

Oct. 27, 1953

E. S. BRISTOL

2,657,347

MULTIPLE UNIT CONTROL SYSTEM

Filed Feb. 14, 1952

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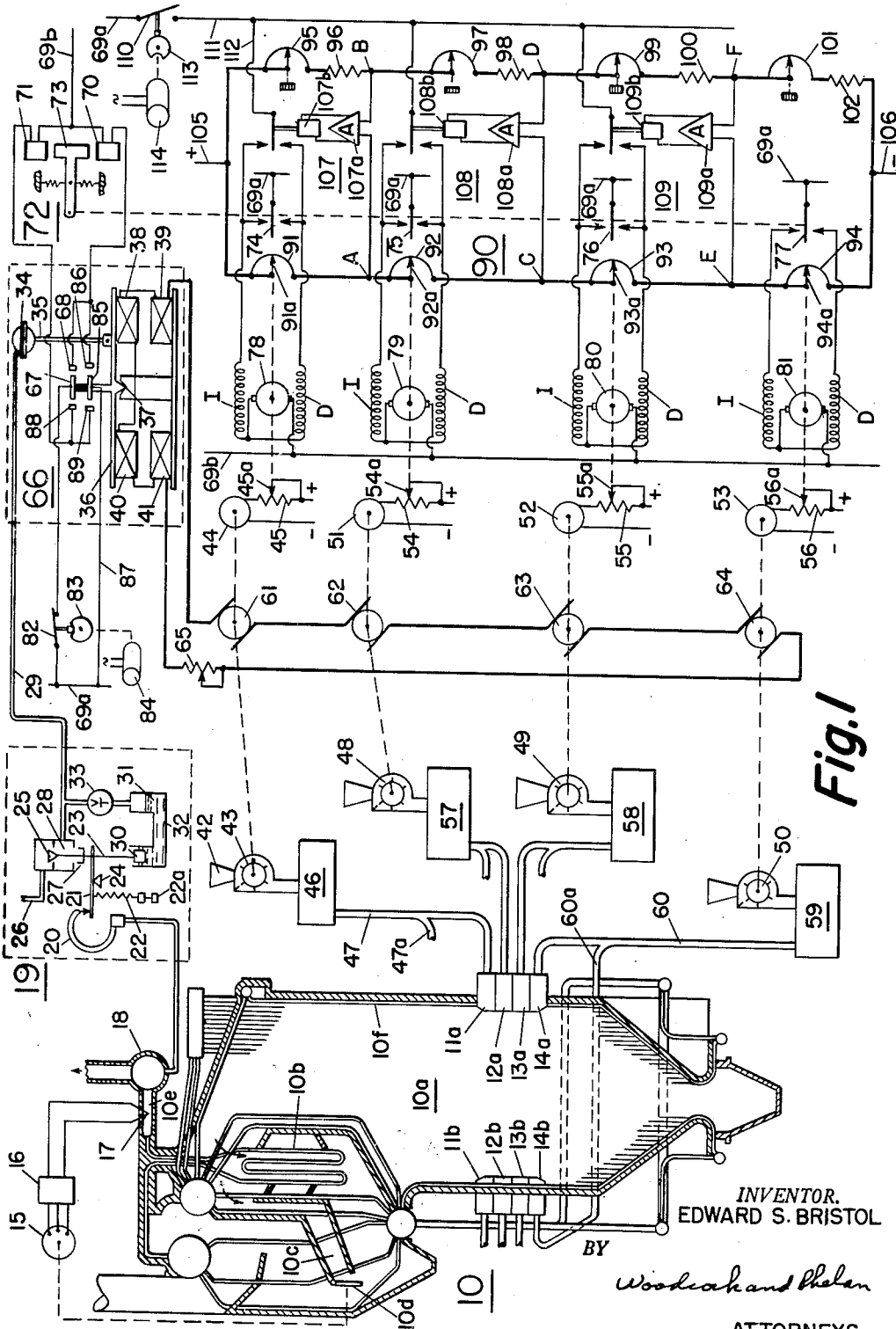


Fig. 1

Oct. 27, 1953

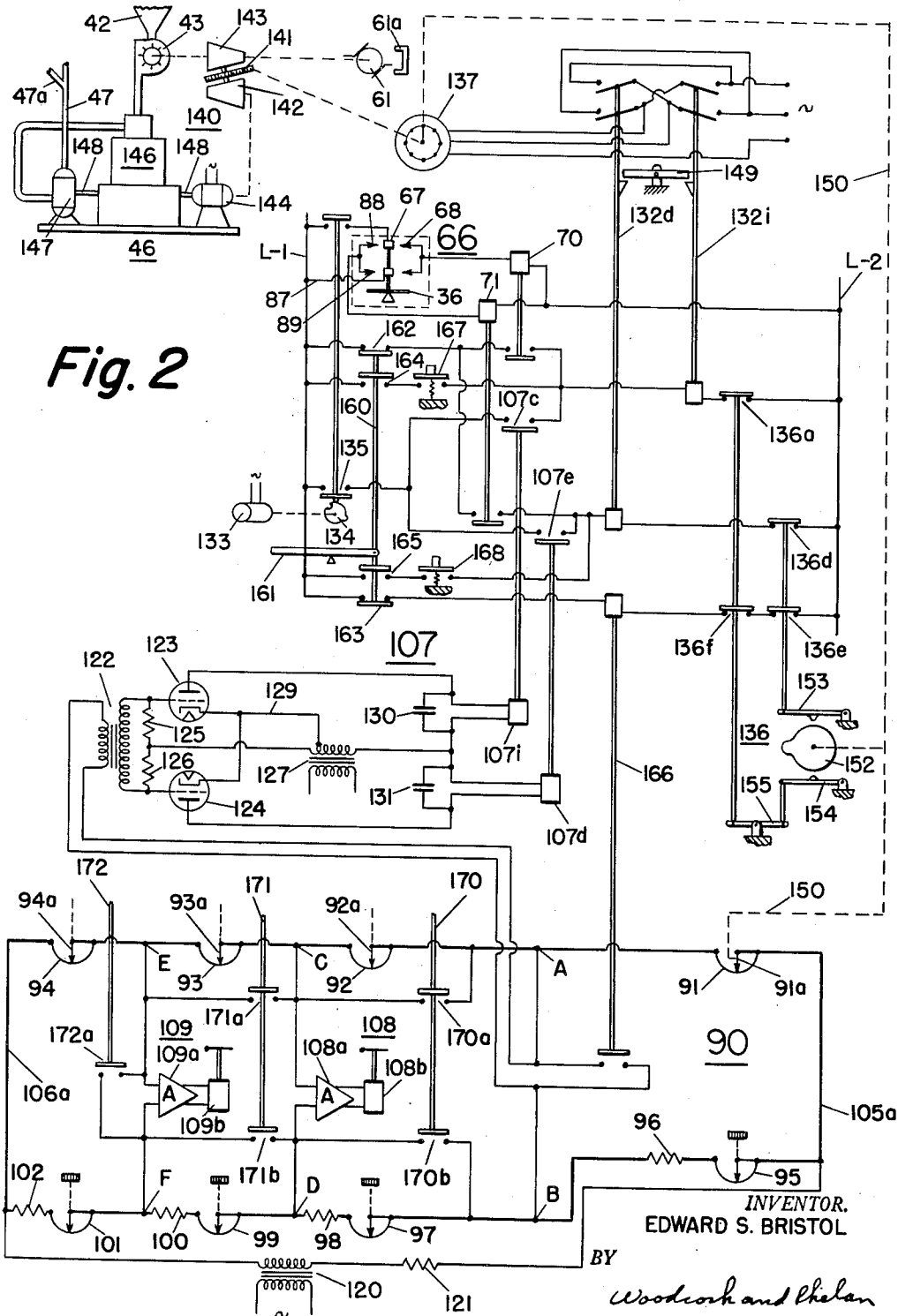
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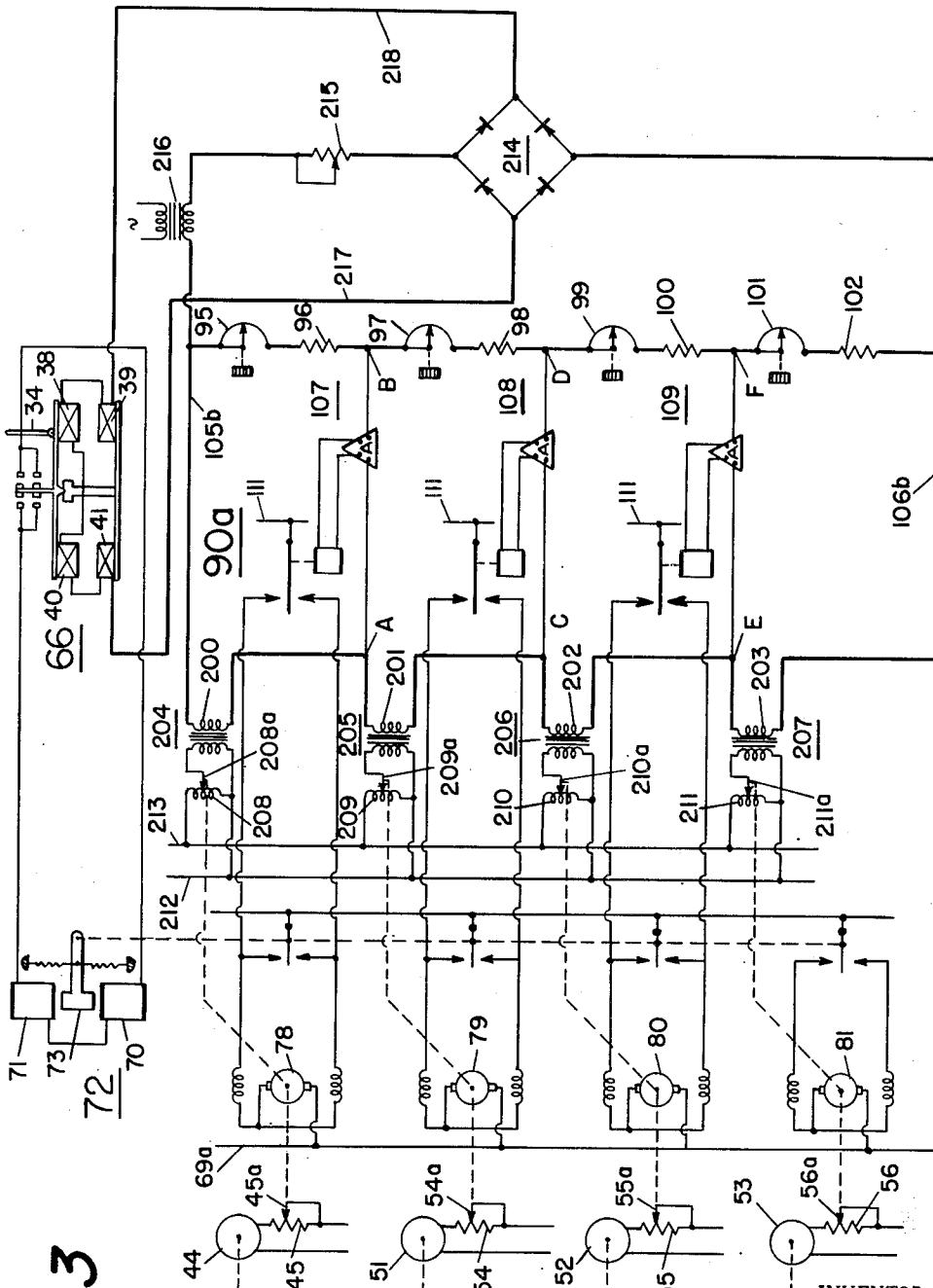


Fig. 3

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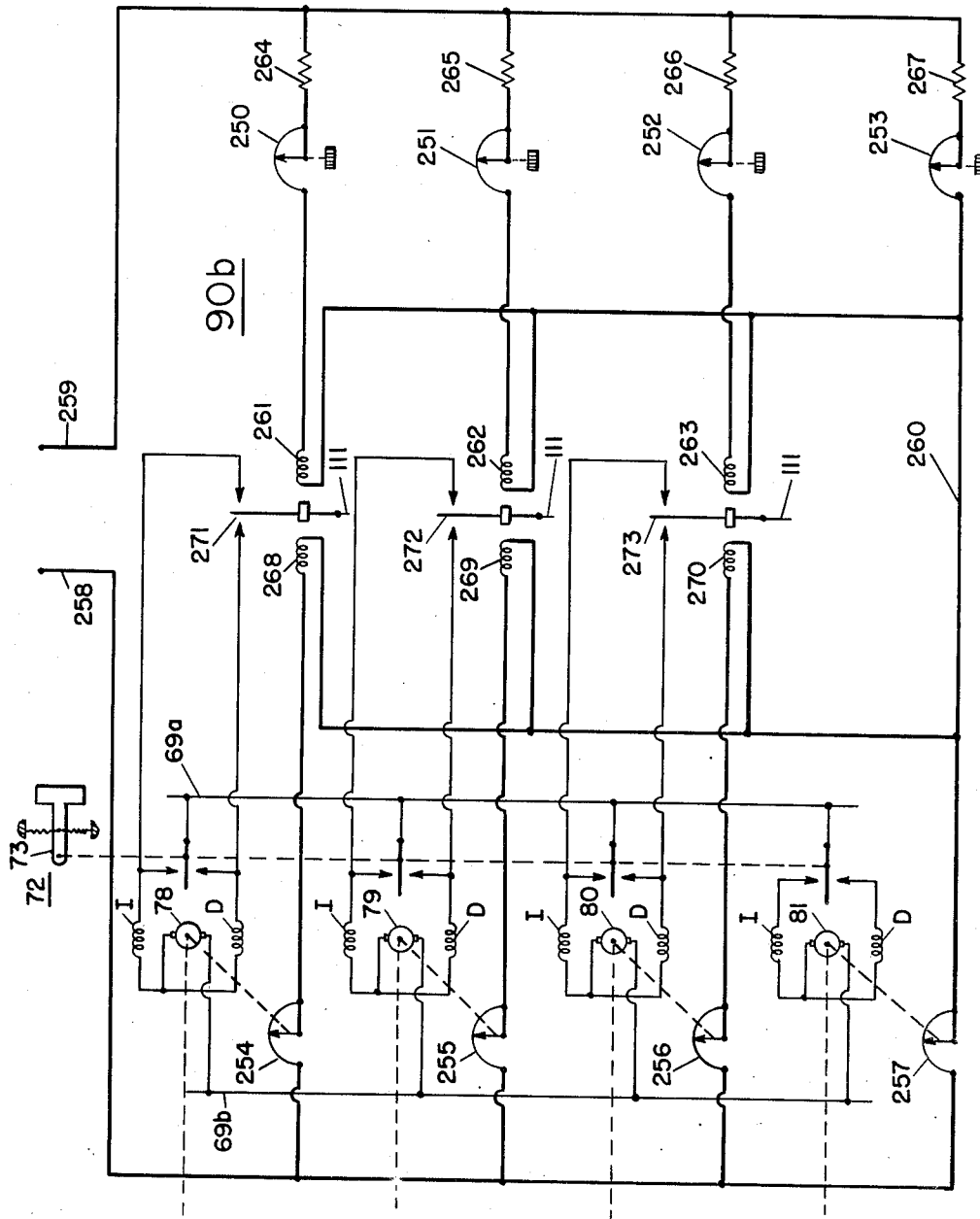
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2,657,347

MULTIPLE UNIT CONTROL SYSTEM

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Application February 14, 1952, Serial No. 271,487

20 Claims. (Cl. 318—19)

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This invention relates to control systems of the type applicable to the control of a plurality of units which are arranged to cooperate one with another in a predetermined manner and has for an object the provision of a control system in which several final control units may jointly respond to a change in the magnitude of a condition in accordance with a predetermined schedule of load division between the units.

Though the invention has many applications where similar problems of control are involved, it has been found particularly useful in the operation of vapor generators, such for example as the type utilized as a source of steam for steam turbines and the like. As is well understood by those skilled in the art, it is important to provide pressure control of the vapor output in order to maintain the generation of vapor or steam in accordance with the load demand imposed upon the turbine. As this load demand rises, the total rate of fuel supply to the vapor generator is increased, and vice versa. In the modern boiler or vapor generator a plurality of burners are utilized, and the total needed fuel supply must be divided between the several burners to secure desired combustion conditions and adequate distribution of heat within the furnace of the steam generator. For example, it may be desired to increase the rate of fuel supply to certain burners, such as an upper set of burners, to increase the temperature of combustion gases exiting from the furnace and thereby increase the temperature of combustion or flue gas flowing through a superheater section of the steam generator.

It is a further object of the invention to provide a control system in which the total fuel demand upon the vapor generator or boiler is divided between the several burners, with simultaneous change in fuel supply thereto in response to change in vapor demand and with supplementary control for maintaining at selected burners a rate of fuel supply thereto representing predetermined fractions of the total load, with the total fuel supply varied to meet changed conditions of load demand upon the boiler.

It will be further understood by those skilled in the art that the heat distribution varies greatly in boilers depending upon design configuration thereof and that a predetermined fuel division between a plurality of burners in a boiler of one type will produce quite different end results as regards combustion and furnace conditions, such as slag formation, in other types of boiler installations. In accordance with the pres-

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ent invention, however, the control system provides the needed flexibility to achieve a desired division of the fuel as between the multiple burners in any manner needed to establish desired furnace conditions in the boiler.

In carrying out the invention in one form thereof, there is provided a reference circuit having adjustable elements which develop in the circuit electrical quantities whose magnitudes are fractions of the total quantity as determined by the relative adjustments of the adjustable elements. A responsive circuit associated with the reference circuit also includes a plurality of adjustable control elements to establish in the responsive circuit electrical quantities whose magnitudes are fractions of the total quantity and respectively of size dependent upon the relative adjustments of a plurality of adjustable final control units. More specifically, the final control units to be controlled, the fuel supply means, include means operable in accordance with the adjustment of the fuel supply means to adjust a control element to establish in the responsive circuit an electrical quantity, such as a potential difference. The magnitude of this potential difference is related to the adjustment of the corresponding final control unit. The potential difference thereby developed is, then, a fractional part of the total potential developed across all of the control elements in the responsive circuit and these fractional parts correspond to fractions of a total manipulated variable (rate of fuel feed) controlled by the final control units. By providing detectors responsive to differences in the electrical quantities developed in the respective reference circuit and responsive circuit, an adjustment of a supplementary nature is provided in accordance with the settings of the adjustable elements of the reference circuit. Thus, the total fuel demand can be divided among the several burners as determined by the setting of the elements in the reference circuit, while maintaining the total fuel supply to all of the burners as required to meet the steam demand on the vapor generator.

With the foregoing outline of the broad aspects of the invention in mind, it will be understood that many modifications may be made and that many further objects and advantages result therefrom. These will all be set forth in detail in the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 diagrammatically illustrates the invention as applied to control the rate of fuel supply to a vapor generator, shown as a steam boiler;

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Fig. 2 diagrammatically illustrates additional features of the invention as applied to a commercial form thereof to control division of the rate of fuel supply to a steam generator;

Fig. 3 is a schematic representation of another circuit useful in the arrangements of Figs. 1 and 2 and illustrating alternative arrangements for developing potential difference in accordance with the present invention, and

Fig. 4 is a schematic representation of a further circuit embodying the invention and particularly illustrates a control circuit employing current division in the branches of said circuit.

As shown in Fig. 1, the invention has been illustrated as applied to the control of the fuel supply means of a steam boiler 10. The fuel supply means comprises a plurality of burners disposed at different levels in the furnace 10a. At the uppermost level there may be four burners equally spaced around the furnace, as at the corners, two of which, the burners 11a and 11b, appear in Fig. 1.

As an example of one of the ways in which division of total fuel supply may be utilized, it is to be noted that the burners 11a and 11b are nearest the steam super-heater section 10b. Thus, if the total supply of fuel to all of the burners 11a, 11b to 14a, 14b is maintained the same and a greater fraction of the total fuel is supplied to burners 11a and 11b, the volume of the combustion gases passing through steam super-heater section 10b will be the same, but their temperature is elevated to a greater degree than would be the case if the same fractional increase in supply of fuel were made to the lowermost burners 14a and 14b. This is due to the greater absorption of heat from the hot combustion gases by the water tubes 19j around the periphery of furnace 10a, in the latter case as compared to the former. Thus, it will be seen that by differently regulating the supply of fuel as between the several burners a substantial measure of control of the temperature of the steam in the super-heater section 10b may be achieved. Further control of that temperature is afforded by the provision of a by-pass section 10c through which combustion gases may flow in avoidance of the steam super-heater section 10b, the volume of combustion gases passing through the by-pass 10c being under the control of any suitable means such as a damper or flow-controlling element 10d, the position of which is adjusted by a motor 15. The motor 15 may be controlled in response to temperature of the steam within the steam output line by any desired system, such as indicated at 16 under the control of a thermocouple 17 disposed in the steam output line 10e. Such a system may be of the type fully disclosed in my co-pending application Serial No. 266,818, filed January 17, 1952.

In accordance with the embodiment of the invention of Fig. 1, the load demand upon the vapor generator may be detected by changes in the pressure within the steam header 18 connected to output line 10e of the steam boiler 10, which is taken as the controlled variable. As shown, that steam pressure as appearing at header 18 is applied to a master controller device 19, and more particularly, to a Bourdon tube 20 biased by spring 22 and operatively engaging a lever 21. The lever 21 pivoted at 24 positions a valve-actuating element 23 and an air-inlet valve 25 to regulate the admission of fluid under pressure, such as compressed air supplied through

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a supply pipe 26. By means of a bleed or leak-valve 27 cooperating with valve 25 the air pressure within chamber 28 and applied to line 29 will have a magnitude dependent upon the steam load on boiler 10, as represented by the steam pressure within header 18. The master controller 19 includes a component of control generally known as reset action provided by a float 30 attached to element 23. Float 30 acts to apply a force to element 23 dependent upon the level of liquid, such as mercury 31, within a U-tube 32, the application of pressure upon the right-hand leg thereof being under the control of a throttling valve 33.

The pneumatic pressure in line 29 is applied by means of a diaphragm or other pneumatic actuating device 34 through a rod 35 to one side of an arm 36 pivoted at 37. The force applied by the rod 35 is opposed by the magnetic repulsion force developed between a pair of coils 38 and 39 on one side of pivot 37 and the magnetic attractive effort between magnetic coils 40 and 41 disposed on the opposite side of the fulcrum or pivotal mounting 37.

Inasmuch as the steam pressure in the header 18 is an index of the balance between heat input and steam output at boiler 10, the rate of fuel supply or the rate of firing of the burners may, in accordance with the embodiment of the invention shown in Fig. 1, be taken as the manipulated variable. The manipulated variable, the rate of fuel supplied, is the quantity, in Fig. 1, which is varied automatically to maintain the value of the controlled variable, the pressure of the output steam, at the set point, i. e. the pressure selected for preferred operation of the boiler 10. This predetermined pressure is established by adjustment of spring 22 as by knob 22a, thus establishing the pressure in header 18 which must be developed in the Bourdon tube 20. If the pressure in Bourdon tube 20 rises, the valve 25 closes and leak-valve 27 opens to greater degree and the pressure within pipe 29 decreases. As will later be explained, the action is to decrease the rate of firing to reduce the pressure within header 18 to the set value as established by the setting of spring 22. Upon decrease in steam pressure at header 18, master controller 19 acts to increase the air pressure in pipe 29 and thereby increase the rate of firing to boiler 10 to return the steam pressure to the set point.

The burners 11a, 11b, 12a, 12b, 13a, 13b and 14a, 14b, though of any suitable type, such as oil-fired or gas-fired burners, have been illustrated as particularly adapted for the firing of powdered coal. For example, the burners 11a and 11b receive coal from a hopper 42 at a rate dependent upon the speed of rotation of a coal-feeding device 43 driven by a variable-speed motor 44, the speed of which is determined as by a resistor 45. Coal at rate determined by the rotation of motor 44 and fuel-feeder 43 is delivered to a pulverizing device 46 which includes a fan or exhauster for producing a flow of air to transport pulverized coal through line 47 in suitable condition for immediate burning upon discharge from burner 11a. Branch pipes, such as the branch pipe 47a, are provided for supplying other burners, such as burner 11b. Similar elements are provided for supplying fuel to each of the remaining burners, the coal-feeding devices 48, 49 and 50 being operated by motors 51, 52 and 53, respectively provided with speed-regulating means, such as series resistors 54, 55 and 56. It will be observed that the pulverizing devices 57, 58 and 59 associated with feeders 48, 49 and 50 function

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in the same manner as the device 46, and it will be further observed that the branch 60a from pipe 60 is shown as extending to the lowermost burner 14b, in manner above described.

From the foregoing it will be seen that the fuel feeders represent adjustable final control units, the adjustment or speed of operation of which determines the amount of fuel delivered to its associated burners for steam generator 10.

Means are provided to measure the total amount of fuel delivered to the boiler, such means in Fig. 1 being illustrated as tachometers 61—64. Since the output rate of pulverizing devices 46, 57—59 is substantially proportional to the fuel input rate, the rate of fuel supply in the form of pulverized or powdered coal depends upon the speed of operation of each of the control units 43, 48—50. Accordingly, the voltage developed by each of the tachometer generators 61—64 driven by motors 44, 51—53, will be representative of the rate of feed of fuel of each corresponding unit. By electrically connecting the tachometer generators in a series totalizing circuit the total rate of firing or fuel supply will be represented by the sum of the voltages of the individual tachometers. This voltage is applied by way of a calibrating resistor 65 to the series-connected coils 38—41 of a fuel feed controller 66. Thus, the fuel-feed controller 66 operates in response to unbalanced forces as between those developed by the coils 38—41 and the pressure applied from the pneumatic actuator 34.

When the force applied by the actuator 34 is greater than that developed by the coils, resulting from a decrease in steam pressure at header 18, the arm 36 is tilted about its fulcrum 37 first to complete a circuit between a movable contact 67 supported by arm 36 and a stationary contact 68 and, second, to complete an energizing circuit from one side 69a of a source of supply for relay coil 70 of a switch actuator 72 and thence to the other side 69b of the supply source. Under the control of the switch actuator 72 each of motors 44, 51—53 is adjusted to increase the rate of fuel supply and preferably by equal amounts. This change in rate of fuel will result in returning the steam pressure at the header 18 to the set point.

In more detail, when the coil 70 is energized, an arm 73, shown biased to mid-position by a pair of springs, is rotated in clockwise direction to actuate movable contacts 74—77 to complete circuits from one supply line 69a through upper stationary contacts for energization of the "increase," I, field windings of motors 78—81. By energizing these windings, simultaneous rotation of the motors is produced in a direction to move contacts 45a, 54a, 55a and 56a to decrease the resistance of speed-controlling resistors in circuit with each of motors 44, 51—53 and thereby increase the speed thereof.

It will be observed that the energizing circuit for the coil 70 from line 69a includes a circuit interrupter 82. The interrupter 82 is periodically opened and closed by any suitable means, such as a cam 83 driven by a constant speed or synchronous motor 84. The effect of the cyclically operable interrupter 82 is to provide current pulses through coil 70 which actuates the movable contacts 74—77 into and out of engagement with their upper contacts to provide speed changes of motors 44, 51—53 by a series of steps. By interposing the step adjustment of the speed of the motors, a certain amount of time is provided for the reflection of change in pressure in header 18 as a result of a change in rate of fuel supplied

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to the steam generator 10. However, if the pressure in header 18 be substantially less than desired, the increased pressure in line 29 actuates the movable contact 67 sufficiently to displace upper contact 68 and to bring lower contact 85 (insulated from contact 67) into engagement with stationary contact 86. There is thereby completed by way of conductor 87 a by-pass circuit around the interrupter contact 82 for continuous energization of coil 70 and continuous completion of the motor circuits 78—81 for continuous adjustment of the speed of fuel-feeding devices 43, 48—50 until the voltage generated by the tachometers 61—64 produces an opposing force which first opens contacts 85, 86 and subsequently opens contacts 67, 68, there being a transition from continuous operation of the motors 78—81 to intermittent operation as above described.

Upon an increase in the pressure in header 18 reversed operation occurs which will not be described in the same detail, it being merely necessary to state that movable contact 67 is moved into engagement with a stationary contact 88 to complete an energizing circuit for the actuating coil 71 of actuator 72, this circuit being traced by way of the intermittently actuated interrupter 82. When the deviation is beyond a predetermined amount, movable contact 85 is moved into engagement with stationary contact 89 to complete a by-pass circuit by way of conductor 87 around the interrupter for continuous energization of coil 71. The movement of actuator 72 by coil 71 moves contacts 74—77 into engagement with the lower stationary contacts for energization of the "decrease" windings D of motors 78—81 for rotation thereof in the opposite direction to adjust contacts 45a, 54a, 55a and 56a to increase the resistance in series with the associated motors and thereby decrease the speed of operation of the fuel-feeding devices 43, 48—50.

With the understanding of the several parts and the manner in which they cooperate together, reference will now be had to the manner in which an additional control means functions to modify the action so that the final control units 43 and 48—50 may be readjusted to divide the rate of fuel supply between them in such manner as may be desired without changing the total rate of fuel delivery required, as determined by the master control means. The master control means may be defined to include the master controller 19, the fuel-feed controller 66, the switches 74—77, the actuator 72, the motors 78—81, the speed adjusters and their motors 44, 51—53, as well as tachometers 61—64.

The additional control means includes an electrical network 90 which in one form of the invention includes a responsive branch having a plurality of slidewires or variable resistors corresponding with each of the final control units 43, 48—50 and identified respectively as slidewires 91—94. In a second or reference branch of the network there are provided additional variable resistors or slidewires 95, 97, 99, 101 and in series therewith fixed resistors 96, 98, 100 and 102. It will be understood that the fixed resistors are not essential but are preferred to limit the effect of the additional control means.

The two branches of the circuit are connected to a suitable source of voltage as represented by supply lines 105 and 106. The movable contacts 91a—94a associated with slidewires 91—94 are respectively driven by motors 78—81. The voltage between lines 105 and 106 divides across

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slidewires 91—94. If the resistance values of each slidewire be the same, it is important to observe that the voltage division will be equal; that is to say, as long as the movable contacts 91a—94a are moved by equal amounts similarly to change the resistance of slidewires 91—94, the potential differences developed in the responsive branch of the circuit will remain the same fractional parts of the total voltage between lines 105 and 106, irrespective of the value of that total voltage.

It will be understood that the voltage across the resistors in the other branch of the circuit will divide in like manner. More particularly, as long as the resistance value of a slidewire, such as slidewire 95 and its associated resistor 96 are equal to the resistance value of each remaining slidewire and resistor, the voltage will equally divide or the potential differences developed by them in that branch of the circuit will be of equal magnitude one to another and will each be the same fractional part of the total voltage between lines 105 and 106, irrespective of the absolute value of the total.

Advantage is taken of the above characteristics of the network 90 as a part of an additional means to re-adjust the final control units 43, 48—50 to divide the total rate of fuel supply (the magnitude of the manipulated variable) amongst the several control units in any desired manner without changing the total magnitude established by the master control means as required to maintain the pressure within header 18 at the control or set point. The foregoing re-adjustment of the control units is accomplished by manual adjustment of slidewires 95, 97, 99 and 101, as by their associated knobs. The movable contacts associated with each of these slidewires is illustrated in the mid-position.

If the effective resistance value of one of the slidewires 95, 97, 99, or 101 is increased, in what has been referred to as the reference branch of the circuit, the voltage division across the several parts thereof is changed. More specifically, if the resistance of slidewire 95 is increased, the potential difference across slidewire 95 and its associated resistor 96 is greater by the amount of the increased resistance than the potential difference across slidewire 97 and its associated resistor 98, the same also being true for slidewire 99, its associated resistor 100, and for slidewire 101 and its associated resistor 102. Accordingly, a potential appears between the points A and B to which a detector 107, including an amplifier 107a, is connected. There will be applied to the input circuit of the detector a potential difference with the point A at a higher potential than that of point B. In response to this supplementary signal, a relay 107b of detector 107 is energized to complete a circuit through the upper stationary contact for the winding I of motor 78 for energization of the winding in a direction to increase the speed of motor 44, tachometer 61 and fuel-feeding device 43.

The energizing circuit may be traced from supply line 69a, the periodically-operated switch 110, conductors 111 and 112, the upper stationary contact, motor winding I, motor armature, and thence to the other supply conductor 69b. The switch 110 is periodically opened and closed by any suitable means such as a cam 113 driven by a constant speed or synchronous motor 114. The motors 84 and 114 are operated

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in predetermined phase relationship one with the other, and as shown, switch 82 is closed while switch 110 is open. The phasing and the relative periods during which the switches 82 and 110 are operated and remain closed may be widely varied. There is nothing of a critical aspect to the adjustments, the preferred arrangement having been illustrated and described. Both control actions may be continuous, if desired.

It will be understood that the adjustment of the motor 78 occurs during the time interval of closure of switch 110. With rotation of motor 78 the movable contact of slidewire 91 is adjusted in a direction to increase the resistance in the responsive branch of network 90, this being in the correct direction to decrease the potential difference between points A and B. By reason of the increase in speed of tachometer 61, the force exerted by coils 38—41 on pivoted lever 36 is increased to complete through its contacts 88 or 89 an energizing circuit for the coil 71 for operation of movable contacts 74—77 into engagement with their lower stationary contacts for energization of motors 78—81 in a direction to decrease the speed of motors 44, 51—53, their associated tachometer generators 61, 62, 63, 64 and fuel-feeding devices 43, 48—50. The speed of motor 44, of tachometer 61 and fuel-feeding device 43 remains relatively greater than that of motors 51—53, and the effect of the decreased speed of the motors 51—53 is in a direction to compensate for the increased speed of motor 44. Stated differently, the tachometer circuit is a totalizing circuit representative of total manipulated variable rate of fuel delivered to the steam generator 10. Thus, with increased speed of motor 44 and fuel-feeding device 43, there is produced a compensating adjustment of motors 51—53 and fuel-feeding devices 48—50 which maintains the total fuel delivered to the boiler at the same rate as before.

There is some interaction and cooperation between detectors 108 and 109. However, in practice after a manual adjustment has been made of one of slidewires 95, 97, 99 or 101, the system after a short interval of time readjusts the speeds of motors 44 and 51—53 to deliver to the steam generator 10 fuel at selected rates through the several banks of burners with the same total fuel delivery as before adjustments of said slidewires.

From the foregoing it will be seen that with but three detectors 107—109 the four fuel-feeding devices 43, 48—50 can be controlled to operate at different selected speeds without change of total fuel delivery to the steam generator. In the foregoing description the assumption was tacitly made that the load demand on the boiler 10 has remained constant and that a constant force has been applied to the lever 36 by the rod 35 from the pneumatic actuator 34.

If the slidewire 95 had been adjusted in the opposite direction, that is, to decrease the value of the resistance in the reference circuit, the new division of voltage resulting therefrom produces a potential difference between points A and B of polarity opposite to that described above. Thus, the motor winding D of motor 78 is energized through detector 107 and energizing relay 107b to complete an energizing circuit therefor from supply line 69a through the lower stationary contact of relay 107b. Motor 78 decreases the speed of motor 44 and the tachometer 61. The decrease in the voltage at

tachometer 61 results in rotation of pivoted lever 36 in the opposite direction to complete a circuit through the coil 70 of actuator 72. Through the movable contacts 74-77 the motors 78-81 are energized in directions to increase their respective speeds, thus restoring voltage balance in what has been termed the totalizing circuit including the tachometers. Thus, a decrease in speed of motor 44 results in an increase in the speeds of motors 51-53 by amounts which restore the total fuel-delivery to the steam boiler 10 to the same value it had before the adjustment of slidewire 95.

Though a detector is not provided for auxiliary control of motor 81, nevertheless the slidewire 94 will be adjusted by motor 81 to bring to zero value the potential between points E and F and to bring the slidewire 94 to a position corresponding with that of slidewire 101. More particularly, if slidewire 101 be adjusted to increase its resistance in the reference circuit, again assuming that the load demand is constant and that the steam pressure is at the control point, there will be immediately changed the voltage distribution across the resistance elements in the reference branch, and potential differences will appear between points E and F, C and D, and A and B. The detectors 107-109 will each respond to their respective potential differences and will energize motors 78-83 in direction to decrease the speeds of motors 44, 51 and 52 and adjust contacts 91a-93a to decrease the resistances of slidewires 91-93 in the responsive circuit. By reason of the corresponding reduction in voltage of tachometer generators 61-63, the fuel-feed controller 66 will energize coil 70 of actuator 72 to complete circuits through the I-windings of motors 78-81 to increase the speeds of motors 44, 51-53 with synchronous adjustment of movable contacts 91a-94a of slidewires 91-94. It will be observed that the adjustment of contacts 91a-94a is in a direction to increase the resistance value of each slidewire 91-94 in the responsive branch of the circuit and that the potential difference which appeared between points E and F solely by reason of adjustment of slidewire 101 is reduced and it is eventually brought to zero value by the combined operation of the master control means and the additional control means. At termination of the combined control actions, the end result is that slidewires 91-93 occupy positions to reduce to zero the voltage between points A and B, C and D, and E and F, while slidewire 94 is brought to a position of increased resistance where the voltage developed or the potential difference across slidewire 94 is equal to the potential difference developed across slidewire 101 and resistor 102. Thus, there will have been accomplished a readjustment of the speed of motor 53 in accordance with the setting of slidewire resistor 101 with corresponding compensating adjustments in the speeds of motors 44, 51 and 52 to maintain substantially constant the total rate of fuel delivered to boiler 10.

It is to be understood that the master controller in cooperation with the fuel-feed controller 66 functions through the upper contacts 68 and 80 and the lower contacts 85 and 89 for control of the actuator 72 to readjust the speeds of motors 44, 51-53 to change the total fuel delivered to the boiler 10 in accordance with the load demand. However, there is always superimposed upon the control of total fuel de-

livery, the supplementary control which divides the fuel requirements between the several fuel-feeding devices in manner determined by the settings or adjustments of the slidewires 95, 97, 99 and 101.

While the system of Fig. 1 has in many respects included diagrammatic representations of the several elements, it is again emphasized that many variations in components may be made to adapt the invention to applications of widely differing character.

In Fig. 2 there has been illustrated additional features of the invention utilized in connection with a commercial form of the apparatus. In this arrangement, the network 90 has been illustrated as being supplied by alternating current from any suitable source by way of power transformer 120 through a "swamping" resistor 121 to conductors 105a and 106a. The detectors 108 and 109 have been illustrated in the same manner as in Fig. 1, but the detector 107 has been illustrated in detail. It will be understood that detectors 108 and 109 are of the same type as 107 and that each comprises an input transformer 122, the primary winding of which is connected across the input points, such as A and B, of network 90. The outer ends of the secondary winding of transformer 122 are connected to the grids of thermionic tubes 123 and 124, while their cathodes are effectively connected to the mid-point of the secondary winding of transformer 122 as by resistors 125 and 126. It will be observed that the cathode-grid circuits include a fractional part of the secondary winding of a transformer 127 supplied from a suitable alternating-current source. The connection is such that when the anodes or plates of tubes 123 or 124 are positive with respect to cathode, the grids of the two tubes are made adequately negative with respect to cathode to bias them to a non-conductive operating condition. The tubes may be of any suitable type, meeting the foregoing requirement of bias to cut-off and with current output adequate to operate one or the other of relays 107d and 107i.

When an unbalance voltage appears between points A and B, there will be applied to the input transformer 122 a signal whose phase relative to the phase of the alternating current applied to the plate-cathode circuits of tubes 123 and 124 by transformer 127 will depend upon the direction of the voltage unbalance. If the potential difference or voltage division across slidewire 91 is less than the potential difference across slidewire 95 and its associated resistor 96, the tube 123 will be made conductive, while the tube 124 will, to even greater degree, be rendered non-conductive. Thus, current will flow from one side of the secondary winding of transformer 127 by way of relay winding 107i through the tube 123 and by way of conductor 123 to the other side of the transformer. Since only half cycles of one polarity flow through coil 107i, a capacitor 130 is provided in shunt with the coil to maintain it energized during the period the tube is not conductive, corresponding with the appearance of negative half-cycles of voltage across the secondary winding of transformer 127. When the potential unbalance is in the opposite direction with a greater potential difference across slidewire 91, the phase of the signal applied to the input transformer 122 reverses, tube 124 is rendered conductive, and relay 107d is energized with a capacitor 131 maintaining the coil ener-

gized during the negative half-cycle in manner already described.

Assuming now that the relay coil 107i is energized as above described, the energizing circuit for the operating coil of a motor contactor 132i is partially completed by the closure of relay contacts 107c. This circuit is completed as soon as the synchronous motor 133 rotates cam 134 so that the crest thereof closes the contacts 135. The energizing circuit may then be traced from line L—1 through contacts 135, contacts 107c, operating coil of contactor 132i, contacts 136a of a limit switch 136, and thence to the other supply line L—2. Accordingly, the contactor 132i closes and energizes a motor 137, shown as being of the three-phase induction type, to rotate a speed-controlling member of a variable speed drive 140. As schematically illustrated, the speed-controlling drive 140 includes threaded member 141 which adjusts the driving element between a pair of conical members 142 and 143, the former being driven by any suitable means, such as motor 144. The conical element 143 drives the fuel-feeding device 43 at a speed determined by the setting of the driving element positioned by threaded member 141.

It will be observed that in Fig. 2 the coal from hopper 42 is fed by unit 43 to a pulverizing mill 146 of pulverizing unit 46. After reduction of particle size the coal is delivered by an exhaustor fan 147 and is forced through fuel supply lines 47 and 47a to the burners 11a and 11b (Fig. 1). It will be observed the motor 144 by drive shaft 148 drives both the pulverizer 146 and the exhaustor fan 147.

Returning now to the operation of the system, it will be recalled that upon energization of motor 137 the relative position between slidewire 91 and its contact 91a is changed, the mechanical connection being shown by the broken line 150. The length of time the motor 137 is energized is determined in the first instance by the energization of relay 107i, and secondly by the movement of cams 134 to close contacts 135.

The operation of the detector 107 and detectors 108 and 109 is the same as in the modification described in Fig. 1. Each of the variable speed drives 140 will have associated with it a tachometer, only one of them being shown, the tachometer 61 together with its associated permanent magnet 61a. The remaining tachometers will be electrically connected in a totalizing circuit in the same manner as shown in Fig. 1, and they will function as there described to apply a force to the pivoted operating lever 36 of the fuel-feed controller 66, a fractional part only of which appears in Fig. 2.

When relay 107d is energized, a similar energizing circuit is completed by way of its contacts 107e for the operating coil of the other motor contactor 132d for energization of the motor 137 in the reverse direction, namely, to decrease the speed of the final control unit or coal feeder 43 to decrease the rate of fuel delivered to the steam generator 10. The motor contactors 132i and 132d in reversing one phase only of the three-phase alternating-current source of supply are provided with a mechanical interlock 149 so that after energization of the coil of one of the contactors 132i or 132d the other may not be closed upon energization of its coil.

While separate limit switches may be utilized, the single limit switch 136 has been shown associated with a single cam 152 driven through mechanical connection 150 so that upon movement

of the driving element positioned by screw 141 to near its low-speed position, the lever 153 is actuated by the cam to open limit switch contacts 136d and 136e, while at the position of the maximum speed for unit 43, the levers 154 and 155 open contacts 136a and 136f.

At times in the operation of a steam boiler it may be desired to control the rate of firing or fuel delivery thereto by manual control of one or more fuel feeders independently of the automatic control already described in detail. As shown in Fig. 2, this is conveniently done by operation of a transfer switch 160 as by raising handle 161 to open contacts 162 and 163 and to close contacts 164 and 165. The opening of contacts 162 opens the energizing circuits controlled by relays 70, 71, 107i and 107d. The opening of contacts 163 opens the energizing circuit for the operating coil of a relay 166 which closes its contacts to short-circuit the detector 107. By connecting points A and B together the potential therebetween is equalized at the same time that the input of detector 107 is short-circuited.

The closure of contacts 164 by operation of transfer switch 160 partially completes an energizing circuit for the motor contactor 132i which can be completed at will by operation of a push-button switch 167. Similarly, the closure of contacts 165 partially completes the energizing circuit for the motor contactor 132d which may be completed at will by the push-button switch 168. Thus, either of motor contactors 132i or 132d can be energized manually for change of speed of the control unit 43 in a desired direction.

It is to be observed that with relay 166 de-energized and the potential equalized as between points A and B, the detectors 108 and 109 may continue to function to control their respective final control units 48 and 49 (Fig. 1) automatically and in cooperation with the fuel-feed controller 66 will position final control units 50 and 51 in manner already described. In this connection the tachometer 61 remains in the totalizing circuit in series with the remaining tachometers 62—64 so that the force applied to the pivoted lever 36 by coils 38—41 is representative of the total fuel feed to the steam generator 10. The result is that the automatic control remaining in operation functions to maintain the total rate of fuel delivery at a constant value, notwithstanding the change in fuel delivery effected by manual control of the control unit or coal feeder 43.

While only one of the detectors 107 and associated control circuits has been illustrated in detail in Fig. 2, it is to be understood that each of the remaining control units 48—50 will be provided with identical control systems and that any one of them may be changed from manual to automatic operation with the several tachometers continuing to function in the totalizing circuit as above described. The only difference between the remaining control systems is the arrangement of contacts on the relays corresponding with the relay 166. When relay 170 is deenergized, the arrangement of contacts for relay 170 is such that contacts 170a short-circuit or reduce to zero the potential drop across slidewire 92 in the responsive circuit and contacts 170b short-circuit or reduce to zero the potential drop across slidewire 97 and its associated resistor 93 in the reference circuit. By operation of contacts 170a and 170b the potential between the points A and C is equalized, and the potential between points B and D is equalized. Similarly, the contacts

171a and 171b of a relay 171 equalize the potentials between points C and E as well as between points D and F.

There is one further variation in the control means associated with the drive of contact 94a and with a relay 172 having contacts 172a for reducing the potential between the points E and F to zero. For reasons explained hereinbefore, there is omitted from such control means the counterpart of relays 107i and 107d and their associated functions, since a detector is not associated with the control for the fuel-feeding unit 50.

While the invention in both Figs. 1 and 2 has been set forth in connection with the control of four final control units, it is, of course, to be understood that the principles involved are applicable to any desired number—two or more—of final control units. In a system with a greater number of units, the control circuits and switching arrangements for the intermediate detectors will correspond with those provided for detectors 108 and 109, while the control circuits at the outermost parts of the control system 90 will correspond with relays 166 and 172. Likewise it is to be noted that the supplementary or additional control means provided by network 90 and detectors 107—109 is capable of functioning independently of or in the absence of the master control means including master controller 19, fuel-feed controller 66 and tachometer generators 61—64 to maintain predetermined relations between the control units. Such a system may be employed where it is not essential to maintain the total fuel supply at a predetermined value.

Referring now to the arrangement of Fig. 3, there is shown a schematic representation of another circuit useful in the arrangements of Figs. 1 and 2. There is particularly illustrated in Fig. 3 an alternative circuit for developing potential differences in the responsive branch of the supplementary control system.

The supplementary control circuit, identified as 90a, includes a reference circuit of the same type as that shown in Figs. 1 and 2, including slidewires 95, 97, 99 and 101 as well as the associated resistances 96, 98, 100 and 102. However, in the responsive branch of network 90a, potential differences are developed across impedance members 200, 201, 202 and 203 which in the present arrangement are secondary windings of transformers 204—207. The potential differences across windings 200—203 are of course dependent upon the voltages applied to the primaries of transformers 204—207. These primary windings are respectively arranged to be energized from variable output auto-transformers 208—211. The variable auto-transformers 208—211 are excited from a source of alternating current potential such as lines 212, 213. Associated with each of the variable output auto-transformers 208—211 are movable contacts 208a—211a respectively moved in accordance with the rotation of motors 78—81. As shown in both Fig. 3 and Fig. 1, the rotation of motors 78—81 controls the positioning of contacts 45a and 54a—56a on resistors 45, 54—56 respectively to control the speed of motors 44 and 51—53 and the final control units 43, 48—50.

In operation, the potentials developed across impedance elements 200—203 function in manner similar to the arrangements shown in Figs. 1 and 2, since elements 200—203 establish a potential division in the responsive branch of network 90a, in the same manner that slidewires 91—94 per-

form that function in Figs. 1 and 2. However, in the present arrangement impedance elements 200—203 are also potential developing means and the total potential developed between lines 105b and 106b will be the sum of the individual potentials across windings 200—203.

A particular advantage of the arrangement of Fig. 3 is that the totalizing circuit including coils 38—41 of fuel-feed controller 66 is supplied directly from network 90a rather than from a separate circuit requiring auxiliary potential generating devices such as tachometer generators 61—64, as in Figs. 1 and 2. In the present embodiment the totalizing circuit is energized by means of a full-wave rectifier 214 connected across lines 105b and 106b through a variable resistor 215 and a supplementary transformer 216. The transformer 216, whose primary may be supplied by any suitable source of alternating current provides compensation for the variable resistance characteristics of the rectifier elements of full-wave rectifier 214. In practice, the potential applied by the secondary winding of transformer 216 may be from 4 to 6 volts as compared to a total voltage between lines 105b and 106b of from 80 to 100 volts for maximum fuel supply by final control units 43, 48—50. The output of rectifier 214 is connected in series with coils 38—41 of fuel-feed controller 66 by way of lines 217 and 218.

From the foregoing description of the arrangement of Fig. 3, it will be apparent that upon adjustment of the slidewires 95, 97, 99 or 101, detectors 107—109 respectively operate to drive motors 78—80 in manner described in connection with Figs. 1 and 2, which motors, as well as motor 81, are arranged to drive movable contacts 208a—211a. Movement of contacts 208a—211a varies the potential applied from auto-transformers to transformers 204—207 so as to maintain the potential difference between points A and B, C and D, as well as E and F at substantially zero in the same manner as described in the operation of Figs. 1 and 2.

While the functions of the slidewires and resistances in the reference circuit are substantially identical with the arrangement of Figs. 1 and 2, desirably, the total resistance across elements 95—102 in the present arrangement is substantially higher than the circuit through rectifier 214 and coils 38—41 of fuel-feed controller 66. By making this total resistance high, adjustment of any of the reference slidewires 95, 97, 99 or 101 will not have appreciable effect upon current flow through coils 38—41.

In the arrangement of Fig. 4, there is shown in schematic form a further modification of the supplementary control circuit, identified in the present embodiment as 90b. As particularly distinguished from the arrangements of Figs. 1—3, that of Fig. 4 illustrates the present invention as applied to a control network in which the electrical quantity to be divided in the responsive circuit and reference circuit is a total current flow, as distinguished from a total potential difference. The reference branch of control network 90b, including slidewire resistors 250, 251, 252 and 253 is so connected with the responsive branch of the network, including slidewires 254—257, that the total current through both branches is the same. In the circuit shown in Fig. 4 both the reference and responsive branches are connected to a source of current through input lines 258 and 259 and the two branches interconnected by conductor 260.

As particularly distinguished from the foregoing embodiment, it will be observed that the slidewires 250-253 in the reference branch are connected in parallel, and in series with each of the slidewires 250, 251 and 252 there are respectively connected current detector windings or coils 261, 262 and 263. Each of the slidewires 250-253 may have connected in series therewith fixed resistances 264-267. Correspondingly, the adjustable control elements 254-257 in the responsive branch of network 39b are connected in parallel; and in series with elements 254, 255 and 256, there are connected current detector windings or coils 268, 269 and 270. The windings 261 and 268 are mechanically arranged to form a differential current detector means for operation of an armature 271 in accordance with the sense of unbalance of current flow in the respective circuits to which responsive windings 261 and 268 are connected. Armature 271 is arranged to connect drive motor 78 through either its increase, "I," winding or its decrease, "D," winding in manner similar to the operation of detector relay 107b in Fig. 1. In similar manner, the direction of drive of motors 79 and 80 may be controlled by the movement of armature 272 positioned between windings 262 and 269 and the direction of drive of motor 80 may be controlled by movement of armature 273 positioned between windings 263 and 270.

In the operation of the arrangement of Fig. 4, upon any relative change in current flow in one of the four branches of the reference circuit as determined by the relative adjustments of slidewires 250-253, associated current detectors will operate armatures 271-273 to establish corresponding relative current flows in the associated branches of the responsive circuit in manner to make the division of current in each branch of the responsive circuit similar to the current division in each branch of the reference circuit.

Though the terms used herein in general have the same meaning as the definitions proposed by the Terminology Committee of the Industrial Instruments and Regulators division of the American Society of Mechanical Engineers (see "Mechanical Engineering" for February 1946), they are susceptible of somewhat broader interpretations. For example, the controlled variable is in general a quantity or condition which is measured and controlled while the manipulated variable is the quantity or condition which is varied by an automatic controller or by the final control element or unit. However, the two variables in some instances may be the same and hence the use of one term is not used to the exclusion of the other. Similarly, the reference to an electrical quantity is to be taken as generic to voltage or current or to another selected electrical condition.

While modifications and changes will become apparent to those skilled in the art from the foregoing description, all such modifications and changes as fall within the scope of the appended claims are intended to be embraced thereby.

What is claimed is:

1. A control system comprising adjustable final control units, control elements connected together in a responsive circuit and respectively corresponding with said control units, means operable in accordance with adjustments of said units for adjusting said control elements to establish in said responsive circuit electrical quantities whose magnitudes are fractions of a total

electrical quantity and respectively of fractional size dependent upon the extent of relative adjustments of said units, a reference circuit having elements for establishing electrical quantities whose magnitudes are desired fractions of a total electrical quantity as determined by the relative values of said reference circuit elements one to the other, and means including electrical quantity difference detectors respectively connected between different portions of said circuits for changing the adjustments of said units until the fractional electrical quantities of said responsive circuit and of said reference circuit bear the same relationships one to the other.

2. A control system comprising adjustable final control units, control elements connected together in a responsive circuit and respectively corresponding with said control units, means operable in accordance with adjustments of said units for adjusting said control elements to establish in said responsive circuit potential differences whose magnitudes are fractions of the total potential across said responsive circuit and respectively of fractional size dependent upon the extent of relative adjustment of said units, a reference circuit having elements for developing potential differences whose magnitudes are desired fractions of the total potential across said reference circuit as determined by the relative values of said reference circuit elements one to the other, and means including detectors respectively connected between different portions of said circuits for changing the adjustment of said units until the fractional potential differences of said responsive circuit and of said reference circuit bear the same relationships one to the other.

3. A control system comprising adjustable final control units, control elements at least one for each control unit connected together in a responsive circuit, means operable in accordance with the adjustments of said units for adjusting said control elements to establish in said responsive circuit electrical currents whose magnitudes are fractions of the total current in said responsive circuit and respectively of fractional size dependent upon the extent of relative adjustments of said units, a reference circuit having elements for establishing electrical currents whose magnitudes are desired fractions of the total current in said reference circuit as determined by the relative values of said reference circuit elements one to the other, and means including detectors respectively connected between different portions of said circuits for changing the adjustments of said units until the fractional currents of said responsive circuit and of said reference circuit bear the same relationships one to the other.

4. A control system comprising adjustable final control units, control elements connected together in a responsive circuit and respectively corresponding with said control units, means operable in accordance with adjustments of said units for adjusting said control elements to establish in said responsive circuit electrical quantities whose magnitudes are fractions of a total electrical quantity and respectively of fractional size dependent upon the extent of relative adjustments of said units, a reference circuit having adjustable elements for establishing electrical quantities whose magnitudes are desired fractions of a total electrical quantity as determined by the relative adjustments of said reference circuit elements one to the other, and

means including electrical quantity difference detectors respectively connected between different portions of said circuits for changing the adjustments of said units until the fractional electrical quantities of said responsive circuit and of said reference circuit bear the same relationships one to the other.

5. A control system comprising adjustable final control units, control elements connected together in a responsive circuit and respectively corresponding with said control units, means operable in accordance with adjustments of said units for adjusting said control elements to establish in said responsive circuit electrical quantities whose magnitudes are fractions of a total electrical quantity and respectively of fractional size dependent upon the extent of relative adjustments of said units, a reference circuit having adjustable elements for establishing electrical quantities whose magnitudes are desired fractions of said total electrical quantity as determined by their relative adjustments, one to the other, and means including electrical quantity difference detectors respectively connected between different portions of said circuits for changing the adjustments of all but one of said units until the fractional electrical quantities of said responsive circuit and of said reference circuit bear the same relationships one to the other.

6. A control system for maintaining a controlled variable at a set point comprising a plurality of adjustable final control units, each establishing a fractional part of a manipulated variable, control elements connected together in a responsive circuit and respectively associated with said control units, means operable in accordance with adjustments of said units for adjusting said control elements to establish in said responsive circuit electrical quantities whose magnitudes are fractions of a total electrical quantity and respectively of fractional size depending upon the extent of relative adjustments of said units and the total manipulated variable controlled by said units, a reference circuit having adjustable elements for establishing electrical quantities which represent fractions of a total electrical quantity as determined by their relative adjustments, one to the other, for predetermining the division between said units of said manipulated variable, and means including electrical quantity difference detectors for changing the adjustments of said units until the fractional electrical quantities of said responsive circuit and of said reference circuit bear the same relationship one to the other thereby establishing the fractional parts of said manipulated variable controlled by each of said units.

7. A control system for maintaining a controlled variable at a set point comprising a plurality of adjustable final control units, each establishing a fractional part of a manipulated variable, control elements connected together in a responsive circuit and respectively associated with said control units, means operable in accordance with adjustments of said units for adjusting said control elements to establish in said responsive circuit electrical quantities whose magnitudes are fractions of a total electrical quantity and respectively of fractional size depending upon the extent of relative adjustments of said units and the total manipulated variable controlled by said units, a reference circuit having adjustable elements for establishing electrical quantities which represent fractions of a total electrical quantity as determined by their rela-

tive adjustments, one to the other, for predetermining the division between said units of said total manipulated variable, means including electrical quantity difference detectors for changing the adjustments of said units until the fractional electrical quantities of said responsive circuit and of said reference circuit bear the same relationship one to the other thereby producing said division of said total manipulated variable between said units, and means for simultaneously adjusting all of said units in response to deviation of said manipulated variable from a predetermined value.

8. A control system for maintaining a controlled variable at a set point comprising a plurality of adjustable final control units, each establishing a fractional part of a manipulated variable, control elements connected together in a responsive circuit and respectively associated with said control units, means operable in accordance with adjustments of said units for adjusting said control elements to establish in said responsive circuit electrical quantities whose magnitudes are fractions of a total electrical quantity and respectively of fractional size depending upon the extent of relative adjustments of said units and the total manipulated variable controlled by said units, a reference circuit having adjustable elements for establishing electrical quantities which represent fractions of said total electrical quantity as determined by their relative adjustments, one to the other, for predetermining the division between said units of said manipulated variable, means including detectors for changing the adjustments of all but one of said units until the fractional electrical quantities of said responsive circuit and of said reference circuit bear the same relationship one to the other thereby producing said division of said manipulated variable between said units, and means for simultaneously adjusting all of said units in response to deviation of said manipulated variable from a predetermined value.

9. A control system for maintaining a controlled variable at a set point comprising a plurality of adjustable final control units, each establishing a fractional value of a total manipulated variable, a control element for each of said units capable of developing a potential difference, a responsive circuit in which said control elements are connected, master control means responsive to the magnitude of the controlled variable for simultaneously adjusting said final control units for maintaining that total magnitude of said manipulated variable as required to maintain said controlled variable at said set point with simultaneous related adjustment of said control elements, each of said control elements developing in said responsive circuit a potential difference whose magnitude is a fraction of the total potential across said responsive circuit and of fractional size dependent upon adjustment of its associated unit relative to adjustments of other of said units, means including a reference circuit having adjustable elements for developing potential differences of magnitudes which are fractions of the total potential across said reference circuit as determined by differences one to the other in their relative settings, and additional means to readjust said control units to divide said total magnitude of the manipulated variable between the several control units, said additional means including detectors for changing the adjustment of all but one of said units in response to differences between the fractional potential differences in

said responsive circuit and the corresponding fractional potential differences in said reference circuit.

10. A control system for maintaining a controlled variable at a set point comprising a plurality of adjustable final control units, each establishing a fractional value of a total manipulated variable, a control element for each of said units capable of developing a potential difference, a responsive circuit in which said control elements are connected, master control means responsive to the magnitude of the controlled variable for simultaneously adjusting said final control units for maintaining that total magnitude of said manipulated variable as required to maintain said controlled variable at said set point with simultaneous related adjustment of said control elements, each of said control elements developing in said responsive circuit a potential difference whose magnitude is a fraction of the total potential across said responsive circuit and of fractional size dependent upon adjustment of its associated unit relative to adjustments of other of said units and which fractions are independent of the total potential difference across said responsive circuit, means including a reference circuit having adjustable elements for developing potential differences of magnitudes which are fractions of the total potential across said reference circuit as determined by differences one to the other in their relative settings and which fractions are independent of said total potential across said reference circuit, and additional means to readjust said control units to divide said total magnitude of the manipulated variable between the several control units, said additional means including detectors for changing the adjustment of all but one of said units in response to differences between the fractional potential differences in said responsive circuit and the corresponding fractional potential differences in said reference circuit.

11. A control system for dividing a manipulated variable among a plurality of final control units comprising a plurality of series connected control elements and a plurality of series connected adjustable impedance elements, connected in parallel to a source of potential, detector means connected between the junction of two of said control elements and two of said adjustable impedance elements, means operable in response to potential differences between said junctions for adjusting one of said control units, and means for reducing substantially to zero said potential differences in response to adjustment of said control units.

12. A control system for dividing a manipulated variable among a plurality of final control units comprising a responsive circuit including a plurality of series connected control elements and a reference circuit including a plurality of series connected adjustable impedance elements, said circuits being connected in parallel to a source of potential, detector means connected between the junction of two of said control elements and two of said adjustable impedance elements, means operable in response to potential differences between said junctions for adjusting one of said control units, and means for reducing substantially to zero said potential differences in response to adjustment of said control units.

13. A control system for dividing a manipulated variable among a plurality of final control units comprising a plurality of series connected control elements and a plurality of series connected adjustable impedance elements connected

in parallel to a source of potential, one of said control elements and one of said adjustable impedance elements corresponding to each of said plurality of control units, a detector means connected between the junctions of two of said control elements and the corresponding two of said adjustable impedance elements, means operable by said detector means in response to potential differences between said junctions for adjusting one of said control units corresponding to said elements adjacent one of said junctions to which said detector means is connected, and means operable in response to adjustment of said control units for reducing said potential differences between said junctions substantially to zero.

14. In a control system, the combination of a plurality of control units, each adjustable to divide a common output, master control means including a totalizing circuit for simultaneously adjusting each of said units to maintain said common output, control elements associated with each of said control units, said elements being connected in series in a responsive circuit to develop potential differences of magnitude related to the fraction of said common output on a corresponding control unit, a reference circuit, adjustable elements connected in series in said reference circuit corresponding to each of said units for developing potential differences in said reference circuit corresponding to desired fractions of said common output, the sum of the potential differences across the adjustable elements in said reference circuit being equal to the sum of the potential differences across said responsive circuit, and means including a detector responsive to potential differences between adjacent adjustable elements and adjacent control elements for adjusting a corresponding control unit and its associated control elements to maintain at substantially zero said potential differences between said adjacent elements.

15. A control system in accordance with claim 14 which includes transfer means for manual control of at least one of said control units, said means operating simultaneously to disconnect the corresponding detector from said control system.

16. A system in accordance with claim 14 in which said control elements are potential-generating means and said totalizing circuit is connected in parallel with said series connected control elements.

17. A control system in accordance with claim 16 in which said potential-generating means are a plurality of series connected transformer windings upon which there is impressed an alternating current potential corresponding in magnitude with the fraction of the common output on each of the corresponding control units.

18. In a control system comprising a plurality of control units each movable between predetermined limits, means for applying a total potential to a circuit comprising a series connected impedance element for each of said control units adjustable in accordance with the position of that unit between said limits, means for applying said total potential to a reference circuit comprising series connected impedance means for each of said units adjustable in accordance with desired relative positions of said units, and means including detectors responsive to the potential difference between each point intermediate between two impedances in said first circuit and a corresponding point intermediate between two impedances in said reference circuit for read-

justing the positions of all except one of said units.

19. A control system for a group of final control units comprising control elements corresponding to said units each connected as a parallel branch of a responsive circuit to divide a total current in relation to the adjustments of said units, a reference circuit having corresponding parallel branches for dividing in a predetermined manner a current of the same magnitude as divided by said responsive circuit, detector means responsive to differences between the currents in said branches of said responsive circuit as compared with the currents in associated branches of said reference circuit to adjust said control units to the desired predetermined relationship as predetermined by the current division in said reference branch.

20. A control system for a group of final control units comprising means for establishing a signal related to the deviation of a controlled variable from a predetermined set point, balanceable means operable jointly in response to said signal and the adjustment of said final control units for adjusting said final control units to change the manipulated variable, supplementary

control means comprising control elements corresponding to said final control units and adjusted relative to the adjustments of said control units, each of said control elements being connected as a circuit branch of a responsive circuit to divide the total electrical current flowing in said branches in relation to the adjustments of said units, a reference circuit having corresponding parallel branches for dividing in a predetermined manner a total current equal in magnitude to the total current in said responsive circuit, means operable to readjust said final control units in response to current differences until the division of current in said branches of said responsive circuit is the same as the division of current in said branches of said reference circuit.

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