharging said capacitor through said primary winding on half-cycles of the opposite polarity, and in which said circuit means is energized by the voltage of said first polarity appearing across the series combination of said primary winding and said capacitor.

4. In combination with a gas burner, a pair of spaced ignition electrodes located adjacent said burner to ignite gas escaping from the burner when the electrodes are excited by a pulse of voltage of sufficient magnitude to arc across the space between them, and a solenoid valve connected between a source of gas and said burner and operable when energized to admit gas to said burner, an ignition and temperature control circuit, comprising a pulse transformer having a first secondary winding connected across said electrodes, a second secondary winding, and a primary winding, first capacitor connected in series with the primary winding of said pulse transformer, an electronic switch connected in parallel with the series combination of said capacitor and primary winding and actuable from a first non-conducting state to a second state conducting current in a first sense through the switch in response to an applied voltage of a first polarity, rectifying means responsive to an applied alternating voltage to apply alternate half-cycles of voltage of a second polarity opposite said first polarity to said switch and said series combination to charge said capacitor through said primary winding, means responsive to half-cycles of voltage of said second polarity applied to said rectifying means for periodically actuating said electronic switch to its second state to discharge said capacitor through said primary winding, producing voltage pulses across said secondary windings, a bridge circuit having input terminals connected across said second secondary winding, output terminals, and a thermally responsive impedance located in position to reflect by its impedance the temperature of a region heated by a flame produced by the ignition of gas from said burner to produce a signal across said output terminals, when pulses appear across said primary winding, of a polarity dependent on said temperature, a control circuit including a second electronic switch actuable to a conducting and a non-conducting state and operatively connected to said solenoid valve and terminals adapted to be connected to a source of voltage to open the valve in its conducting state, and means connecting said output terminals to said switch to actuate it to its nonconducting or its conducting state according as said signal is of a first or an opposite polarity, respectively.

5. In combination with a fuel burner and a pair of terminals adapted to be connected to a source of alternating voltage, pulse generating means connected to said terminals and responsive to alternating voltage to produce a train of pulses, pulse excited temperature responsive means connected to said pulse generating means and located in a space adapted to be heated by said burner for producing an output signal when supplied with pulses and exposed to a temperature below a predetermined value, an ignition circuit connected to said pulse generating means for igniting fuel supplied to said burner when energized by pulses from said pulse generating means, valve means electrically operable to supply fuel to said burner, and circuit means including a switch controlled by pulses from said temperature responsive means to enable operation of said valve means to supply fuel to said burner when said output signal is produced.

6. The apparatus of claim 5 in which said circuit means further comprises, in series with said switch, a second switch, and flame detecting means for opening said second switch a predetermined time after a flame produced by ignition of fuel supplied to said burner is extinguished.

7. The apparatus of claim 5, in which said temperature responsive means comprises a bridge circuit including a thermally responsive resistor located in said space and an adjustable resistor for determining said predetermined value of temperature, said bridge circuit having input terminals connected to said pulse generating means and output terminals connected to said switch.

8. The apparatus of claim 5, in which said pulse generating means comprises a pulse transformer having a primary winding and first and second secondary windings, and means for supplying pulses to said primary winding, said first secondary winding being connected in said ignition circuit, and said second secondary winding being connected to said temperature responsive means.

9. The apparatus of claim 8, in which said primary winding is tightly coupled to said second secondary winding and loosely coupled to said first secondary winding.

10. The apparatus of claim 9, in which said ignition circuit comprises a pair of spaced electrodes located adjacent said burner and connected in series with said first secondary winding, and said apparatus further comprising a third secondary winding on said transformer, switching means operable to a first state and a second state, means controlled by said switching means in its second state for connecting a low impedance across said third secondary winding to reduce the voltage of pulses across said second secondary winding to a value insufficient to arc across said electrodes in the absence of a flame, means responsive to the flow of current through said electrodes to enable said switch and timing means responsive to alternating voltage applied to said terminals to sequentially operate said switching means to its first state and then to its second state to initially operate said valve means when and only when ignition current is flowing and subsequently close said valve in the absence of flame adjacent said electrodes.

11. In a pulsed spark gas ignition system, the combination comprising a pair of electrodes defining a spark gap, a pulse generating means connected to said electrodes and responsive to an applied voltage for supplying pulses of voltage to said electrodes to produce sparks across said gap, said pulse generating means including a pulse transformer having a primary winding and two secondary windings and means for applying pulses to said primary winding, a first of said secondary windings being connected to said electrodes, said primary winding and said second secondary winding being tightly coupled and said primary winding and said first secondary winding being more loosely coupled, a third secondary winding loosely coupled to said primary winding, a capacitor, a Zener diode, and timing means responsive to voltage supplied to said pulse generator for connecting said diode and capacitor in parallel across said third secondary winding a predetermined time after voltage is supplied to said pulse generating means to reduce the voltage across said second secondary winding to a value insufficient to arc across said electrodes unless fuel is burning adjacent said electrodes, valve means actuable by an applied signal to supply fuel to said gap, temperature responsive means operable when energized to produce an output signal indicative of the temperature of a region heated by fuel ignited by sparks across said gap, said temperature responsive means including a bridge circuit having input terminals connected to a second of said secondary windings, output terminals connected to said switching means, and including a temperature responsive impedance, said temperature responsive impedance being located in said region, said pulse generating means energizing said tem-

perature responsive means when said pulse generating means is supplying pulses, and switching means controlled by the output signal of said temperature responsive means for applying a signal to said valve when the temperature of said region is below a predetermined value.

12. A fuel supply control circuit for a pulsed spark ignition system, comprising a pair of spaced ignition electrodes, a capacitor and a source of unidirectional voltage pulses connected in series with said electrodes, a thermally responsive resistor located in position to be heated by fuel ignited by said electrodes, a bridge circuit including said resistor and excited by said unidirectional pulse source to produce a signal in accordance with the temperature of said resistor when said source is producing pulses, valve means responsive to an applied electrical signal to admit fuel to a region adjacent said electrodes, and switching means jointly controlled by the signal from said bridge circuit and said capacitor for applying an electrical signal to said valve means when said capacitor is charged and said resistor is below a predetermined temperature.

13. The apparatus of claim **12**, in which said source of pulses includes a pulse transformer having a primary winding and a first secondary winding, said first secondary winding being connected in series with said capacitor and said electrodes, and in which said bridge circuit including said thermally responsive resistor has input terminals connected across a second secondary winding of said pulse transformers, said bridge circuit having output terminals for producing a current signal of a first or a second

polarity in dependence on the temperature of said resistor, a controlled rectifier having a gate circuit connected to said terminals in a sense gating said rectifier into conduction when the temperature of said resistor is below a predetermined value, and said controlled rectifier having load terminals connected in a control circuit for supplying said electrical signal to said valve means, whereby said controlled rectifier is gated into conduction to supply a signal to said valve means or not according as the temperature of said resistor is below or above said predetermined value, respectively, when and only when said source is producing pulses, said control circuit being responsive to the voltage appearing across said capacitor in series with said electrodes.

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