Dec. 6, 1938. W. J. KING 2,139,504

THERMAL RESPONSIVE CONTROL MECHANISM

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Fig. 1.

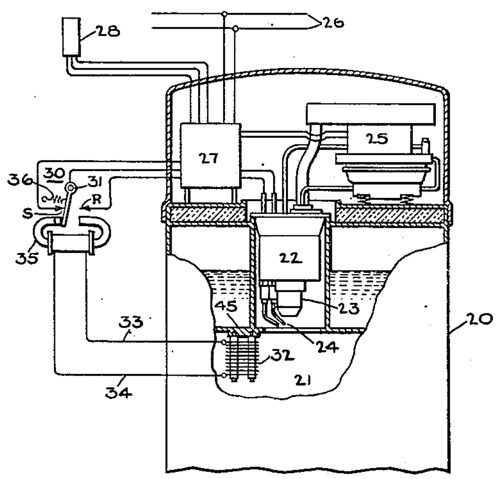


Fig. 2.

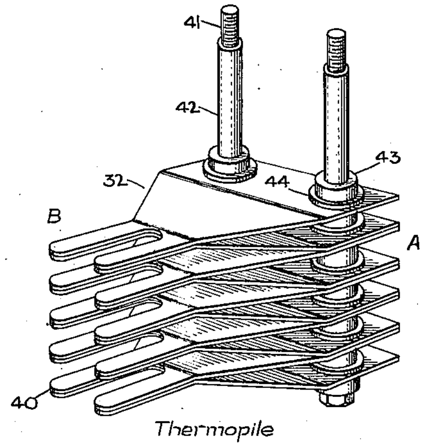


Fig. 4

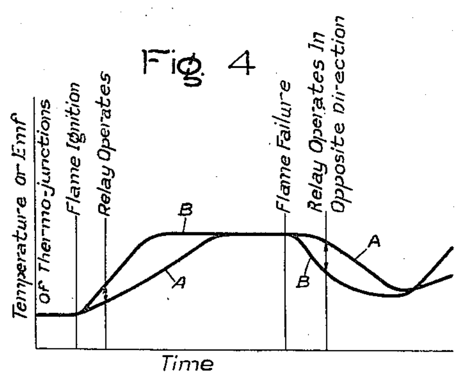


Fig. 3.

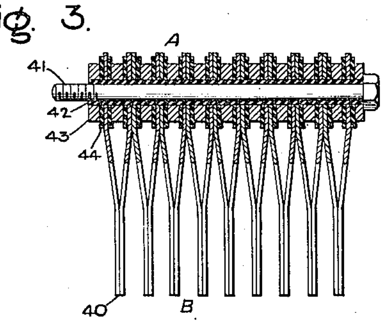


Fig. 5.

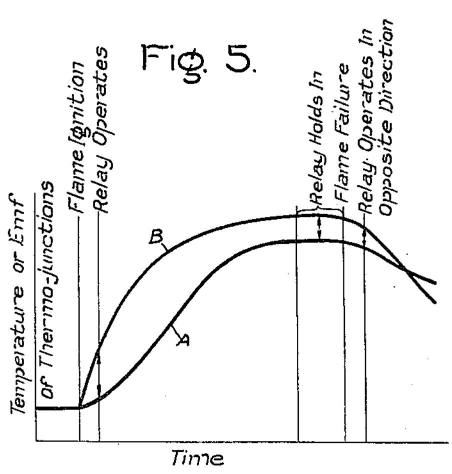
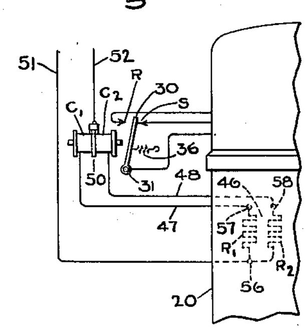


Fig. 6.



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THERMAL RESPONSIVE CONTROL MECHANISM

Filed Oct. 23, 1934 2 Sheets-Sheet 2

Fig. 9.

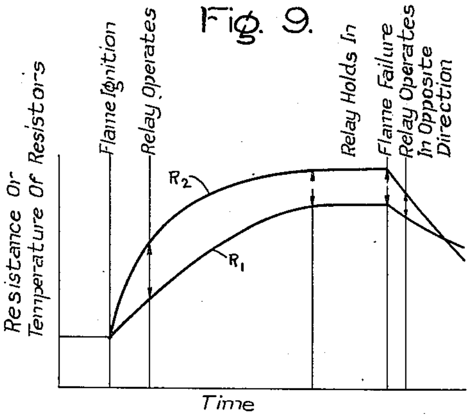


Fig. 10.

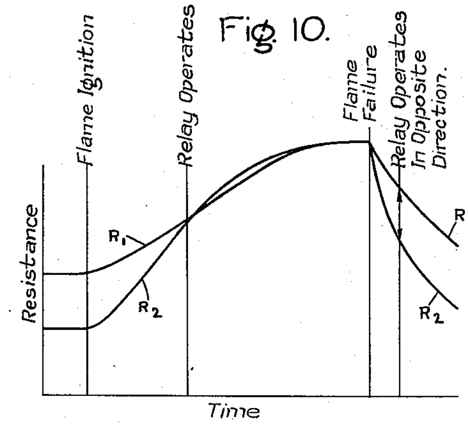


Fig. 7.

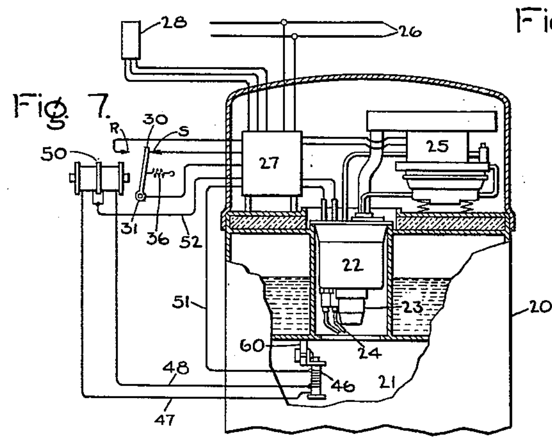


Fig. 8.

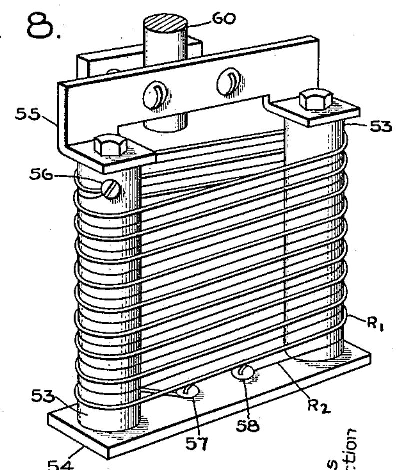


Fig. 11.

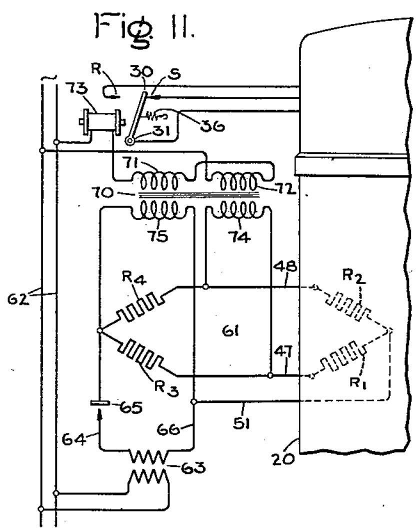
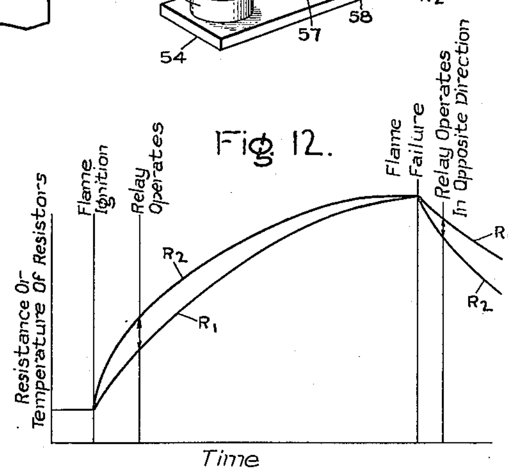


Fig. 12.



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UNITED STATES PATENT OFFICE

2,139,504

THERMAL RESPONSIVE CONTROL MECHANISM

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Application October 23, 1934, Serial No. 749,566

16 Claims. (Cl. 158—28)

This invention provides an improved form of thermal-responsive control mechanism particularly adapted for use in controlling an oil burner in response to the presence or absence of flame although not necessarily limited thereto.

One of the principal objects is to obtain a maximum speed of response upon a rapid variation of temperature.

Another object is to enable the maximum speed of response to be obtained upon a rapid increase of temperature between relatively low values and also upon a rapid decrease of temperature between relatively high values.

A further object is to obtain automatically a "follow up" action whereby the response of the mechanism is obtained during the initial part of a rapid temperature increase or decrease.

Another one of the principal objects is to provide an improved electrical type of thermal-responsive mechanism which is responsive to rate of change of temperature rather than to a mere change of temperature.

In the installation of heating equipments such as oil burners and the like it is common practice to provide control apparatus for starting and stopping the supply of fuel and air to the burner and for energizing the fuel ignition means, all in proper sequence and automatically in response to operation of a room thermostatic regulator. It is usual to include in such control apparatus a thermal-responsive mechanism for insuring that no appreciable quantity of fuel is fed into the furnace when the flame is not burning and also for providing protection against ignition failure during the starting cycle and against flame failure at any time during the operation of the burner.

A specific object of this invention is the provision in an oil burner control of an improved thermal-responsive mechanism which is particularly characterized by its speed of response to flame failure, either initial or occurring subsequent to ignition, and which will operate in a simple and reliable manner to prevent the supply to the furnace combustion chamber of unburned oil in an amount which would give rise to dangerous or undesirable conditions.

The desired rapidity of response and operation both upon flame ignition and flame failure is primarily secured in the mechanism of the present invention by the use of an electrically energized heat sensitive device the operation of which is not hampered by the inertia of moving parts and which at the same time is so constructed that it provides the desired "follow up" action necessary for a prompt response immediately subsequent to the initiation of either an increase or a decrease in temperature.

In its preferred embodiment the thermal-responsive mechanism of the present invention is adapted to effect operation of a two-position switch, which may be either a "start-run" or a "start-stop" switch or the like, incorporated in the electrical control apparatus of an oil burner furnace. In general the mechanism comprises an electrically energized heat sensitive device subjected to the heat of combustion and consisting of at least two electrical current controlling elements having thermal electric characteristics which change at relatively different rates in response to change in a variable temperature condition to which the device is subjected, and apparatus electrically connected to said device for effecting predetermined operation of the above referred to two-position switch in response to predetermined differentials between the values of current flowing through the respective elements of the heat sensitive device.

A clear understanding of the details of the invention may be secured from the following description taken in conjunction with the accompanying drawings in which are illustrated various aspects thereof.

In the drawings, Fig. 1 diagrammatically illustrates an oil burner boiler furnace with electrical control incorporating one embodiment of the invention employing a thermopile as the heat sensitive device, Figs. 2 and 3 are respectively a perspective and a cross section showing the details of construction of the thermopile, and Figs. 4 and 5 are curves diagrammatically representing the characteristics of operation of the thermopile and associated mechanism. Fig. 6 is a schematic showing of the electrical connections of a second embodiment of the invention employing a pair of temperature variable resistors as the heat sensitive device, Fig. 7 diagrammatically illustrates the manner of mounting the heat sensitive device in an oil burner furnace in electrical connection with the control apparatus of the furnace, Fig. 8 shows in detail the construction of the heat sensitive device employing the aforesaid variable resistors, and Figs. 9 and 10 are curves representing the characteristics of the operation of the thermal-responsive mechanism illustrated in Figs. 6 to 8 inclusive. Fig. 11 shows schematically the electrical connections of a modified form of the invention in which the variable resistor type of heat sensitive device is employed and Fig. 12 is a curve representing the characteristics of operation of this modification. Like parts are designated by the same numerals in all the figures.

Referring to Fig. 1, 20 represents a vertical type boiler furnace having a combustion chamber 21 in the top of which is an opening for the seating of a burner head unit 22 provided with an oil and air nozzle 23 and ignition electrodes 24. Oil, atomizing air and primary combustion air are supplied under proper pressures to the nozzle 23 by the combined blower-compressor unit 25 which is energized from the electrical supply line 26 through the electrical automatic control apparatus represented at 27. 28 designates a room thermostat for initiating operation of the control apparatus and 30 designates a two-position switch having fixed "start" and "run" contacts, represented as S and R respectively, and a movable contact 31 incorporated in the control apparatus 27 for modification of the operation thereof in a manner to be described hereinafter. For purposes of illustration and description, the boiler furnace 20, burner head 22, blower-compressor 25, control apparatus 27, and room thermostat 28 are represented diagrammatically as being of the forms disclosed respectively in the copending applications of H. S. Woodruff, S. N. 676,651, filed June 20, 1933; W. O. Lum and J. Eaton, S. N. 691,320, filed Sept. 28, 1933; W. O. Lum, S. N. 553,119, filed July 25, 1931, and S. N. 737,063, filed July 26, 1934; John Eaton, S. N. 735,103, filed July 14, 1934; and W. N. Mischler, S. N. 715,631, filed March 15, 1934, all of which applications are assigned to the assignee of the present invention. It is to be understood, however, that it is not intended that the field of application of the present invention be limited to association with these specific forms of apparatus. On the contrary, it is contemplated that the invention may be incorporated with equal advantages in other similar forms of control apparatus in conjunction with various forms of fluid fuel burner equipments. For a detailed description of the operation of the various elements of the burner and control apparatus referred to, reference should be had to the above identified applications, but sufficient description will be given hereinafter for a proper understanding of the present invention.

Operatively associated with the switch 30 of the control apparatus 27 is a thermal-responsive mechanism constructed in accordance with the present invention and comprising a heat sensitive device 32 located in the combustion chamber 21 in position to be subjected directly to the heat of combustion of the fuel and air discharged from the nozzle 23, and electrically connected by means of leads 33 and 34 to the operating coil of the polarized relay 35 which is arranged to operate the movable contact 31 between the fixed contacts S and R. Contact 31 is normally held by spring 36 in the "start" position engaging contact S.

The embodiment of the heat sensitive device 32 which is employed in the thermal-responsive mechanism illustrated in Fig. 1 and the construction of which is shown in detail in Figs. 2 and 3, comprises a number of thermocouples 40 connected in series to form a thermopile. In accordance with well known principles the couples generate a thermal electromotive force (thermal E. M. F.) which is nearly proportional to the difference in temperatures of the "hot" and "cold" junctions and the E. M. F. generated by the thermopile as a whole is directly proportional to the number of such couples connected in series. Since the E. M. F. per couple is small, sufficient number thereof are connected in series with the operating coil of the relay 35 to produce the voltage required to operate the contact 31.

An important feature in which the thermal-responsive mechanism of the present invention differs from the common forms of such mechanisms employing thermocouples as the heat sensitive means, resides in the fact that both sets of the thermojunctions of the thermopile are mounted to be directly subjected to the heat of combustion of the fuel. However, for the sake of simplicity the oppositely disposed sets of thermojunctions of the thermopile 32 will be referred to respectively as the "cold" junctions, designated as A, and the "hot" junctions, designated as B. In accordance with the invention, the thermopile is so constructed that the "hot" junctions heat up and cool off rapidly so that their temperature follows closely a change in temperature of the surrounding conditions, while the "cold" junctions heat up and cool off at a relatively slower rate so that their temperature lags behind that of the "hot" junctions upon a given change in temperature of the surrounding conditions. This may be accomplished in a number of different ways but in the embodiment illustrated the portions of the metal strips which comprise the "hot" junctions are made smaller than the portions which comprise the "cold" junctions and also are bifurcated as shown in Fig. 2 so that they have a relatively small thermal capacity and a large ratio of heat transfer area to mass. The "cold" junctions not only comprise the portions of the metal strips having the larger mass, but are mounted on the pins 41 which pass therethrough and are separated therefrom by electrical insulating tube 42, and also have interposed between them the metal washers 43 and insulating washers 44. Hence the mass of the "cold" junctions is appreciably larger than that of the "hot" junctions and the ratio of heat transfer area to mass is appreciably smaller which will result in a decided lag of temperature of the "cold" junctions behind that of the "hot" junctions.

When the thermopile 32 is subjected to a varying temperature condition, the temperatures of the respective sets A and B of the thermojunctions and hence the thermal effects produced therein, change at relatively different rates, resulting in the production of a variable differential E. M. F. in the thermopile. This differential E. M. F. is in one direction upon a temperature increase and in the opposite direction upon a temperature decrease, and produces electrical currents in corresponding directions in the circuit comprising leads 33 and 34 and the operating coil of polarized relay 35. The relay is set to operate in each direction upon a predetermined value of current flow of the respectively proper directional sense. It will be evident from the preceding description that it is possible for any one skilled in the art, keeping in mind the principles of the present invention, to readily vary the construction of the heat sensitive device or thermopile 32 and the adjustment of the relay 35 to secure any desired range of operation of the thermal-responsive mechanism.

The operation of the mechanism hereinbefore described is as follows: Assuming that the contact 31 of the switch 30 is in its normal position engaging the "start" contact S, a call for heat by the thermostat 28 initiates operation of the control device 27 which in turn starts the blower-compressor 25 and energizes the ignition electrodes 24. Oil is supplied to the nozzle 23 from the blower-compressor and is atomized there by means of high pressure air likewise supplied from the blower-compressor. The atomized oil is discharged from the nozzle into the combustion chamber 21 along with primary combustion air supplied by the blower-compressor and, providing the burner is properly operating, is ignited by means of the electrodes.

Fig. 4 illustrates the characteristics of operation of the thermal-responsive mechanism when the thermopile 32 is so constructed that the temperatures of the "hot" and "cold" junctions will eventually be the same although the "cold" junctions A lag behind the "hot" junctions B in attaining this value of temperature, and the polarized relay 35 is so adjusted that the magnetic bias imposed upon the movable contact 31 is just sufficient to hold this contact in engagement with the contact R against the pull of the spring 36 but is not sufficient to move the contact from S to R. Initiation of flame in the combustion chamber causes an immediate rapid rise of the temperature of the "hot" junctions B and, as illustrated in Fig. 4, a relatively slower rise of the temperature of the "cold" junctions A. Within a few seconds, the differential E. M. F. generated in the thermopile becomes large enough to produce a current flow in the operating coil of the relay 35 sufficient to move the contact 31 from engagement with the "start" contact S into engagement with the "run" contact R. This point is designated on the curves by the words "relay operates". The temperatures of the two sets of junctions of the thermopile continue to rise until that of the "hot" junctions eventually reaches a steady state value and that of the "cold" junctions also reaches the same steady state value which is approximately the temperature of the burning fuel. It will be evident that at this point there is no current flowing through the coil of the relay 35 but the contact 31 will continue to be held in the "run" position by means of the magnetic bias imposed thereon by the relay.

If, upon initiation of the operation of the oil burner mechanism, combustion is not established, no change takes place in the characteristics of the heat sensitive device 32 and the contact 31 remains in engagement with contact S whereupon the automatic control apparatus 27 goes through a predetermined number of recycling operations, as described in detail in the previously referred to application of John Eaton, S. N. 735,103 until combustion is established or completely shuts down the oil burner mechanism. If, however, combustion is established and the oil burner mechanism continues to operate in proper manner, the contact 31 is thrown into engagement with contact R by the thermal-responsive mechanism and is held there as previously described until the room thermostat 28 is satisfied or until for some reason there is a flame failure within the combustion chamber. In case of subsequent flame failure the "hot" junctions B immediately start to cool down at a rapid rate and the "cold" junctions A at a relatively slower rate so that a differential E. M. F. is produced in a direction opposite to that produced by flame ignition as indicated on the curves in Fig. 4, which differential E. M. F. produces a current in the operating coil of the relay 35 in the proper direction and, after a few seconds, of sufficient magnitude to overcome the magnetic bias imposed upon the contact 31 to hold it in engagement with contact R, thus permitting the spring 36 to pull the contact 31 back into engagement with contact S and allowing the control apparatus 27 to go through the recycling operations or to completely shut down the oil burner mechanism.

Fig. 5 represents the characteristics of operation of the thermal-responsive mechanism when the relay 35 is so adjusted that the magnetic bias imposed upon the contact 31 is insufficient to hold the contact in engagement with the "run" contact R, and the heat sensitive device 32 is so constructed and mounted that the "cold" junctions A will not catch up in temperature at any time with the "hot" junctions B upon a rise in temperature of the conditions to which the device is subjected. In this case the thermopile 32 is so mounted that the "cold" junctions A are in intimate heat conductive relation with the waterbacked surface of the combustion chamber through the mounting pins 41 as shown at 45 and therefore the heat will be radiated from the "cold" junctions at such a rate that they will be unable to catch up in temperature with the "hot" junctions. Upon initiation of combustion the temperatures of the "hot" and "cold" junctions diverge as shown in Fig. 5 until sufficient differential E. M. F. is produced not only to operate the contact 31 from S to R but also to hold the contact in engagement with the contact R. The temperatures of the two sets of junctions A and B continue to rise until a steady state condition is reached whereat a sufficient differential E. M. F. is produced to "hold in" the relay or, in other words, to maintain the contact 31 in engagement with the contact R. This condition continues during proper operation of the burner and until flame failure at which time the temperatures of the "hot" and "cold" junctions begin to converge and a differential E. M. F. shortly is reached which is insufficient to hold the contact 31 in engagement with the contact R whereupon it is drawn by means of spring 36 into engagement with contact S. In all other respects the operation of the mechanism the characteristics of which are illustrated in Fig. 5, is the same as that of the mechanism the characteristics of which are illustrated in Fig. 4.

It is well known in the operation of oil burners that fluctuations may occur in the temperature in the combustion chamber due to irregularities in the operation of the fuel and air delivery nozzle. Some degree of such fluctuation is to be expected and is not harmful to the efficient operation of the furnace but if the fluctuation occurs to too great an extent it indicates that the burner mechanism is operating improperly and should be shut down until adjustments or repairs are made. However, it is preferred that the flame detecting mechanism should not operate as quickly in the case of a drop in temperature due to these undesirable fluctuations of the combustion temperature as it would in the case of a drop of temperature due to complete flame failure. Such a contingency is taken care of by the present invention in that the characteristics of the heat sensitive device 32 are such that the changes in temperature of the combustion chamber attendant upon harmless fluctuations are too slow to produce any divergence or produce such slight divergence of the temperatures of the "hot" and "cold" junctions that the resultant differential E. M. F. is insufficient to operate the relay 35. On the other hand, if the fluctuations attain undesirable proportions, the changes in temperature in the combustion chamber take place at a rate which, though slower than that in the case of a complete flame failure, is rapid enough to produce a sufficient differential E. M. F. between the "hot" and "cold" junctions to operate the relay. The period of time required for operation of the relay upon the occurrence of undesirable fluctuations varies in inverse proportion to the seriousness of the fluctuation since the greater the degree of fluctuation the more rapid the change in temperature in the combustion chamber and hence the shorter is the time required for the production of the required differential E. M. F.

The operational characteristics of the thermal-responsive mechanism which provide a safeguard against operation of switch contact 31 from R to S upon flame fluctuations which are not of sufficient degree to be harmful, also provide a safeguard against operation of the contacts from S to R due to changes in the ambient temperature when the burner is not in operation and the flame is not ignited. Such changes in ambient temperature, due to weather conditions or other causes, ordinarily occur at such slow rates that either no divergence or only slight divergence is produced between the temperatures of the respective sets of thermojunctions A and B. Hence, no current, or insufficient current, is caused to flow in the operating coil of relay 35 and contact 31 remains in engagement with contact S until operation of the burner is initiated and flame is produced.

Another important characteristic of the thermal-responsive mechanism hereinbefore described is the "follow up" action which, after operation of the mechanism upon flame ignition, then places the mechanism in condition to operate quickly in a reverse direction upon flame failure. This has heretofore been accomplished with mechanical flame detectors by means of complicated clutch devices. As illustrated in Figs. 4 and 5, the required differential in E. M. F. between the "hot" and "cold" junctions is produced in a short period of time after flame failure, which period of time is appreciably less than that required for the heat sensitive device to cool down to the temperature at which it originally operated the relay 35 upon flame ignition.

In Figs. 6 to 8 is illustrated a second embodiment of the invention, the principles underlying which are substantially the same as those upon which the first embodiment is based. The heat sensitive device of this second embodiment is represented at 46 as comprising a pair of temperature sensitive variable resistors R_1 and R_2 which have positive temperature coefficients of resistance and which are connected respectively by means of leads 47 and 48 in series with the opposing coils C_1 and C_2 of a differential relay 50 which is arranged to operate the movable contact 31 of the switch 30 electrically connected in circuit with the oil burner control apparatus 27. Electrical energy is supplied to the coils of the relay through resistors R_1 and R_2 by means of lead 51 which, along with return lead 52, is connected to be energized from any suitable electrical source either directly or through the control apparatus 27.

The important characteristics of the thermal-responsive mechanism of this second embodiment are that the resistors R_1 and R_2 are so constructed that their electrical current controlling characteristics vary at relatively different rates in response to a given temperature change of the surrounding conditions, and that the switch contact 31 is adjusted to operate in response to a certain predetermined value of differential flux produced by the opposing coils C_1 and C_2 of the relay 50, which differential flux is the result of the difference in current flow through the unequally variable resistors. The construction and arrangement of the elements of the thermal-responsive mechanism to attain these characteristics are capable of wide variations, and for purposes of illustration several modifications are described and illustrated hereinafter. However, it is to be understood that these modifications are not intended as limiting the scope of the present invention but are set forth only for the purpose of clarifying the principles thereof and to make it possible for one skilled in the art to practice the invention which is capable of numerous modifications within the range of mechanical skill.

One practical form of construction for the heat sensitive device 46 is shown in detail in Fig. 8 from which it will be seen that the resistors R_1 and R_2, in the form of wires, are wound in alternating turns about the supporting spools 53, which may be of soapstone or any other suitable electrical insulating and heat resisting material and which are held in place by means of metal spacing bars 54 and 55. The diameter of the wire forming the resistor R_1 is greater than that of the wire forming the resistor R_2 so that the former has a greater thermal capacity and a smaller ratio of heat transfer surface to mass than the latter. Furthermore, R_2 is made of a very fine wire so that it heats up and cools off rapidly. Hence, the temperature, and therefore the resistance, of R_1 lags appreciably behind that of R_2 with a given change in temperature of the conditions to which the resistors are subjected. The relative diameters of the two wires may be so selected as to give the desired degree of lag for any particular application. The same results may be secured by making the wires of equal diameters and coating the surface of the wire R_1 with heat insulating material so that it absorbs and gives off heat at a slower rate than the wire R_2.

The wires are brought together at one end and secured to the connecting stud 56 to which is secured also the electrical supply lead 51. The other ends of the resistors R_1 and R_2 are secured respectively to connection studs 57 and 58, to which also are secured respectively the relay leads 47 and 48. A mounting arm 60 is attached to the upper spacing bar 55 as shown to provide means for mounting the heat sensitive device 46 beneath the shell of the combustion chamber 21 of the furnace 20 and in proximity to the discharge end of the nozzle 23.

In the construction of the mechanism the characteristics of operation of which are illustrated in Fig. 9, the resistors R_1 and R_2 are so selected that they have the same value of resistance at the low temperature which prevails in the combustion chamber of the furnace when the burner is not operating and that R_2 has a higher positive temperature coefficient of resistance than R_1. As was previously set forth in connection with the description of the operation of the first embodiment of the invention, a call for heat by the thermostat 28 initiates the operation of the control apparatus 27 to start the blower-compressor 25 and energize the ignition electrodes 24. If the flame is properly ignited, the temperature and the resistance of R_2 increase more rapidly than that of R_1 so that more current is allowed to flow through the coil C_1 of the relay 50 than through the coil C_2. Thus a differential flux is produced in the relay which in a few seconds is sufficient to cause the contact 31 of the switch 30 to move from engagement with the contact S into engagement with the contact R in opposition to the pull of the biasing spring 36. R_1, which has a lower temperature coefficient of resistance than R_2, has a lower value of resistance than R_2 when the steady state temperature condition is finally attained in the combustion chamber and the two resistors attain the same temperature. Hence there is produced at all times during proper operation of the burner a sufficient differential flux to hold the contact 31 of the relay in engagement with the "run" contact R as indicated by the curves of Fig. 9. Upon failure of the flame due either to improper operation of the burner or to satisfaction of the room thermostat, the resistors immediately start to cool down, the temperature of R_2 dropping at a faster rate than that of R_1 so that their values of resistance tend to converge and the differential flux produced in the relay 50 becomes so reduced that the spring 36 is able to return the contact 31 to engagement with the contact S.

In the modification of the flame detecting mechanism, the characteristics of operation of which are illustrated in Fig. 10, the resistors R_1 and R_2 are so selected that they have different positive temperature coefficients of resistance and the resistance of R_1 is greater than that of R_2 at the low temperature normally prevalent in the combustion chamber of the furnace when the burner is not in operation. Furthermore, the directions of pull of the relay 50 and of the spring 36 are reversed with relation to the contact 31 so that the contact is held normally in engagement with the contact S by the differential flux produced in the relay as a result of the difference in values of resistance of the resistors R_1 and R_2 when cold. In this case, ignition of the flame causes the resistance of R_2 to increase more rapidly than that of R_1 so that within a few seconds the differential flux produced in the relay is reduced to such extent that the contact 31 is moved from engagement with contact S into engagement with contact R by means of the spring 36 thus breaking the "start" circuit and making the "run" circuit. The temperatures of R_1 and R_2 continue to rise and their resistance values become equal at the operating temperature prevalent in the combustion chamber. Contact 31 then remains in the "run" position during continuation of proper combustion. Upon failure of the flame, the resistance of R_2 decreases more rapidly than that of R_1 so that different values of current are again produced in the coils of the relay and the resultant differential flux moves the contact 31 back into engagement with the contact S.

Fig. 11 diagrammatically illustrates a modified form of electrical circuit to be used in the thermal-responsive mechanism of the present invention in conjunction with a heat sensitive device such as that illustrated in Fig. 8. The operational characteristics of this mechanism are represented by the curves of Fig. 12. In this modification the resistors R_1 and R_2 are so selected that they have the same positive temperature coefficient of resistance and equal values of resistance at both the lower and upper temperatures prevalent in the combustion chamber of the furnace during non-operation and operation respectively of the burner but, as previously described in connection with the other modifications of the invention, the resistance of R_1 lags behind that of R_2 in changing from the lower value to the upper value in response to a change in the temperature of the conditions to which the heat responsive device is subjected. In the presently described modification the heat sensitive device 46 is mounted within the combustion chamber 21 of the furnace 20 in the same manner as illustrated in Fig. 7 and described hereinbefore.

Referring particularly to Fig. 11, it will be seen that the resistors R_1 and R_2 are connected by means of the leads 47 and 48 respectively so that they form two legs of a direct current bridge 61, the other two legs of which are formed by the resistors R_3 and R_4 placed externally of the furnace. The various resistors making up the bridge are so selected that the resistance of R_3 equals that of R_4, and as previously stated the resistance of R_1 equals that of R_2 when the temperatures of R_1 and R_2 are equal. Furthermore, the resistances of R_1, R_2, R_3 and R_4 are all equal when the temperatures of all the resistances are equal, that is, when the burner is not operating and the combustion chamber of the furnace is at ambient temperature. 62 represents the electrical supply lines which may be connected to any suitable source of alternating current either directly or through the control apparatus 27 of the oil burner furnace. Across the supply lines 62 is connected the primary of transformer 63, one side of the secondary of which is connected through lead 64 and rectifier 65 to the end of the bridge 61, which is common to the resistors R_3 and R_4, and the other side of which secondary is connected through leads 66 and 51 to the end of the bridge which is common to the resistors R_1 and R_2, thus forming the input circuit for supplying direct current energization to the bridge. 70 represents a saturable core reactor the primary of which comprises two coils 71 and 72 connected in series with the operating coil of the relay 73 across the altenating current supply lines 62. The secondary of the reactor also comprises two separate coils one of which, the operating coil 74, is connected in the output circuit of the bridge 61, and the other of which, the holding coil 75, is connected by means of leads 64 and 66 across the secondary of the transformer 63. Primary coils 71 and 72 of the reactor are placed in opposition to each other so that no voltage will be induced in the secondary coils. The coil of relay 73 is connected in series with coils 71 and 72 and is so arranged that a predetermined magnitude of flux produced therein by the current flowing through the primary coils 71 and 72 moves the contact 31 of the switch 30 from engagement with the contact S into engagement with the contact R in opposition to the pull of the spring 36.

In the operation of the mechanism just described the saturating current normally flowing through the holding coil 75 lowers the impedance of the reactor 70 to such an extent that the alternating current flowing through the primary coils 71 and 72 is just sufficient to hold the contact 31 in engagement with the contact R after it has once been moved to this position, but is insufficient to move the contact from S to R. Upon ignition of the fuel discharged from the burner nozzle 23 the resulting flame heats up the resistors R_1 and R_2 so that their temperatures and their resistances increase and diverge as indicated in the curves of Fig. 12. This divergence of the values of the resistances produces an unbalance of the bridge which sets up a current in the output circuit thereof and through the operating coil 74 in the same direction as the current already flowing in the holding coil 75. Hence the saturating effect of the two currents is additive and the impedance of the reactor is lowered sufficiently to permit a current flow in the coils 71 and 72 and the relay 73, which current after a few seconds, is sufficient to move the contact 31 from engagement with the contact S into engagement with the contact R. When the maximum temperature is reached in the combustion chamber the resistance of R_1 is equal again to that of R_2 and no current flows through the operating coil 74 since the bridge again becomes balanced. In this state the saturating effect of the holding coil 75 is sufficient to cause the relay 73 to hold the contact 31 in engagement with the contact R. When the flame fails the temperature and resistance of R_2 fall more quickly than that of R_1 with the result that a current is produced in the output circuit of the bridge which is opposite in direction to that produced upon a rise in temperature. The saturating effects of the currents produced in the holding coil 75 and operating coil 74 are now subtractive. Hence the impedance of the circuit of the relay 73 is increased to such an extent that the current flowing therein produces insufficient flux to hold the contact 31 in engagement with the contact R and the contact 31 is moved back into engagement with the contact S by means of the spring 36.

The time required for the operation of the thermal-responsive mechanism employing the dissimilar resistors is inversely proportional to the rate of change of the temperature conditions to which the heat sensitive device is subjected which was also the case with the mechanism employing the thermopile heat sensitive device. In other words, the slower the rate of change of the temperature conditions the longer it takes for the resistances of the resistors R_1 and R_2 to diverge enough to produce a current flow in the relay sufficient to operate the contact 31. Furthermore, the required degree of divergence does not occur at all if the change in the temperature of the surrounding conditions is below a certain rate. The advantages of this characteristic were fully pointed out in connection with the mechanism employing the thermopile heat sensitive device.

Likewise the heat sensitive device employing the dissimilar resistors has "follow up" characteristics similar to those of the heat sensitive device employing the thermopile as previously described. After the flame is ignited and sufficient time elapses for the required divergence of the resistances to cause operation of the relay, the temperatures of the two resistors continue to rise and maintain with respect to each other the proper relationship so that upon flame failure they can produce operation of the relay in the reverse direction in a short period of time which is comparable to that required for operation of the relay upon flame ignition. Hence it is not necessary for the resistors to cool down to the temperatures at which they were when the relay operated upon flame ignition.

To one skilled in the art it will be evident from the description given hereinbefore that the thermal-responsive mechanism constructed in accordance with the present invention may be adjusted so that it will operate with great rapidity both upon flame ignition and flame failure. With a certain heat sensitive device, either of the thermopile or variable resistor type, the rate of change of temperature, and therefore of electrical response, in the respective current controlling elements, i. e., the thermojunctions in the one case and the variable resistors in the other case, produced by a given change in the temperature of the condition to which the device is subjected, will be known since in practice the elements of the device will be selected to have certain predetermined characteristics. Hence it will be possible to determine readily the different degrees of divergence between the temperatures and the electrical response of the respective current controlling elements after different periods of time have elapsed subsequent to flame ignition and flame failure. Curves similar to those diagrammatically illustrated in Figs. 4, 5, 9, 10 and 12 may be plotted showing the operational characteristics of the particular heat sensitive device which it is desired to use under a particular set of conditions. The relay for operation of the "start-run" switch, or the "start-stop" switch as the case may be, of the burner control apparatus may then be adjusted to operate in response to the particular differential which occurs in the predetermined short period of time. In practice it has been found that the thermal-responsive mechanism of the present invention may be made to operate in a period of time which is in the order of two or three seconds subsequent to either flame ignition or flame failure. This is appreciably faster than the speed with which the flame detecting mechanisms heretofore commonly known in the art will operate.

An additional advantage provided by the present invention is the securing of an efficient "follow up action" by simple and reliable electrical means as contrasted to the common forms of mechanical "follow up" devices, such as complicated slipping clutches and the like, the operation of which may be rendered unreliable by heat warping, wear and improper adjustment.

A further advantage of the thermal-responsive mechanism constructed in accordance with the present invention arises from the fact previously pointed out that the mechanism operates in response to rate of change of the surrounding conditions. That is, temperature changes at certain slow rates will not cause operation of the mechanism, but undesirably large fluctuations of combustion resulting in more or less rapid changes in temperature will cause the mechanism to operate at rates which are inversely proportional to the rate of change of the temperature conditions, and an extremely rapid change in temperature such as produced by flame ignition and by complete flame failure will produce practically instantaneous operation of the thermal-responsive mechanism.

It will be obvious that the advantages of the present invention may be secured by various modifications of the apparatus herein illustrated and described, and it is intended that such modifications as do not depart from the true spirit and scope of the invention will be covered by the appended claims in which are set forth those features which are believed to be new and novel.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The combination with an electrically operated fuel burning apparatus and electro-responsive switch control mechanism including an operating winding therefor, of a thermocouple having both the thermojunctions thereof arranged to be heated simultaneously by combustion of the fuel, the thermocouple being electrically con-

nected to energize the operating winding of said switch mechanism by means of the thermo-electric currents produced therein and the two thermojunctions having respectively different rates of change in the thermo-electric effect produced therein upon the initiation and termination of combustion of the fuel.

2. The combination with an electrically operated fuel burning apparatus and electro-responsive switch control mechanism including an operating winding therefor, of an electrical heat sensitive device electrically connected to energize the operating winding of said switch mechanism, said device comprising a thermopile disposed with both the "hot" and the "cold" thermojunctions thereof in position to be subjected to the heat of combustion of the fuel, and means for effecting in the "cold" thermojunctions a slower rate of change in the thermo-electric effect produced therein than in the "hot" thermojunctions upon initiation and termination of fuel burning.

3. In combination with a fuel burning mechanism, an electric energizing circuit therefor, a thermopile having both the "hot" and "cold" thermojunctions thereof positioned to be exposed to the heat of combustion of the fuel, said "cold" thermojunctions having a slower rate of thermo-electric response than said "hot" thermojunctions to a given change in the temperature to which the thermopile is subjected in order that thermo-currents of opposite directional sense will be generated in the thermopile in response to initiation and failure respectively of combustion, and electro-responsive switch mechanism, including a switch and an operating winding, for controlling said circuit, said operating winding being electrically connected to said thermopile to operate the switch in opposite directions in accordance with the directional sense of the thermo-currents generated in the thermopile.

4. In combination with a fuel burning apparatus, an electric energizing circuit therefor, a relay for controlling the circuit, said relay having biasing means tending to produce operation thereof in one direction and an operating winding, a thermopile positioned to be subjected to the heat of combustion of the fuel, certain of the thermojunctions of the thermopile having a slower rate of thermo-electric response to temperature change than others of the thermojunctions whereby thermo-electric currents of opposite directional sense are produced in the thermopile in response to initiation and failure respectively of combustion, said thermopile being electrically connected to cause energization of the operating winding of the relay respectively in aid to and in opposition to the biasing means in response to the thermo-electric currents of opposite directional sense.

5. In combination with an electrically operated fuel burning apparatus including means for producing a flame, means for controlling the operation of the apparatus in response to initiation and failure of the flame including a relay electrically connected to control the energization of the apparatus and having differentially connected windings, and a heat sensitive device for controlling the operation of the relay, said device including a pair of temperature-variable resistance resistors positioned to be commonly subjected to the temperature changes, resulting from flame initiation and flame failure, said resistors being electrically connected in parallel with each other and each in series with one of the windings of the relay, one of the resistors having a slower rate of temperature variation than the other in response to the temperature changes to which the resistors are commonly subjected whereby current differentials are produced in the windings of the relay to operate the same upon flame initiation and flame failure.

6. In combination with a fuel burning apparatus and electro-responsive switch mechanism for controlling the operation thereof, a Wheatstone bridge and an electric supply circuit therefor connected to energize the switch mechanism in response to a predetermied current flow produced in the output circuit of the bridge by electrical unbalance thereof, a pair of temperature-variable-resistance resistors connected each in a separate leg of said bridge and both positioned to be commonly affected by changes in temperature resulting from changes in the burning of the fuel, said two resistors having different rates of temperature variation in response to said changes in temperature.

7. In combination with an electrically operated fuel burning apparatus including means for producing flame, a Wheatstone bridge and an electric supply circuit therefor, an electro-responsive switch mechanism for controlling the operation of said apparatus and electrically connected to be operable in opposite directions between two circuit controlling positions in response to predetermined current flow in the output circuit of the bridge, two of the legs of the bridge including temperature-variable resistance resistors positioned to be commonly subjected to the heat of the flame with the resistor of one of said two legs having a larger thermal capacity and a smaller ratio of heat transfer surface to mass than the resistor of the other of said two legs.

8. The combination with a furnace and combustion means for effecting temperature changes therein, of a device operable into a plurality of different positions for controlling said first means, and means responsive to rate of change of temperature of combustion at any point within the range of said changes for effecting operation of said controlling device into one of said positions during the initial part of a temperature increase within the furnace at a predetermined rate and for effecting operation of said controlling device into a second one of said positions during the initial part of a temperature decrease within the furnace at a predetermined rate.

9. The combination with a furnace having combustion means for producing temperature variation therein, of electro-responsive means for controlling said first means, and means responsive to the rate of variation of the temperature of combustion within the furnace for effecting operation of said electro-responsive means including a plurality of temperature variable electric current controlling elements commonly subjected to the temperature within the furnace, certain of said elements having lower rates of temperature change than other of said elements in response to variation in the temperature to which the elements are commonly subjected.

10. The combination with a furnace having means operable for producing combustion therein, of means for controlling the operation of said first means including at least two thermally responsive elements commonly subjected to the temperature within the furnace and having temperature variable electric current controlling

characteristics, said two elements being variable in temperature at different rates in response to variation in the temperature to which they are commonly subjected, an electroresponsive control device operable alternately into each of two positions for effecting predetermined control of said combustion producing means, and electrical circuits operatively interconnecting said electroresponsive control device and said current controlling elements for effecting operation of said control device into one of said positions in response to the occurrence of a predetermined differential between the current controlling characteristics of said elements resulting from a temperature rise due to combustion initiation and for effecting operation of said control device into the other of said positions in response to the occurrence of a second predetermined differential between the current controlling characteristics of said elements resulting from a subsequent temperature drop due to combustion failure.

11. The combination with a furnace having means operable for producing combustion therein, of means for controlling the operation of said first means including at least two thermally responsive elements commonly subjected to the temperature of combustion within the furnace, one of said elements having smaller thermal capacity and a larger ratio of heat transfer surface to mass than the other of said elements whereby differentials between the current controlling characteristics of said two elements are set up in response to variations in the temperature to which the elements are commonly subjected, and electroresponsive means operatively connected in circuit with said elements for effecting predetermined control of said combustion producing means upon the occurrence of predetermined differentials between the current controlling characteristics of said elements.

12. The combination with a furnace having means for producing temperature variations therein, of electroresponsive means for controlling said first means and means responsive to a predetermined rate of variation of the temperature within the furnace for effecting operation of said electroresponsive means including a plurality of electric circuits connected for operatively energizing said electroresponsive means and a pair of resistors commonly subjected to the temperature within said furnace and connected each in a separate one of said circuits, said resistors having different rates of temperature variation in response to variations in the temperature to which they are commonly subjected and the resistances of said resistors being variable with the temperature of the resistors.

13. The combination with a furnace having electrically operated fuel burner apparatus for producing temperature variations therein, of electroresponsive means for controlling the operation of said apparatus, a plurality of electric circuits connected for effecting actuation of said electroresponsive means, and a pair of temperature-variable-resistance resistors connected each in a separate one of said circuits for controlling the current flow therein and positioned to be subjected to the heat of combustion of the fuel, one of said resistors having a small thermal capacity and a large ratio of heat transfer surface to mass and the other of said resistors having a relatively larger thermal capacity and a relatively smaller ratio of heat transfer surface to area.

14. In combination, a combustion chamber, a pair of temperature responsive elements therein each responsive at a different rate to variations in the temperature within said chamber, heat generating means operable for varying the temperature within said chamber at rates above a predetermined value, and means responsive to a predetermined differential in the response of said elements for controlling said heat generating means only when the rate of change of the temperature within said chamber exceeds said predetermined value.

15. In combination, a combustion chamber, a temperature responsive control device having a pair of cooperating control elements in said chamber each responsive at a different rate to variations in the temperature within said chamber and cooperating to effect response of said device only to rates of temperature change within said chamber greater than a predetermined maximum rate, heat generating means operable for varying the temperature within said chamber at rates above said predetermined maximum value, and means under the control of said temperature responsive control device for controlling operation of said heat generating means.

16. In combination, a combustion chamber, a pair of temperature responsive elements within said chamber, one of said elements being responsive at a slower rate to temperature changes within said chamber than the other, electrical means under the control of said elements and operable only when a predetermined temperature differential exists between said elements corresponding to rates of temperature change within said chamber greater than a predetermined maximum rate, heat generating means operable for varying the temperature within said chamber at rates above said predetermined maximum value and means operable under the control of said electrical means for controlling operation of said heat generating means.

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