

April 8, 1952

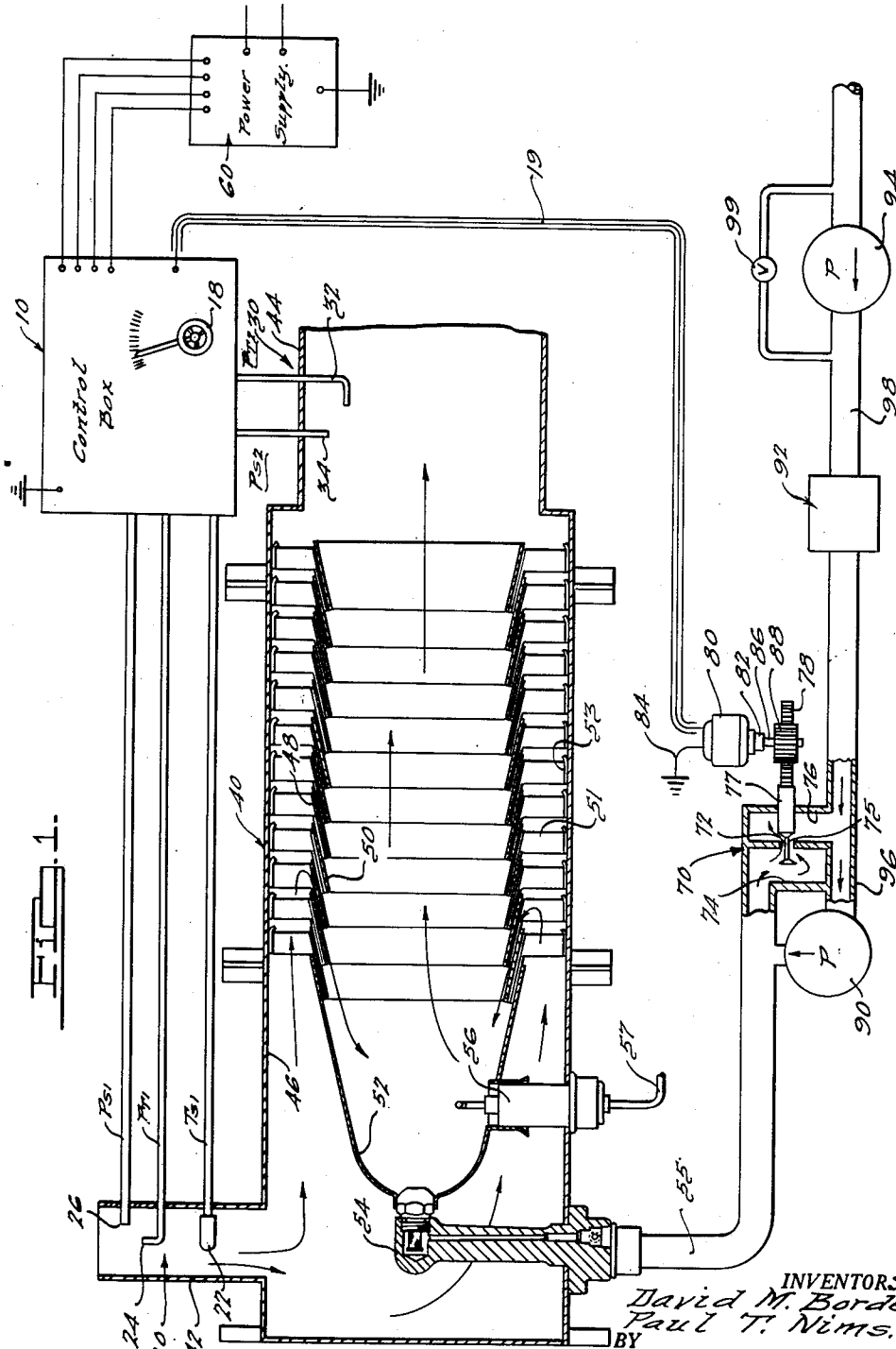
D. M. BORDEN ET AL

2,592,385

COMBUSTION CONTROL APPARATUS

Filed May 27, 1949

3 Sheets-Sheet 1



INVENTORS,
David M. Borden,
Paul T. Nims.
Harness and Harris
ATTORNEYS.

April 8, 1952

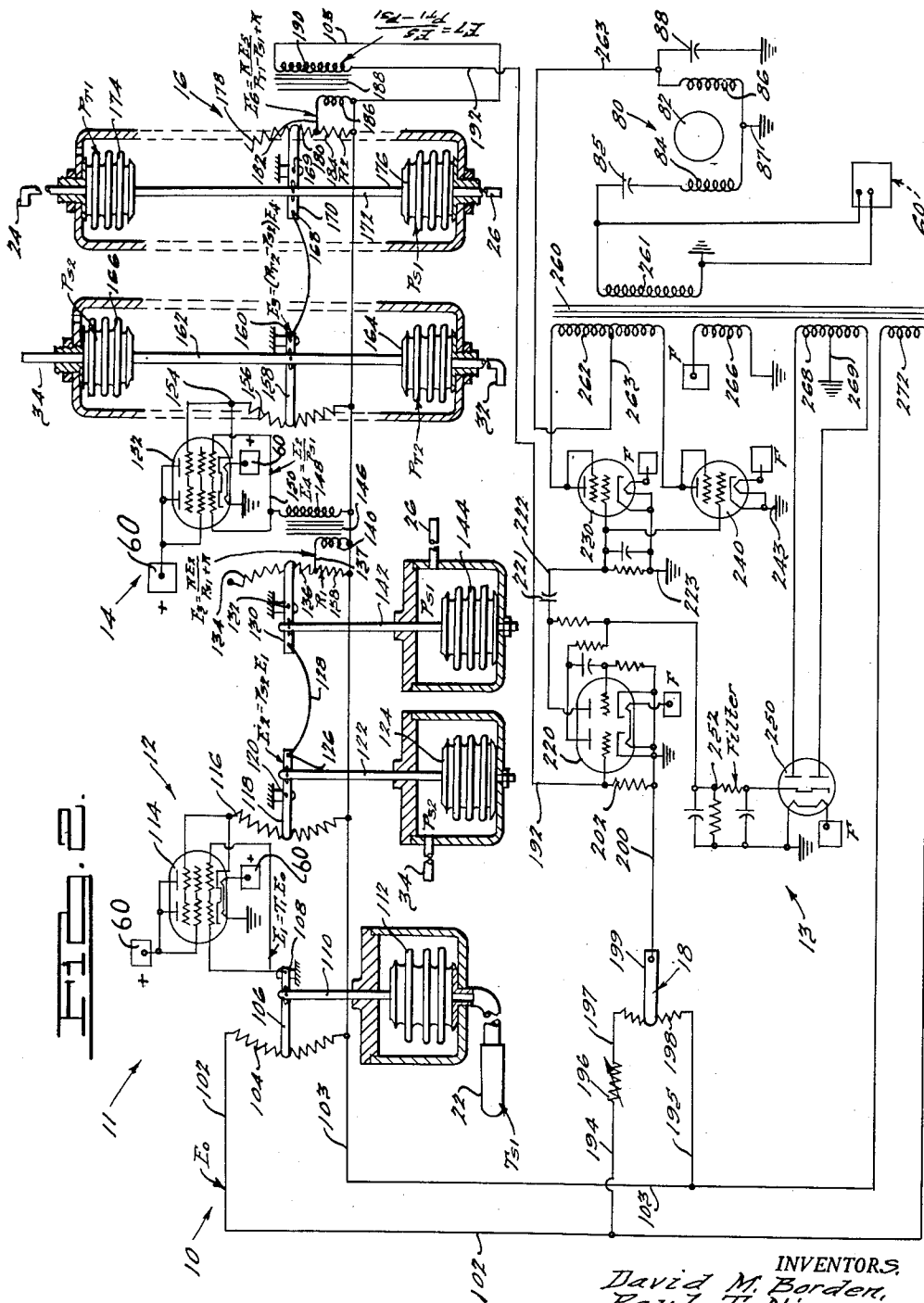
D. M. BORDEN ET AL

2,592,385

COMBUSTION CONTROL APPARATUS

Filed May 27, 1949

3 Sheets-Sheet 2



INVENTORS,
David M. Borden,
Paul T. Nims.
BY

BY
Harness and Harris
ATTORNEYS.

April 8, 1952

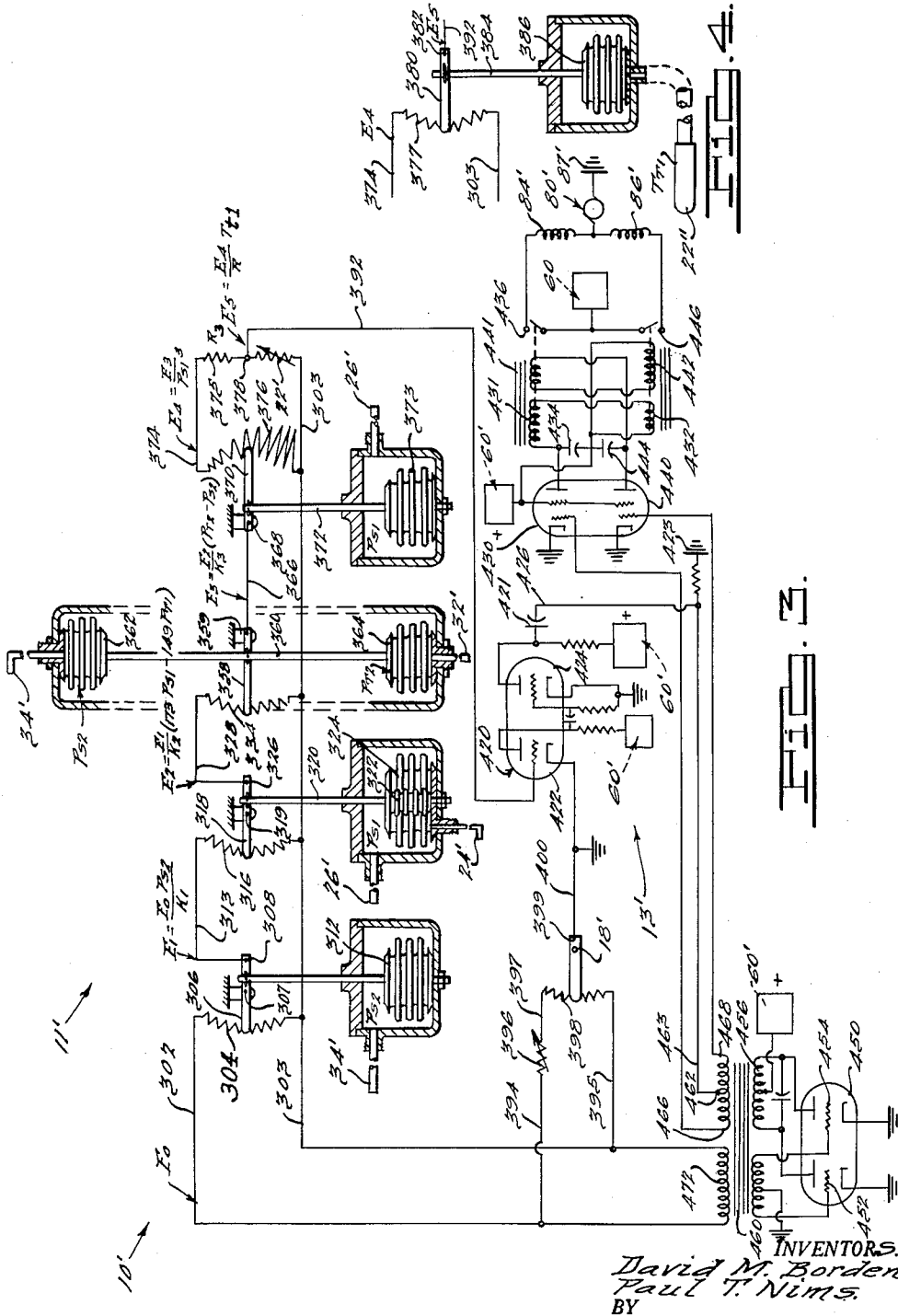
D. M. BORDEN ET AL

2,592,385

COMBUSTION CONTROL APPARATUS

Filed May 27, 1949

3 Sheets-Sheet 3



निदेश

INVENTORS.
David M. Borden,
Paul T. Nims.
BY

BY

Harness and Harris
ATTORNEYS.

UNITED STATES PATENT OFFICE

2,592,385

COMBUSTION CONTROL APPARATUS

David M. Borden, Huntington Woods, and Paul T. Nims, Detroit, Mich., assignors to Chrysler Corporation, Highland Park, Mich., a corporation of Delaware

Application May 27, 1949, Serial No. 95,654

18 Claims. (Cl. 236—15)

1

This invention relates to combustion regulating apparatus, particularly apparatus controlling the process of combustion in a burner of which the fuel supply is regulated according to predetermined rates dependent upon the temperature of the energy gases discharged.

In burner devices for machines of which the combustion characteristic may be commonly referred to as the external type, certain problems arise which lead to complications not found in comparable equipment, for example, internal combustion engines. In internal combustion engines the leanness or richness of the fuel mixture is not critical to the point of eventually incapacitating the machinery in case of error since too rich a mixture merely incurs the result that unburnt fuel for which there is insufficient oxygen in the cylinders is merely discharged without apparent damage. On the other hand, in a burner such as involves an external combustion process the condition of too rich a mixture of fuel is attended by excessive temperatures which can rapidly cause the structure to deteriorate and be permanently damaged. If the mixture is leaned up too drastically, then the danger arises that the fire in the burner will be blown out and lost altogether. To meet this added problem in such combustion devices as the latter, designers in the field have turned to elements by means of which the combustion temperature may be sensed and the fuel flow corrected in time to prevent loss of the flame altogether in the burner as due to too lean a mixture or else excessively elevated temperatures such as may be due to an excessively rich mixture. A familiar technique among the known forms of controlling burners as to their combustion temperature is that of employing a metallic device such as a thermocouple for actually registering the temperature of combustion. Certain disadvantages, however, reside in the use of direct reading devices. For one thing, because of the poor response characteristics inherent in a system of temperature control dependent on the sensing of metal temperatures such a method has come to be considered generally impracticable particularly in the event of high temperatures existing in the burner. The sensing and control of combustion gas temperatures appears to be more advantageous than an attempt to control directly the temperature of the critical burner component. The combustion gas temperatures method appears more practical for high temperature application and moreover is not affected by the errors of radiation, conduction, and oxidation such as affect conventional gas temperature-sensing devices.

An object of the present invention resides in the provision of control apparatus not dependent

2

upon a direct reading temperature device in the path of the combustion gases from a burner. According to this feature of the invention there is no need for continual calibration of any such thermocouple device exposed to the deteriorating effects of gases having an elevated temperature and moreover, the problems introduced owing to errors in radiation, conduction, and oxidization of a thermocouple are rendered inconsequential.

Another object of the invention resides in the provision of electrical apparatus which when calibrated and set, is free from operating errors continually introduced by sediment deposits and the like such as are attendant with counterpart types of control apparatus which involve calibration and adjustments for errors in valving.

A further object resides in the provision of electrical slider means of which the friction characteristic is a minimum such as may be readily operated by pressure and temperature-sensitive control devices with a minimum loss as to the actuating forces available.

Still another object is to provide a control apparatus from which a series of valves and restrictions may effectually be eliminated in order to prevent a cascading of errors and in which each sensing device varies more or less with its own error and not according to accumulative errors of the associated sensing elements.

A still further object resides in the provision of metering valve setting means in the form of a rapidly responsive electric motor adapted by a suitable amplifier to respond to small electrical signals.

A yet further object resides in the provision of control apparatus by means of which combustion temperatures can be effectively controlled by inferential means such as are not necessarily exposed to excessive heat effects for which present day materials and their uses are not adequate.

Other objects and advantages will be more particularly pointed out hereinafter or will become apparent as the description proceeds.

The instant invention takes advantage of certain fundamental relations which may be set up from a thermodynamic standpoint upon proper analysis of fuel combustion processes. As regards an isolated burner having a combustion zone it may be assumed first that the weight of the gases entering the combustion zone is substantially equal to the weight of the gases leaving that combustion zone. Of benefit in making a more complete analysis of the combustion process is the assumption of an upstream station No. 1 and a downstream station No. 2 on the respective sides of a combustion zone at which stations the quality of the gases may be conceived of in

terms of the generally accepted symbols set forth below:

Station No. 1		Station No. 2
$P_{s1}P_{t1}T_1A_1$	Combustion zone	$P_{s2}P_{t2}T_2A_2$
W_1V_1		W_2V_2
Upstream		Downstream

At the upstream side of the combustion zone, the static pressure (P_{s1}), the total pressure (P_{t1}), and the gas temperature (T_1) are known. On the downstream side, the static pressure (P_{s2}) and the total pressure (P_{t2}) are known, while the gas temperature is unknown. The thermodynamic relationship between these known and unknown quantities may be established as follows. The notation to be used consists of:

A =cross sectional area
 c =specific heat at constant pressure
 g =acceleration of gravity
 J =mechanical equivalent of heat
 P =pressure
 T =temperature
 V =gas velocity
 W =gas weight
 p =mass density of gas
 r =ratio of specific heats
 s =static
 t =total
 1 =upstream or cold point
 2 =downstream or hot point

$$(1) \quad V^2 = 2gJc \left[\left(\frac{P_t}{P_s} \right)^{\frac{r-1}{r}} - 1 \right] T_s$$

$$(2) \quad V = \frac{W}{pgA}$$

$$(3) \quad \frac{V_2}{V_1} = \frac{W_2 p_1 A_1}{W_1 p_2 A_2}$$

$$(4) \quad \frac{p_1}{p_2} = \frac{P_{s1} T_{s2}}{P_{s2} T_{s1}}$$

Substituting, since $W_1 = W_2$ (approximately):

$$(5) \quad \frac{V_2}{V_1} = \frac{A_1 P_{s1} T_{s2}}{A_2 P_{s2} T_{s1}}$$

$$K_5 = \left(\frac{A_2}{A_1} \right) \frac{c_2}{c_1}$$

From (5) and (1):

$$(6) \quad \left(\frac{V_2}{V_1} \right)^2 = \left(\frac{A_1}{A_2} \right)^2 \left(\frac{P_{s1}}{P_{s2}} \right)^2 \left(\frac{T_{s2}}{T_{s1}} \right)^2 =$$

$$\frac{2gJc_2}{2gJc_1} \frac{\left[\left(\frac{P_{t2}}{P_{s2}} \right)^{\frac{r-1}{r}} - 1 \right] T_{s2}}{\left[\left(\frac{P_{t1}}{P_{s1}} \right)^{\frac{r-1}{r}} - 1 \right] T_{s1}}$$

$$(7) \quad \frac{T_{s2}}{T_{s1}} = \left(\frac{A_2}{A_1} \right)^2 \left(\frac{P_{s2}}{P_{s1}} \right)^2 \frac{c_2}{c_1} \frac{\left[\left(\frac{P_{t2}}{P_{s2}} \right)^{\frac{r-1}{r}} - 1 \right]}{\left[\left(\frac{P_{t1}}{P_{s1}} \right)^{\frac{r-1}{r}} - 1 \right]}$$

Simplifying by using $K_5 = \left(\frac{A_2}{A_1} \right) \frac{c_2}{c_1}$:

$$(8) \quad T_{s2} = K_5 T_{s1} \left(\frac{P_{s2}}{P_{s1}} \right)^2 \frac{\left[\left(\frac{P_{t2}}{P_{s2}} \right)^{\frac{r-1}{r}} - 1 \right]}{\left[\left(\frac{P_{t1}}{P_{s1}} \right)^{\frac{r-1}{r}} - 1 \right]}$$

An analysis of Equation 8 reveals that for the temperatures and pressures involved during the normal range of operation, the exponent

$$\frac{r-1}{r}$$

may be reasonably accurately evaluated as a decimal constant and certain other quantities likewise evaluated. Then by holding the quantity

$$\frac{P_{t1}}{P_{s1}}$$

temporarily constant, a plot of T_{s2} as "y" along the Y axis on coordinate paper against the variable quantity

$$\frac{P_{t2}}{P_{s2}}$$

as "x" along the X axis, yields a simple curve. Another reasonable operating value for quantity

$$\frac{P_{t1}}{P_{s1}}$$

yields another curve, and if the process is repeated throughout the normal operating conditions, a series of simple curves results.

Mathematically it has been determined that these simple curves may be substantially duplicated, save for the specific slopes involved, by using this simpler equation:

$$(9) \quad T_{s2} = K_5 T_{s1} \left(\frac{P_{s2}}{P_{s1}} \right)^2 \frac{\left[\left(\frac{P_{t2}}{P_{s2}} \right)^{\frac{r-1}{r}} - 1 \right]}{\left[\left(\frac{P_{t1}}{P_{s1}} \right)^{\frac{r-1}{r}} - 1 \right]}$$

Changing the slope of the curves of the plots of Equation 9 is accomplished simply by multiplying the right side by slope constant K_6 , which when united with the constant K_5 already in the equation, may be designated combined constant K .

Accordingly, for the practical range of values employed, the Equation 8 may be reduced to:

$$(10) \quad T_{s2} = K T_{s1} \left(\frac{P_{s2}}{P_{s1}} \right)^2 \frac{\left[\left(\frac{P_{t2}}{P_{s2}} \right)^{\frac{r-1}{r}} - 1 \right]}{\left[\left(\frac{P_{t1}}{P_{s1}} \right)^{\frac{r-1}{r}} - 1 \right]}$$

$$(11) \quad T_{s2} = K T_{s1} \left(\frac{P_{s2}}{P_{s1}} \right)^2 \frac{P_{t2} - P_{s2}}{P_{t1} - P_{s1}}$$

$$(12) \quad T_{s2} = K T_{s1} \frac{P_{s2} (P_{t2} - P_{s2})}{P_{s1} (P_{t2} - P_{s1})}$$

or, since

$$\frac{T_{s2}}{T_{s1}} = \frac{T_{t2}}{T_{t1}}$$

and T_{t1} is easily measured

$$(13) \quad T_2 = K T_1 \frac{P_{s2} (P_{t2} - P_{s2})}{P_{s1} (P_{t1} - P_{s1})}$$

where T_2 and T_1 represent respectively the total temperature at station 2 and the total temperature at station 1.

Relations derived from fundamental Equation 8, such as Equation 13 and other modifications, will be seen to be used to advantage in the instant invention. It is by means of these relations that the combustion temperature of the burner may be inferentially determined and brought into conformity with the combustion tempera-

ture actually desired by the operator of the burner.

In the accompanying drawings in which like reference numerals are used to designate similar parts throughout, there are diagrammatically illustrated suitable mechanical embodiments for the purpose of disclosing the invention. The drawings, however, are for the purpose of illustration only and are not to be taken as limiting or restricting the invention since it will be apparent to those skilled in the art that various changes in the illustrated embodiments may be resorted to without in any way exceeding the scope of the invention.

In the drawings:

Figure 1 is a longitudinal sectional view of a fuel system to which the control apparatus of the instant invention has been applied;

Figure 2 is a schematic view of a control apparatus of Figure 1;

Figure 3 is a schematic view of a modified control apparatus; and

Figure 4 shows a further modification.

In particular regard to Figure 1 of the drawings, the control box 10 constructed according to the principles of the instant invention is shown applied to a controlled combustion system. A manual setting lever 18 is provided on box 10 to afford a means of setting the selected operating temperature for the combustion system. Into one side of control box 10 are fed signals from a sensitive device 20 going to form a set comprised of a temperature responsive element 22, a total pressure responsive element 24, and a static pressure responsive element 26. An additional set 30 of sensing elements is provided for the control box, which is comprised of a total pressure responsive element 32 and a static pressure responsive element 34. The foregoing sets of sensitive elements are adapted to be mounted in conjunction with a burner 40 having a means 42 forming an inlet passage for the air or other combustion-supporting medium introduced into the burner. A structural member 44 serves to provide a passage for the flow of the energy laden products of combustion of the burner being discharged from the combustion zone. The combustion-supporting medium is led through the inlet 42 along the inside of the walls 46 of the outer tube of the burner. Inwardly spaced from walls 46 are walls 48 formed by a series of frustoconical elements 50, which are positioned to constitute an inner tube for the burner. Suitable brackets and clips 51 and 53 serve to position the frustoconical elements 50 against displacement within the burner. The air from the chamber between the respective outer and inner tubes is led through the spaces between the frustoconical elements and directed inside the inner tube in a direction toward the closed end 52 thereof. Arranged through suitable openings in wall 52 are respectively a spray nozzle 54 served by a fuel inlet line 55 and an igniter 56 energized by a conductor 57. The fuel may ordinarily be introduced into the inner tube in a suitable spray pattern by nozzle 54 and ignited by the device 56 to burn in the presence of the turbulent air flow within the inner tube. The products resulting from the combustion are led from the burner in an energy laden state through the discharge outlet 44.

Control box 10 may be powered from a supply generally indicated at 60 from which it derives energy that is translated into a fuel control signal and passed along a cable 19. Suitable val-

ing at 70 provides for fuel control to be exerted by the control box over the atomizing nozzle just described. The valving mechanism is provided with a metering orifice 72 which establishes communication between a chamber 74 leading from the fuel supply line of the nozzle, to the bypass chamber 76. Valving 75 is adapted to be positioned within the metering orifice 72 by means of a member 77 on which it is carried and to which is connected a rack 78. The control signals emitted from the control box through cable 19 may be fed into a motor 80 of which the rotor 82 carries a shaft 86 therewith. A pinion 88 carried by the rotor and shaft 86 meshes with the rack 78 to position metering valving 75. A suitable ground at 84 may be provided for motor 80. The main fuel pump 90 is adapted to receive fuel from the line 96 and introduces this fuel under pressure into the supply line 55 for atomizing nozzle 54. The bypass of pump 90 is arranged to be controlled by the metering motor 80 such that the quantity of fuel actually available for introduction into the burner may be accurately controlled. Intake line 96 for pump 90 is itself supplied from flow structure 92 provided with fuel by a line 98. Transfer pump 94 serves the line 98 and is provided with a bypass valve 99 for regulating the operation thereof.

During normal operation of the combustion system just described, a controlled supply of fuel is introduced into the inner tube 48 of the burner and there broken into small particles readily consumed in the mixture of burning energy gases. The temperature and the pressures of the incoming relatively cooler air is registered by the sensing set 20 and communicated to control box 10. The energy gases passing along discharge 44 may be expected to have a characteristic highly elevated temperature. Therefore only the static pressure and total pressure of the energy gases is conveniently registered by means of the sensing set 30 and communicated to the control box 10. These data afforded by the sensing sets are sufficient of themselves to provide the control box with sufficient information to regulate the temperature of combustion accurately by means of the metering control which the control box effectively exercises over metering valve 75.

In Figure 2 is schematically shown a system designed to control the nozzle box temperature T_2 by action based on the values of the other variables of Equation 13. The voltage level at point E_7 is a continuous indication of temperature at the nozzle box.

This control system is unusual in that the required multiplication, division, and subtraction are accomplished automatically by electro-mechanical means. The results of the computation, represented by voltage level E_7 , is communicated to the operator's temperature setting lever 18 and assembly to establish a balanced circuit. When, however, the lever 18 is moved to call for a temperature at the nozzle box different from that indicated by voltage level E_7 , an unbalance is created which is transmitted in modified electrical form as a signal to amplifier means and to fuel metering motor 80. The motor 80 then varies the flow of fuel supplied to the burner to accord with the nozzle box temperature demanded and eventually a balance is struck again in the system. An examination of the detailed operation of the balancing circuits is reserved to a later portion of the instant discussion.

In particular regard to the calculating means, the basic circuit is a positionable means in the form of a potentiometer connected to give an output voltage which is proportional to the product of the input voltage and slider position. If each slider is positioned by one of the pressures or temperatures in Equation 13 then the electrical circuit will perform the necessary computation. The arrangement uses amplifier tubes in the cathode follower circuit to make the currents in the various potentiometers less dependent on one another.

The calculating means 11 may conveniently be divided into three operating portions 12, 14, and 16. At the input side of portion 12, is a conductor 102 leading from the power supply 60, in series with a potentiometer 104. The slider of the potentiometer is carried by a bar 106 pivoted at 108. The positioning means for the bar includes a rod 110 attached to the free end of a temperature bellows 112 which expands or contracts in accordance with temperature changes sensed by the remote temperature bulb or capsule 22. Bulb 22 is arranged on one end of a sealed conduit communicating with bellows 112 and disposed in the inlet air passage of the burner. Since the slider of the potentiometer varies its position with the temperature of the inlet air and taps off from level E_0 at 102 a voltage proportional to the temperature, the voltage level E_1 at point 108 may be related properly to the temperature by the following equation:

$$(14) \quad E_1 = T_1 E_0$$

The cathode follower circuit 114 is used to impress the voltage E_1 onto potentiometer 116 without adding a current drain to potentiometer 104. The slider of the potentiometer 116 is mounted in a similar fashion on bar 118 pivoted at 120, to take a position in respect to the static pressure P_{s2} of the hot gases. Tapped off at point 126 of vacuum bellows unit 124, the voltage E_2 may be expressed in equation form as:

$$(15) \quad E_2 = P_{s2} E_1$$

As such, the voltage E_2 is transmitted to operating portion 14.

In regard to portion 14, the voltage E_2 is transmitted by conductor 128 to the slider on bar 130 pivoted at 132. The bar swings along the potentiometer dividing it into an upper segment 134 and a lower segment 135. The lower segment 135 is connected to the paralleled low resistor 133 and high resistance primary winding 140. Bar 130 moves in response to the static inlet pressure P_{s1} through the agency of vacuum bellows unit 144. Hence the pressure P_{s1} is represented by the value of the electrical resistance offered by segment 135. For all practical purposes, the current carried by segment 135 is all directed through the low resistor 133 of resistance value R_1 . The voltage drops across these resistors may be expressed in equation relationship as follows:

$$(16) \quad \frac{E_3}{E_2} = \frac{R_1}{P_{s1} + R_1}$$

The value of R_1 is purposely chosen low relative to resistance P_{s1} such that equation may be transposed and reduced as:

$$(17) \quad E_3 = \frac{R_1 E_2}{P_{s1} + R_1} = \frac{R_1 E_2}{P_{s1}}$$

The high resistance coil 140 is the primary winding of a transformer 146 whose ratio is predetermined as

$$\frac{1}{R_1}$$

The secondary 148 is connected to conductor 150 whose potential E_4 bears this relation to the input voltage E_3 :

$$(18) \quad E_4 = \frac{1}{R_1} E_3 = \frac{R_1 E_2}{P_{s1}}$$

which may be simplified to:

$$(19) \quad E_4 = \frac{E_2}{P_{s1}}$$

Conductor 150 is connected to a cathode follower circuit 152 in such a manner as to render the output of transformer 146 at zero.

The voltage E_4 is impressed through potentiometer terminal 154 onto potentiometer 156. The slider bar 158 is pivoted at 160 to provide a tapped off potential E_5 . The value of E_5 depends on the position of the slider, set in proportion to the differential in pressure afforded by P_{t2} over P_{s2} ; that is to say, the velocity pressure at station 2. As the pressure in the lower bellows 164 rises relative to that of the upper or P_{s2} bellows 166, the voltage E_5 approaches the impressed voltage at 154, E_4 . In other words:

$$(20) \quad E_5 = (P_{t2} - P_{s2}) E_4$$

This adjusted voltage, E_5 , is transferred over to operating portion 16.

In the operating portion 16, connection 168 energized at the level of E_5 , is carried by the end of slider bar 170 which is pivoted at 169 and positioned in accordance with the value of the velocity pressure at station 1. The positioning mechanism includes a differential rod 172 controlled downwardly by the excess in pressure rise of the total pressure P_{t1} , transmitted to pressure bellows 174, over static pressure P_{s1} , in bellows 176. The potentiometer for slider bar 170 is inverted in the manner of the potentiometer for bar 130, explained above. The potential E_6 supplied to line 182 may be expressed by the following relation in which symbol R_2 refers to the resistance offered by low resistor 184:

$$(21) \quad E_6 = \frac{R_2 E_5}{(P_{t1} - P_{s1}) + R_2}$$

Since R_2 is relatively low, Equation 21 can be simplified in the fashion of Equation 17.

$$(22) \quad E_6 = \frac{R_2 E_5}{(P_{t1} - P_{s1})}$$

Primary voltage E_6 is modified in transformer 188, the transformer ratio being designed at

$$(23) \quad \frac{1}{R_2}$$

to yield a voltage E_7 equalling:

$$(24) \quad E_7 = \frac{1}{R_2} E_6 = \frac{1}{R_2} \frac{R_2 E_5}{(P_{t1} - P_{s1})}$$

an equation simplified as was Equation 18 to:

$$(25) \quad E_7 = \frac{E_5}{(P_{t1} - P_{s1})}$$

Substituting in Equation 24 the quantities of Equations 14, 15, 19, and 20 results in an Equation 25 like the fundamental control equation number 13:

$$(25) \quad E_7 = E_0 T_1 \frac{P_{s2} (P_{t2} - P_{s2})}{P_{s1} (P_{t1} - P_{s1})}$$

This potential is fed from the computing section 11 of control box 10 into the fuel motor controlling section 13.

As previously stated, the tube in each cathode follower circuit serves the purpose of tapping off voltages from the preceding potentiometer without taking current of consequence out of the slider of that potentiometer. Thus the follower circuit cannot by its own variances introduce an error in the calculation process of the preceding potentiometer. Otherwise, the error in the first potentiometer 104 of the group would represent a cascading of variables in the succeeding potentiometers, 116, 134, etc., and be nowhere near to allowable. Practically, it may be found desirable to install a cathode tube, similar to 114 and 152, between the operating portions 12 and 14, and another between portions 14 and 16. The purpose in the one case would be to make the operation of potentiometer 116 entirely independent of potentiometer 136; in the other case, potentiometer 156 would be made less dependent on potentiometer 180.

As to the controlling section 13, as a unit it operates to balance up the voltage level of E_7 as against that level in terms of temperature setting, called for and instituted by the manually set lever 18. In equation form the relation may be expressed:

$$(26) \quad \frac{dW_f}{dt} = K_f(T_{set} - T_2)$$

where

W_f = rate of fuel flow,

t = time, and

K_f = constant for fuel system.

The mode of operation is a devious one whereby section 13 actuates the fuel metering motor 80 to change the rate of fuel flow and consequently the downstream temperature T_2 . The voltage level at E_7 then changes to balance out the temperature setting, T_{set} , called for.

Potentiometer 198 is bridged across supply lines 194 and 195 so as to be in series with a calibration resistor 196. Temperature setting lever 18, grounded by the pivot 199 and its line 200 is mounted to slide along the potentiometer 198. Line 192, at the voltage level of E_7 , connects with the lever 18 and ground line 200 through a resistor 202. Any unbalance in the system is reflected by suitable signal owing to voltage drop or rise over this resistor 202 to ground line 200.

For providing D. C. power to the audio amplifier tube 220 and phase discriminator tubes 230 and 240, conventional means may be provided such as rectifier tube 250. The above tubes have a common terminal for their grounded heaters denoted by the character F and may be connected thereby, in parallel, to one terminal of the secondary winding 266 of transformer 260, similarly marked F. The plates of the rectifier tube 250 may be connected to the transformer 260 at the terminals of secondary winding 268 seen to be grounded by center tap 269. On the cathode side of tube 250 is a filter 252 which delivers a steady D. C. supply to audio amplifier tube 220.

During balanced condition of the system, that is when the voltage E_7 at line 192 is at the level of ground line 200 or ground level, the grid in amplifier tube 220 is uncharged and the tube conducts uninterruptedly. Associated with the plate circuit of tube 220 by a coupling condenser 221 in line 222 are grids of phase discriminator tubes 230 and 240. These grids are grounded through

a suitable resistance at point 223. During steady state conditions these grids accordingly will have neutral charges and will allow the discriminator tubes 230 and 240 to conduct steadily. The cathodes of these discriminator tubes are grounded at 223 and 243 respectively, the plate connections are led to the end terminals of secondary winding 262 in transformer 260, each plate lead going to the opposite end respectively. Winding 262 is provided with a center tap 263 which is led over to field coil 86 grounded at 87 and condenser 88 in parallel, also grounded. This field coil is located in fuel metering motor 80 which comprises a rotor 82 and another field winding or coil 84 disposed in a 90° relation to the field coil before mentioned. The motor is of two-phase type and is actuated by these two coils. Field coil 84 is energized by power source 60 which also energizes the primary winding 261 of the transformer 260. However, the interposition of condenser 85 in series with the coil 84 causes a phase shift as between the voltages over these respective coils 84 and 261 such that the voltage of winding 84 leads the voltage of coil 261 by an angle ϕ . The phase relation of coils 261 and 262 is essentially the same. Hence the variance between the phase angles of the voltage of coil 262 and winding 84 is of the same order as ϕ . As has been stated above, the charge on the grids of the discriminator tubes normally is neutral. These tubes under this condition normally conduct alternately, that is, tube 230 will conduct for half the cycle through the upper half of coil 262 through motor winding 86 and then tube 240 conducts for the second half of the cycle through the lower half of coil 262 through the center tap to the winding 86. The condenser 88 serves in a flywheel capacity and tends to maintain an unwavering direct current flow through winding 86 with the result that a steady flux is maintained in the field. Within the influence of coil 84 an alternating flux is maintained and the two fluxes do not provide any field which actuates the fuel metering motor rotor 82. As to operation of the system of the embodiment of Fig. 2, the first indication of unbalanced activity will be that voltage E_7 in line 192 will attain a level alternately above and below the ground level maintained in line 200. Let it be assumed that the instantaneous charge on the grid of tube 220 during the unbalanced state will be positive at the same instant that the top terminal of coil 262 goes positive. Conduction in tube 220 is decreased and the input plate of condenser 221 goes less negative with the result that the grids of tubes 230 and 240 go positive. Since the upper terminal of coil 262 is positive, the upper tube 230 is the one which will conduct for this half cycle at a stimulated production due to the change in the charge on the grid. Accordingly, the coil 86 has the effect of an increased field. During the next half cycle, however, the charge on the grid of amplifier tube 220 goes negative with the result that during this second half of the cycle when tube 240 conducts, the grid of tube 240 goes negative to the end that tube 240 conducts only a fraction of its steady state output. Hence, the flux in winding 86 dies down appreciably with the effect that the field of winding 86 has a pulsing action. As has been stated, the voltages actuating windings 84 and 86 are disposed at an angle ϕ to one another and the windings themselves physically are disposed at an angle of 90°. Their fields tend to cooperate yielding a resultant

which imparts a rotating field to fuel motor 80. The more the grid charges are, relatively speaking, the greater the vector quantity of the resultant is, such that motor speed depends upon the amount of unbalance in the system. On the other hand, if the unbalance in the system over resistor 202 is in the other direction the instantaneous charge on the grid in the amplifier 220 will be negative at the same time that the upper terminal of coil 262 is itself positive. Under such condition the tube 240 will conduct at a more stimulated pace while the conduction of tube 230 will be retarded. The field produced by winding 86 will be growing and dying in an exact opposite relation to what it was during the first situation considered. Hence the rotating field will take the opposite direction and the fuel motor will rotate in an opposite direction. The shaft rotation then may be said to correspond in direction and magnitude with the temperature error. Of significance in the overall operation is this last mentioned fact that the greater is the unbalance created in the system the greater is the field created and collapsed in winding 86 and the stronger is the fuel motor response.

The embodiment shown in Figure 3 is arranged to operate from a modified control equation. This modification is accomplished by substituting directly in Equation 8 some actual values met over the normal range of operation, the remaining terms reducing to:

$$(27) \quad T_{s2} = K_5 T_{s1} \frac{P_{s2}}{(P_{s1})^3} [173P_{s1} - 149.2P_{s1}] [P_{s2} - P_{s2}]$$

$$(28) \quad T_{s2} = K_5 T_{s1} \frac{P_{s2}}{(P_{s1})^3} [173P_{s1} - 149.2P_{s1}] [P_{s2} - P_{s2}]$$

$$(29) \quad T_2 = K' T_1 \frac{P_{s2}}{(P_{s1})^3} [173P_{s1} - 149.2P_{s1}] [P_{s2} - P_{s2}]$$

The equipment used is essentially the same as for the first embodiment, depending upon the same variables as formerly except employing them in a slightly different manner. The layout of Figure 1 again applies.

The device of Figure 3 is different in some marked respects however. The sole source of power relied on by the control box and the metering equipment is of D. C. nature. The fuel metering motor is D. C. as well. Any alternating current required in the net is self-converted within the system by an oscillator incorporated therein. All the vacuum tubes and the fuel control motor have the same direct current power source in common. Metering motor 80' may be provided with two motor windings of which one, when selectively energized, will cause motor rotation in one direction whereas the other when selectively energized will cause motor 80' to rotate in the other direction.

The control box 10' may be comprised of a computing section 11' and a controlling section 13'. Both sections may be furnished a supply of alternating current by transformer 460. Supply line 302 to the computing section is maintained as potential E_0 which is alternately above and below the ground level at a value determined by the relative position of the grounded slide wire bar 12' relative to its potentiometer 398.

Line 302 is connected to the terminal of a potentiometer 304 whose other terminal is served by return 303. This potentiometer is the first of a series of positionable potentiometers, including 316 and 334, each of which is in parallel with the

circuit of the slider of the respective preceding potentiometer. Every time a voltage is tapped off by one of these sliders, a step such as multiplication for instance, in the computation is performed. The mechanics involved are essentially as set for in regard to the first embodiment described.

Slider bar 306 may be mounted on a pivot 307 and is adapted to communicate the voltage tapped off, by means of connection 308, to conductor 313. The voltage level in conductor 313, E_1 , may be expressed as:

$$(30) \quad E_1 = \frac{P_{s2}}{K_1} E_0$$

where K_1 is a correction factor for the system. Also:

$$(31) \quad E_2 = E_1 \frac{1}{K_2} (173P_{s1} - 149.2P_{s1})$$

Equation 31 is transformed into a reality owing to the ratio of areas selected to be exposed in the bellows 322 and bellows 324. From an upstream station number 1', the static pressure registered by tube 28' may be transmitted to the outside surface of bellows 324. The total pressure P_{t1} is communicated to the inside of this bellows from Pitot tube 24. The inside of the top of bellows 324 however, is partially blanked off to pressure P_{t1} by a vacuum bellows 322 to the extent that the ratio of effective areas exposed to the actuating pressures are in the ratio of 173 to 149.2 for the top outside and top inside respectively. The net force acting in rod 320 depends then on the quantity

$$(173P_{s1} - 149.2P_{t1})$$

Slider bar 318 is pivoted at 319 and connected at 326 to conductor 328.

Another subtraction transpires at positionable potentiometer 334 which is actuated by the pressure differential between P_{t2} and P_{s2} , or inversely to the velocity pressure at an upstream station number 2', whichever way is more suitable for the reader to look upon the situation. Slider bar 358 is pivoted at 359 and there connected to conductor 366. A correction factor is necessary to be introduced at this computation, and the following equation relating the level at 366, E_3 , to the level at 328, E_2 may be derived:

$$(32) \quad E_3 = E_2 \frac{1}{K_3} (P_{t2} - P_{s2})$$

Potentiometer 376, next in the circuit, is of different design from the previous instruments. It is not only inverted as connected, but also constructed to have a cubic taper winding. The static pressure signal from tube 26 operates to yield inversely to the cube of its own value, the voltage E_4 in conductor 374. It may be accordingly stated that:

$$(33) \quad E_4 = \frac{1}{(P_{s1})^3} E_3$$

Slider bar 378 is pivoted at connection 368.

To complete the circuit between conductor 374 and return line 303 are two resistors in series, 375 and 22'. The resistance offered at 375 is of high value R_3 . The resistor 22', a temperature sensitive type located in the air inlet of the burner substantially as is the thermometer bulb of Figure 1, offers relatively low resistance which varies directly with the total temperature at station number 1. The voltage E_5 at tap 378

between these resistors may be related to E_4 as follows:

$$(34) \quad \frac{E_5}{E_4} = \frac{T_{11}}{R_3 + T_{11}}$$

$$(35) \quad E_5 = \frac{T_{11}}{R_3 + T_{11}} E_4$$

Yet T_{11} is only a negligible fraction of R_3 and the sum $(R_3 + T_{11})$ is practically equal to R_3 . Hence,

$$(36) \quad E_5 = \frac{T_{11}}{R_3} E_4$$

A substitution in Equation 36 of values derived in Equations 30, 31, 32, and 33, yields:

$$(37) \quad E_5 = \frac{E_0}{K_1 K_2 K_3 R_3} T_{11} \frac{P_{s2}}{(P_{s1})^3} [173P_{s1} - 149.2P_{11}] [P_{12} - P_{s2}]$$

$$(38) \quad E_5 = K' T_{11} \frac{P_{s2}}{(P_{s1})^3} [173P_{s1} - 149.2P_{11}] [P_{12} - P_{s2}]$$

The resulting voltage E_5 , representing the temperature T_2 (that is the total temperature at station 2) of Equation 29, is used to provide the charge on the grid in section 422 of amplifier tube 420 through the medium of conductor 392.

Within the control box 10' is an oscillator tube 450 of the push pull type. This oscillator tube is powered from the D. C. power source 60' and serves to control the polarity of transformer 450 according to the relative algebraic sign of the charges on the grids 452 and 454. The primary winding 456 of the transformer creates a field of alternating polarity. Secondary windings 472 and 462 power respectively the computing portion 11' and the controlling portion 13' of the control box. Tapped across secondary winding 472 is a potentiometer similar to that illustrated in the embodiment of Figure 2, in series with a calibration rheostat 396. The slide wire bar 18' is grounded. The cathode of the amplifier tube 422 of the controlling unit 13' is at the ground level with the slide wire 400. When the voltage E_5 in lead 392 is at ground level, that is, the charge is neutral, this tube 422 conducts. The plate in the side 424 of tube 420 is led suitably to the power source 60' through a resistor. Associated with this plate circuit is a line 426 containing a condenser 421 which is led to a resistor grounded at 423 in parallel with a line 463 leading to the center tap in secondary winding 462 of transformer 460. The terminals of coil 462 are led one to the grid of phase discriminator tube 430 and the other to the grid of phase discriminator tube 440. The plates of these latter mentioned tubes are led to a relay circuit comprising coils 431, 432, 441, 442, and relays 436 and 446. Interposed in this coil circuit are two condensers 434 and 444 which will be described later. These solenoid coils are set up in opposed relation and when one overcomes the other, these coils serve to close relays 436 and 446 as the case may be which throw onto the line motor 80', grounded at 81'. This motor is an ordinary direct current machine and revolves in a direction depending upon which of its field coils, either 84' or 86', happens to be energized. The relay and motor are conventional. As to the connections between the circuits of the amplifier tube and the discriminator tube during steady state condition the center tap 463 of secondary winding 462 is uncharged and the grids of tubes 430 and 440 alternately go positive-negative, then negative-positive.

The effect will be that tube 430 will conduct for half a cycle and then tube 440 will conduct for the next half cycle. Consider the half cycle when tube 430 is conducted during the steady state condition. A field will be created in coil 431 and also in coil 432, the former tending to close relay contact 436 and the latter tending to open relay contact 446. The condenser 434 serves in the flywheel effect to maintain a fairly steady field intensity through these two coils under consideration even during the half cycle when tube 430 is not conducting. On the other hand, during the next half cycle when tube 440 conducts, the solenoid coil 441 is energized which tends to open relay 436. Simultaneously coil 442 is energized which tends to close relay contact 446. A condenser 444 in this circuit likewise tends to provide constant flux through the two pertinent windings. The output of the tubes is the same during this situation because their capacities have been predetermined to be the same and the coils tend to counteract the effect of one another and let the relay contacts remain unaffected. Accordingly, the motor 80 is idle. As to the active operation of the embodiment of Figure 3 the first change to be noted will be that voltage E_5 in conductor 392 will go either above or below ground level and begin to carry an alternating charge. This condition will, of course, be brought about by movement of the said lever 18' calling for more fuel and accordingly causing the voltage E_5 to be at variance with the ground. For a practical illustration of the mechanics involved, let it be assumed that the instantaneous charge on the grid of tube 422 is positive. This tube begins to conduct at an accelerated pace and causes less activity in tube 424 which conducts, by virtue of the condenser coupling with the tube 422, in a decreasing fashion with lowered output. The charge on the output side of condenser 421 becomes less positive and accordingly by means of line 426 the potential at center tap 463 rises above ground level. If the instantaneous polarity of secondary winding 462 happens at this time to be positive at terminal 466 and negative at terminal 468, the voltage level will be at point 465 actually more positively charged than when it was charged during existence of the normal ground level potential of the center tap. At all times that the terminal 466 is positive, tube 430 is the discriminator tube which is conducting, and the added potential to the grid will cause tube 430 to conduct even more with the result that the field in the coils 431 and 432 begins to strengthen. At this same time when center tap 462 becomes positive the potential at terminal 468 becomes less negative than it was and during the next half cycle will be less positive than what it is during the normal steady state condition. The result is that during this second half cycle when tube 440 is conducting, the coils 441 and 442 will be producing less of a flux density and their field will be altogether overcome by the stronger fields 431 and 432. Relay contacts 436 accordingly, will close, relay contacts 446 will be enforcedly held open, and the motor winding appropriately energized will cause motor 80' to revolve in one direction. The alternate condition which could have been chosen would be that when the grid in amplifier tube 422 goes positive the terminal at 468 happens to be the positive terminal. Under such circumstances an opposite effect will be experienced and the field coils actuated by discriminator tube 440 will dominate, causing relay 436 to open and

the contact 446 to close thereby selectively energizing the alternate winding for so effecting the motor 80' that it rotates in the opposite direction. The motor 80', it will be recalled, operates through the means of a rack and pinion to alter the fuel flow to the burner. Any change in fuel flow will bring about a change in the voltage level at E₅, which represents the temperature at station 2 and the system will be brought back into balanced condition.

In regard to Figure 4, a modification is shown for the embodiment of Figure 3 just described whereby in place of a temperature sensitive resistor there is used a thermometer bulb 22''. This thermometer bulb located in the inlet air passage as was the thermometer bulb of Figure 1 and mounted on one end of a sealed conduit, causes by means of pressure changes the actuation of a potentiometer and varies the tapped-off voltage in direct relation to the temperature measured, that is, the higher the temperature, the higher the voltage tapped off. The mode of operation for such thermometers was discussed in detail in connection with the first embodiment shown and operates in the same fashion as the instant thermometer capsule or bulb arrangement.

In order that the current drawn by each successive potentiometer in the embodiments of Figures 3 and 4 does not seriously introduce an error into its preceding potentiometer, it may be found advantageous to arrange the resistances in proportion to one another such that the current flowing in the conductor energized at the voltage E₀ is of the order of one ampere, for instance, whereas the current flowing in the conductor energized at voltage E₁ of the order of one-tenth ampere whereas the current in the conductor

energized at the voltage E₂ is of the order of one-hundredth of an ampere and so on. It is also contemplated that in certain instances the potentiometers be formed of varying resistors which will readily compensate for the additional current carried by it for the succeeding potentiometers.

The embodiments just described have certain features in common with one another. The positionable members comprising the rack and pinion, motor shaft, and motor rotor are adapted accurately to adjust the valving in the restricted fuel path which ultimately determines the rate of flow of fuel allowed for consumption by the burner. So long as the drive into the initial section of the amplifier device remains at the zero or ground level the disposition of the valving remains unchanged. Fluctuations in the flow pressures of the intake air and discharge gases as well as fluctuations in the intake air temperature are compensated for by the control apparatus which properly re-positions the valving in the fuel flow control. While temperature sensitive means are used, such means only contribute to the determination of the discharge temperature and paradoxically enough, are located in the inlet air passages. If the quality of fuel used is changed such that the heat output per unit quantity is changed, the instant control apparatus senses the discharge temperature change and self-compensates the fuel flow rate. Moisture content of the air supplied may be changed whereupon automatic compensation is effected. Thus changes in the actual quality of the fuel and air supplied do not necessitate a recalibration of

the instant device since the thermal level is automatically controlled by compensated fuel rate of flow. Inasmuch as the variables just mentioned have been interrelated by well known and fundamental thermodynamic laws the combustion temperature will be automatically maintained at a constant value by an inferential method. Once, however, is the manually operable slider changed as to its position so as to vary the input voltage to the control apparatus, then the resulting electrical signal arising out of the condition that the voltage equilibrium of the system has been changed into an unmatched state is impressed upon the amplifier and causes the fuel metering motor to readjust the position of the valving and change the combustion temperature by an appropriate amount. So soon as the combustion temperature changes, then according to the control equation the various temperatures and pressures are registered whereby the positionable potentiometer sliders are operated to match the new voltage setting inaugurated by the manually operable temperature setting lever. The control equations of the embodiments of the invention described as has been pointed out, involve the same variables except in a slightly different fashion. These expressions, however, have been interrelated with the control apparatus so as to yield a suitable electrical signal to which the amplifier is responsive and to bring the system back into a state of equilibrium. For any assigned combustion temperature, the T_{set} is equalled by the actual T₂ on the downstream side of the burner owing to the automatic positioning tendency of the potentiometers. That is to say, so long as the respective expressions set forth yield constant values:

$$T_1 \frac{P_{s2}}{P_{a1}} \left(\frac{P_{a2} - P_{s2}}{P_{a1} - P_{a2}} \right) = Ct. \quad \left\| \quad T_1 \frac{P_{s2}}{P_{a1}} [173P_{a1} - 149.2P_{a1}] [P_{a2} - P_{s2}] = Ct.$$

the actual temperature maintained equals the discharge temperature desired. In the first embodiment the fuel control motor was controlled in response to demands of the amplifier by means of one variable winding for which the energization could be controlled to varying degrees. In the second and third embodiments shown the metering motor was controlled by two windings which were selectively energized by the amplifier in an alternative fashion. That is to say, when the one winding was energized the other winding was de-energized altogether.

By way of further summary, it may be said that the last embodiment shown differed from the second embodiment in the manner by which intake air temperature was employed to vary the matching voltages in the electrical system of the control apparatus.

It will thus be seen that there has been disclosed suitable apparatus for determining combustion temperatures which is not subject to the poor response characteristics of a thermocouple or other metal temperature-sensing device and that an apparatus has been disclosed which is further not effected by the errors of radiation, conduction, and oxidation.

While suitable physical embodiments for the purpose of disclosing the invention has been illustrated in the accompanying drawings and hereinafter described, it is to be understood that the invention is not limited to the particular embodiments so illustrated and described but that such changes in the size, shape, and arrangements of the various parts and their particular

functions may be exerted to such as will occur to those skilled in the art.

The invention now having been described so that others skilled in the art may clearly understand the same, the claims are set forth to follow. By the term air used therein is meant any suitable combustion-supporting medium and by fuel is meant any liquid, gaseous, crushed, or powdered fuel appropriate for use in burners.

We claim:

1. In a regulative combustion system inferentially determinative of combustion temperatures irrespective of the initial quality of the fluids supplied and characterized by a burner, means providing a path for the flow of air to the burner, means providing a path for the flow of energy gases discharged from the burner, means providing a path for the flow of fuel to the burner, and a metering element adjustable to vary the rate of flow of fuel to the burner: the combination comprising a voltage divider including an indicator element adjustable to positions indicative of specific discharge temperatures of the energy gases, pluralized voltage divider means, a bridge circuit including said voltage divider and said voltage divider means, said voltage divider means comprising first, second, third, fourth, and fifth voltage dividers, each including an adjustable contact and being coupled with one another in predetermined sequence in a manner such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact and at least one divider is coupled across a fixed length of the preceding divider, said first voltage divider including a contact adjustable in accordance with the temperature of the air flowing to the burner effective to adjust the bridge circuit, said second voltage divider including a contact adjustable in accordance with the force differential created by the static and total pressures of the air flowing to the burner acting predeterminedly in opposition to one another and effective to adjust the bridge circuit, said third voltage divider including a contact adjustable in accordance with the force differential created by the static and total pressures of the energy gas from the burner acting predeterminedly in opposition to one another and effective to adjust the bridge circuit, said fourth voltage divider including a contact adjustable in accordance with the static pressure of the air flowing to the burner effective to adjust the bridge circuit, and said fifth voltage divider including a contact adjustable in accordance with the static pressure of the energy gas from the burner effective to adjust the bridge circuit, and means responsive to the value of unbalance potential existing in the bridge circuit for adjusting an adjustable element above-named.

2. In a regulative combustion system inferentially determinative of combustion temperatures irrespective of the initial quality of the fluids supplied and characterized by a burner, means providing a path for the flow of air to the burner, means providing a path for the flow of energy gases discharged from the burner, means providing a path for the flow of fuel to the burner, and a metering element adjustable to vary the rate of flow of fuel to the burner: the combination comprising a voltage divider including an indicator element adjustable to positions indicative of specific discharge temperatures of the energy gases, pluralized voltage divider means, a bridge circuit including said voltage divider and said voltage divider means, said voltage divider means

comprising first, second, third, fourth, and fifth voltage dividers, each including an adjustable contact and being coupled with one another in predetermined sequence in a manner such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact and at least one divider is coupled across a fixed length of the preceding divider, said first voltage divider including a contact adjustable in accordance with the temperature of the air flowing to the burner effective to adjust the bridge circuit, said second voltage divider including a contact adjustable in accordance with the force differential created by the static and total pressures of the air flowing to the burner acting predeterminedly in opposition to one another and effective to adjust the bridge circuit, said third voltage divider including a contact adjustable in accordance with the force differential created by the static and total pressures of the energy gas from the burner acting predeterminedly in opposition to one another and effective to adjust the bridge circuit, said fourth voltage divider including a contact adjustable in accordance with the static pressure of the air flowing to the burner effective to adjust the bridge circuit, and said fifth voltage divider including a contact adjustable in accordance with the static pressure of the energy gas from the burner effective to adjust the bridge circuit, and means responsive to the value of unbalance potential existing in the bridge circuit for adjusting an adjustable element above-named.

3. In a regulative combustion system inferentially determinative of combustion temperatures irrespective of the initial quality of the fluids supplied and characterized by a burner, means providing a path for the flow of air to the burner, means providing a path for the flow of energy gases discharged from the burner, means providing a path for the flow of fuel to the burner, and a metering element adjustable to vary the rate of flow of fuel to the burner: the combination comprising a voltage divider including an indicator element adjustable to positions indicative of specific discharge temperatures of the energy gases, pluralized voltage divider means, a bridge circuit including said voltage divider and said voltage divider means, said voltage divider means comprising first, second, and third voltage dividers, each including an adjustable contact and being coupled with one another in predetermined sequence in a manner such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact, said first voltage divider including a contact adjustable in accordance with the temperature of the air flowing to the burner effective to adjust the bridge circuit, said second voltage divider including a contact adjustable in accordance with the force differential created by the static and total pressures of the air flowing to the burner acting predeterminedly in opposition to one another and effective to adjust the bridge circuit, and said third voltage divider including a contact adjustable in accordance with the force differential created by the static and total pressures of the energy gas from the burner acting predeterminedly in opposition to one another and effective to adjust the bridge circuit, and means responsive to the value of unbalance potential existing in the bridge circuit for adjusting an adjustable element above-named.

4. In a combustion apparatus for a fuel-fired burner system characterized by fuel and air in-

lets, an energy gas discharge, and a fuel flow controlling mechanism having an adjustable element, the combination with voltage divider means including an adjustable element settable to adjusted positions indicative of changed combustion temperatures established in the burner system, pluralized voltage divider means, bridge circuit means including both divider means aforesaid, and means responsive to unbalance potentials in the bridge circuit to adjust the appropriate adjustable element above-mentioned, said pluralized divider means having at least first, second and third voltage dividers including first, second, and third adjustable contacts respectively interrelated electrically in sequence such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact, of actuating means for adjusting said first, second, and third adjustable contacts consisting of means responsive to inlet air static, pressure (P_{s1}), means responsive to inlet air total pressure (P_{t1}), means responsive to inlet air temperature (T_1), means responsive to energy gas total pressure (P_{t2}), and means responsive to energy gas static pressure (P_{s2}), said actuating means being precalibrated for effecting the above-described adjustments whereby the value of the established combustion temperature in the burner system is yielded by the expression:

$$T_{est} = KT_1 \frac{P_{t2}(P_{t2} - P_{s2})}{P_{s1}(P_{t1} - P_{s1})}$$

5. In a combustion apparatus for a fuel fired burner system characterized by fuel and air inlets, an energy gas discharge, and a fuel flow controlling mechanism having an adjustable element, the combination with voltage divider means including an adjustable element settable to adjusted positions indicative of changed combustion temperatures established in the burner system, pluralized voltage divider means, bridge circuit means including both divider means aforesaid, and means responsive to unbalance potentials in the bridge circuit to adjust the appropriate adjustable element above-mentioned, said pluralized divider means having at least first, second and third voltage dividers including first, second, and third adjustable contacts respectively, interrelated electrically in sequence such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact, of actuating means for adjusting said first, second, and third adjustable contacts consisting of means responsive to inlet air static, pressure (P_{s1}), means responsive to inlet air total pressure (P_{t1}), means responsive to inlet air temperature (T_1), means responsive to energy gas total pressure (P_{t2}), and means responsive to energy gas static pressure (P_{s2}), said actuating means being precalibrated for effecting the above-described adjustments whereby the value of the established combustion temperature in the burner system is yielded by the expression:

$$T_{est} = KT_1 \frac{P_{t2}}{P_{s1}} [173P_{s1} - 149.2P_{t1}] [P_{t2} - P_{s2}]$$

6. Means for automatically controlling the rotative position of a fuel metering motor in an operating combustion system characterized by a burner supplied with the metered fuel and having means providing for a supply of intake air and for discharge of the energy gases, said fuel metering motor having a plurality of windings energizable to position the motor; said means comprising means including an amplifier device

responsive to electrical signals for controlling the energization of at least one of said windings to change the respective metering rate position of the motor, and means including an electrical system in a state of voltage balance comprising operator operated voltage divider means for changing the voltage level to be maintained in the system to a different level thereby introducing a state of unbalance in the system, and pluralized voltage divider means connected to said operator operated divider means for matching the new voltage level and restoring balance to the system, said pluralized divider means being adapted to emit signals to the amplifier device for appropriately changing the metering rate to a different rate only so long as unbalance exists in the system and having first, second, third, fourth, and fifth voltage dividers electrically interrelated in a predetermined sequence such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact and at least one divider is coupled across a fixed length of the preceding divider, said first voltage divider including an element adjustable in accordance with the temperature of the intake air to the burner, said second voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the intake air acting in opposition to one another according to a predetermined relationship, said third voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the energy gas acting in opposition to one another according to a predetermined relationship, said fourth voltage divider including an element adjustable in accordance with one of the static and total pressures of the intake air to the burner, and said fifth voltage divider including an element adjustable in accordance with one of the static and total pressures of the energy gas from the burner.

7. Means for automatically controlling the rotative position of a fuel metering motor in an operating combustion system characterized by a burner supplied with the metered fuel, said fuel metering motor having a plurality of windings energizable to position the motor; said means comprising means including an amplifier device responsive to electrical signals for controlling the energization of at least one of said windings to change the respective metering rate position of the motor, and means including an electrical system in a state of voltage balance comprising operator operated voltage divider means for changing the voltage level to be maintained in the system to a different level thereby introducing a state of unbalance in the system, and pluralized voltage divider means connected to said operator operated divider means for matching the new voltage level and restoring balance to the system, said pluralized divider means being adapted to emit signals to the amplifier device for effecting selective energization of a certain one or another of said motor windings alternatively to change appropriately the metering rate to a different rate only so long as unbalance exists in the system and having first, second, third, fourth, and fifth voltage dividers electrically interrelated in a predetermined sequence such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact and at least one divider is coupled

across a fixed length of the preceding divider, said first voltage divider including an element adjustable in accordance with the temperature of the intake air to the burner, said second voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the intake air acting in opposition to one another according to a predetermined relationship, said third voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the energy gas acting in opposition to one another according to a predetermined relationship, said fourth voltage divider including an element adjustable in accordance with one of the static and total pressures of the intake air to the burner, and said fifth voltage divider including an element adjustable in accordance with one of the static and total pressures of the energy gas from the burner.

8. Means for automatically controlling the rotative position of a fuel metering motor in an operating combustion system characterized by a burner supplied with the metered fuel and having means providing for a supply of intake air and for discharge of the energy gases, said fuel metering motor having a plurality of windings energizable to position the motor; said means comprising means including an amplifier device responsive to electrical signals for controlling the energization of said windings to change the respective metering rate position of the motor, and means including an electrical system in a state of voltage balance comprising operator operated voltage divider means for changing the voltage level to be maintained in the system to a different level thereby introducing a state of unbalance in the system, and pluralized voltage divider means connected to said operator operated divider means for matching the new voltage level and restoring balance to the system, said pluralized divider means being adapted to emit signals to the amplifier device for effecting a variance in the overall character of the energization maintained on a certain winding to cause appropriate change in the metering rate to a different rate only so long as unbalance exists in the system and having a plurality of voltage dividers electrically interrelated in sequence such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact and at least one divider is coupled across a fixed length of the preceding divider, said plurality comprising a first voltage divider including an element adjustable in accordance with the temperature of the intake air to the burner, a second voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the intake air acting in opposition to one another according to a predetermined relationship, and a third voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the energy gas acting in opposition to one another according to a predetermined relationship.

9. Means for automatically controlling the rotative position of a fuel metering motor in an operating combustion system characterized by a burner supplied with the metered fuel and having means providing for a supply of intake air and for discharge of the energy gases, said fuel metering

motor having a plurality of windings energizable to position the motor; said means comprising means including an amplifier device responsive to electrical signals for controlling the energization of said windings to change the respective metering rate position of the motor, and means including an electrical system in a state of voltage balance comprising operator operated voltage divider means for changing the voltage level to be maintained in the system to a different level thereby introducing a state of unbalance in the system, and pluralized voltage divider means connected to the operator operated divider means for matching the new voltage level and restoring balance to the system, said pluralized voltage divider means being adapted to emit signals to the amplifier device for effecting a variance in the overall character of the energization maintained on a certain winding to cause appropriate change in the metering rate to a different rate only so long as unbalance exists in the system and having first, second, third, fourth, and fifth voltage dividers electrically interrelated in a predetermined sequence such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact and at least one divider is coupled across a fixed portion of the preceding divider, said first voltage divider including an element adjustable in accordance with the temperature of the intake air to the burner, said second voltage divider including an element adjustable in accordance with the magnitude of the velocity pressure of the intake air, said third voltage divider including an element adjustable in accordance with the magnitude of the velocity pressure of the energy gas, said fourth voltage divider including an element adjustable in accordance with the first power of the static pressure of the intake air to the burner, and said fifth voltage divider including an element adjustable in accordance with the first power of the static pressure of the energy gas from the burner.

10. Means for automatically controlling the rotative position of a fuel metering motor in an operating combustion system characterized by a burner supplied with the metered fuel and having means providing for a supply of intake air and for discharge of the energy gases, said fuel metering motor having a plurality of windings energizable to position the motor; said means comprising means including an amplifier device responsive to electrical signals for controlling the energization of at least one of said windings to change the respective metering rate position of the motor, and means including an electrical system in a state of voltage balance comprising operator operated voltage divider means for changing the voltage level to be maintained in the system to a different level thereby introducing a state of unbalance in the system, and pluralized voltage divider means connected to the operator operated divider means for matching the new voltage level and restoring balance to the system, said pluralized divider means being adapted to emit signals to the amplifier device for appropriately changing the metering rate to a different rate only so long as unbalance exists in the system and having a plurality of voltage dividers electrically interrelated in sequence such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact and at least one divider is coupled across a fixed length of the preceding divider, said plurality comprising a first voltage

divider including an element adjustable in accordance with the temperature of the intake air to the burner, a second voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the intake air acting in opposition to one another according to a predetermined relationship, and a third voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the energy gas acting in opposition to one another according to a predetermined relationship.

11. In a regulated combustion system characterized by a burner, a supply of fuel for eventual introduction into the burner, means forming a restricted fuel flow path for use in varying the flow rate of the fuel allowed to be introduced into the burner, means forming a path for the flow of air to the burner, and means forming a path for the flow of the products of combustion discharged by the burner: the combination with positionable members, valving in the restricted fuel path connected for movement with one of the positionable members, a voltage divider means adapted for graduation in terms of combustion temperature and including one of said positionable members having positions indicative of graduated temperature, pluralized voltage divider means, a bridge circuit including both divider means aforesaid, and means responsive to unbalance potential existing in the bridge circuit to position one said positionable member, said pluralized voltage divider means comprising first, second, third, fourth, and fifth voltage dividers including first, second, third, fourth, and fifth adjustable elements respectively, said voltage dividers being interrelated electrically in a sequence in a manner such that a majority of the dividers are each coupled across the effective portion of the preceding divider selected by its adjustable element and at least one divider is coupled across some portion of the preceding divider unadjusted by its adjustable element, of means for adjusting the respective adjustable elements of the above-named voltage dividers including means responsive to the flow of air, to the burner, means responsive to the temperature of the air to the burner, and means responsive to the flow of products of combustion discharged by the burner, the above described responsive means being for a given combustion temperature interrelated and arranged at all times as to satisfy the following expression:

$$T_1 \frac{P_{s2}}{P_{s1}} \frac{(P_{t2} - P_{s2})}{(P_{t1} - P_{s1})} = \text{Constant}$$

where

T_1 =temperature of air to the burner
 P_{s1} =static pressure of the air to the burner
 P_{t1} =total pressure of the air to the burner
 P_{s2} =static pressure of the products of combustion
 P_{t2} =total pressure of the products of combustion

12. In a regulated combustion system characterized by a burner, a supply of fuel for eventual introduction into the burner, means forming a restricted fuel flow path for use in varying the flow rate of the fuel allowed to be introduced into the burner, means forming a path for the flow of air to the burner, and means forming a path for the flow of the products of combustion discharged by the burner: the combination with positionable members, valving in the restricted fuel path connected for movement with one of the

positionable members, a voltage divider means adapted for graduation in terms of combustion temperature and including one of said positionable members having positions indicative of graduated temperature, pluralized voltage divider means, a bridge circuit including both divider means aforesaid, and means responsive to unbalance potential existing in the bridge circuit to position one said positionable member, said pluralized voltage divider means comprising first, second, third, fourth, and fifth voltage dividers including first, second, third, fourth, and fifth adjustable elements respectively, said voltage dividers being interrelated electrically in a sequence in a manner such that a majority of the dividers are each coupled across the effective portion of the preceding divider selected by its adjustable element and at least one divider is coupled across some portion of the preceding divider unadjusted by its adjustable element, of means for adjusting the respective adjustable elements of the above-named voltage dividers including means responsive to the flow of air, to the burner, means responsive to the temperature of the air to the burner, and means responsive to the flow of products of combustion discharged by the burner, the above described responsive means being for a given combustion temperature interrelated and arranged at all times as to satisfy the following expression:

$$T_1 \frac{P_{s2}}{P_{s1}} [173P_{t1} - 149.2P_{t1}][P_{t2} - P_{s2}] = \text{Constant}$$

where

T_1 =temperature of air to the burner
 P_{s1} =static pressure of the air to the burner
 P_{t1} =total pressure of the air to the burner
 P_{s2} =static pressure of the products of combustion
 P_{t2} =total pressure of the products of combustion

13. Means for automatically controlling the rotative position of a fuel metering motor in an operating combustion system characterized by a burner supplied with the metered fuel and having means providing for a supply of intake air and for discharge of the energy gases, said fuel metering motor having a plurality of windings energizable to position the motor; said means comprising means including an amplifier device responsive to electrical signals for controlling the energization of at least one of said windings to change the respective metering rate position of the motor, and means including an electrical system in a state of voltage balance comprising operator operated voltage divider means for changing the voltage level to be maintained in the system to a different level thereby introducing a state of unbalance in the system, and pluralized divider means for matching the new voltage level and restoring balance to the system, said positionable means being adapted to emit signals to the amplifier device for appropriately changing the metering rate to a different rate only so long as unbalance exists in the system and having first, second, and third voltage dividers electrically interrelated in a predetermined sequence such that at least a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact, said first divider including a contact adjustable in accordance with the temperature of the intake air to the burner, said second divider including a contact adjustable in accordance with an existing force differential created by the static and total pressures of the intake air acting in opposition to one an-

14. A system for controlling the rate of fuel flow to the combustion zone of a burner, the resulting combustion temperature of which is to be maintained uniformly at predetermined values by adjustment of fuel flow without recourse to the basis of actual measurement of combustion temperatures but rather in accordance with the respective magnitudes of other variable quantities involved in the combustion process, said burner having an adjustable fuel control: comprising, a plurality of voltage dividers each including an adjustable contact and being inter-related consecutively with one another in a manner such that a majority of the dividers are each coupled across the portion of the preceding divider selected by its contact and at least one divider is coupled across a fixed length of the preceding divider, means for adjusting the contact of a first of said divider plurality in accordance with variations of a first of said other variable quantities, means for adjusting the contact of a second of said divider plurality in accordance with variations of a second of said other variable quantities, means for adjusting the contact of a third of said divider plurality in accordance with variations of a third of said other variable quantities, means for adjusting the contact of a fourth of said divider plurality in accordance with variations of a fourth of said other variable quantities, means for adjusting the contact of a fifth of said divider plurality in accordance with variations of a fifth of said other variable quantities, a sixth voltage divider including a contact settable to a position representative of the combustion temperature in the burner, a bridge circuit including said sixth voltage divider and said divider plurality, and means responsive to an unbalance of said bridge circuit for adjusting the fuel flow control of the burners.

3

10

15

20

25

30

35

40

48

54

K

2

•

1

air flowing to the burner effective to adjust the bridge circuit, said second voltage divider including a contact adjustable in accordance with the force differential created by the static and total pressures of the air flowing to the burner acting predeterminedly in opposition to one another and effective to adjust the bridge circuit, and said third voltage divider including a contact adjustable in accordance with the force differential created by the static and total pressures of the energy gas from the burner acting predeterminedly in opposition to one another and effective to adjust the bridge circuit, and means responsive to the value of unbalanced potential existing in the bridge circuit for adjusting an adjustable element above-named.

18. Means for automatically controlling the rotative position of a fuel metering motor in an operating combustion system characterized by a burner supplied with the metered fuel, said fuel metering motor having a plurality of windings energizable to position the motor; said means comprising means including an amplifier device responsive to electrical signals for controlling the energization of at least one of said windings to change the respective metering rate position of the motor, and means including an electrical system in a state of voltage balance comprising operator operated voltage divider means for changing the voltage level to be maintained in the system to a different level thereby introducing a state of unbalance in the system, and pluralized voltage divider means connected to said operator operated divider means for matching the new voltage level and restoring balance to the system, said pluralized divider means being adapted to emit signals to the amplifier device for effecting energization of at least one of said motor windings to change appropriately the metering rate to a different rate only so long as unbalance exists in the system and having first, second, third, fourth, and fifth voltage dividers having coupling means electrically interrelating them in a predetermined sequence such that a majority of the dividers are each coupled across the portion of the preceding divider selected by

its contact and at least one divider is coupled across a fixed length of the preceding divider, said coupling means comprising grid controlled means between at least two said adjacent voltage dividers and having the control grid thereof controlled by the preceding one of the two said adjacent voltage dividers and providing an anode-cathode path included in series with the successive one of the two said adjacent voltage dividers for controlling the energization of the latter in controlled dependence upon said control grid, said first voltage divider including an element adjustable in accordance with the temperature of the intake air to the burner, said second voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the intake air acting in opposition to one another according to a predetermined relationship, said third voltage divider including an element adjustable in accordance with an existing force differential created by static and total pressures of the energy gas acting in opposition to one another according to a predetermined relationship, said fourth voltage divider including an element adjustable in accordance with one of the static and total pressures of the intake air to the burner, and said fifth voltage divider including an element adjustable in accordance with one of the static and total pressures of the energy gas from the burner.

DAVID M. BORDEN.
PAUL T. NIMS.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,455,633	Lundgard	May 15, 1923
1,576,754	McLean	Mar. 16, 1926
1,680,026	McLean	Aug. 7, 1928
2,323,180	Junkins	June 29, 1943
2,337,851	Junkins	Dec. 28, 1943
2,414,314	Machlet	Jan. 14, 1947