April 3, 1951 J. L. RAY 2,547,093

GAS TURBINE SYSTEM

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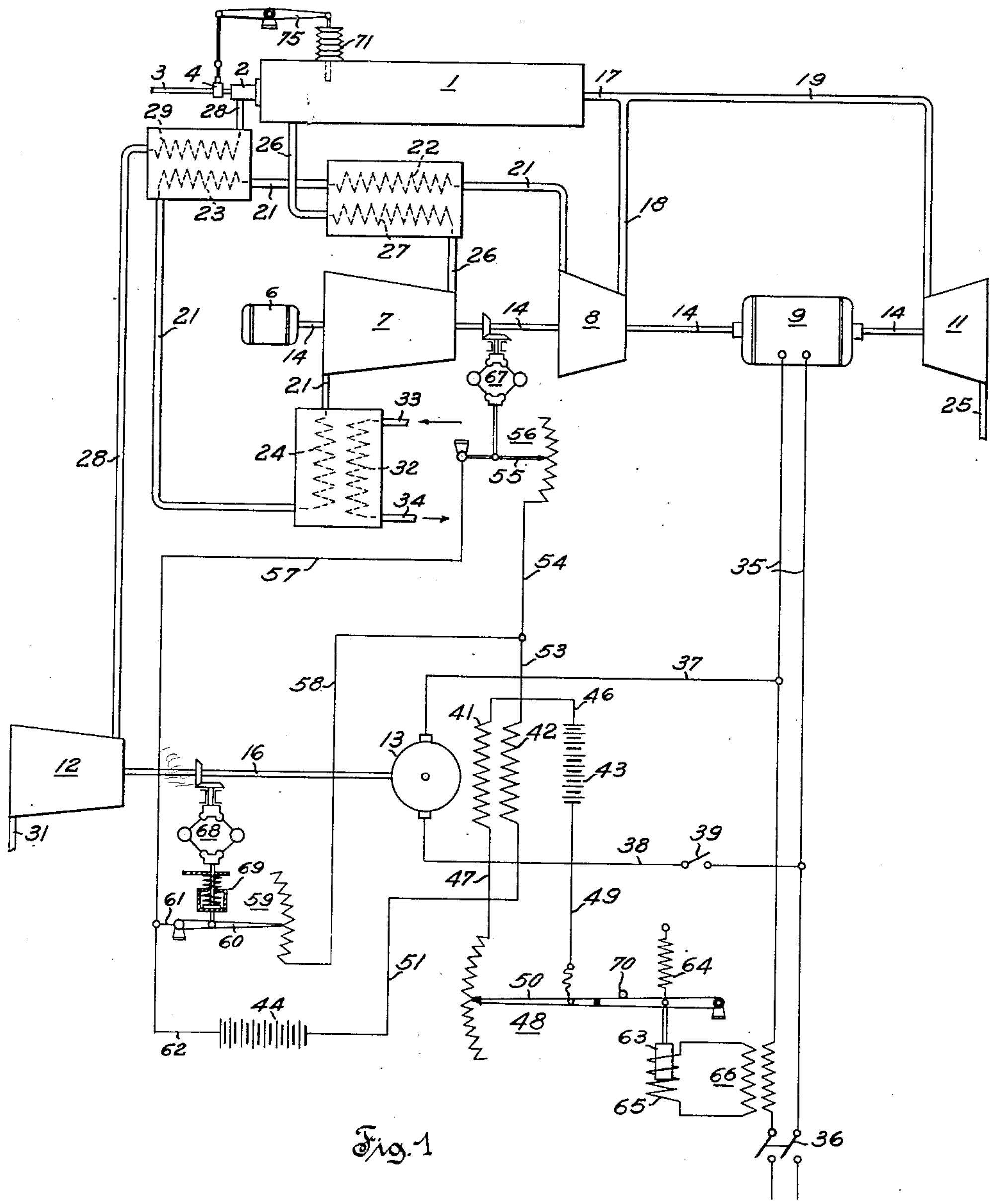

Fig. 1

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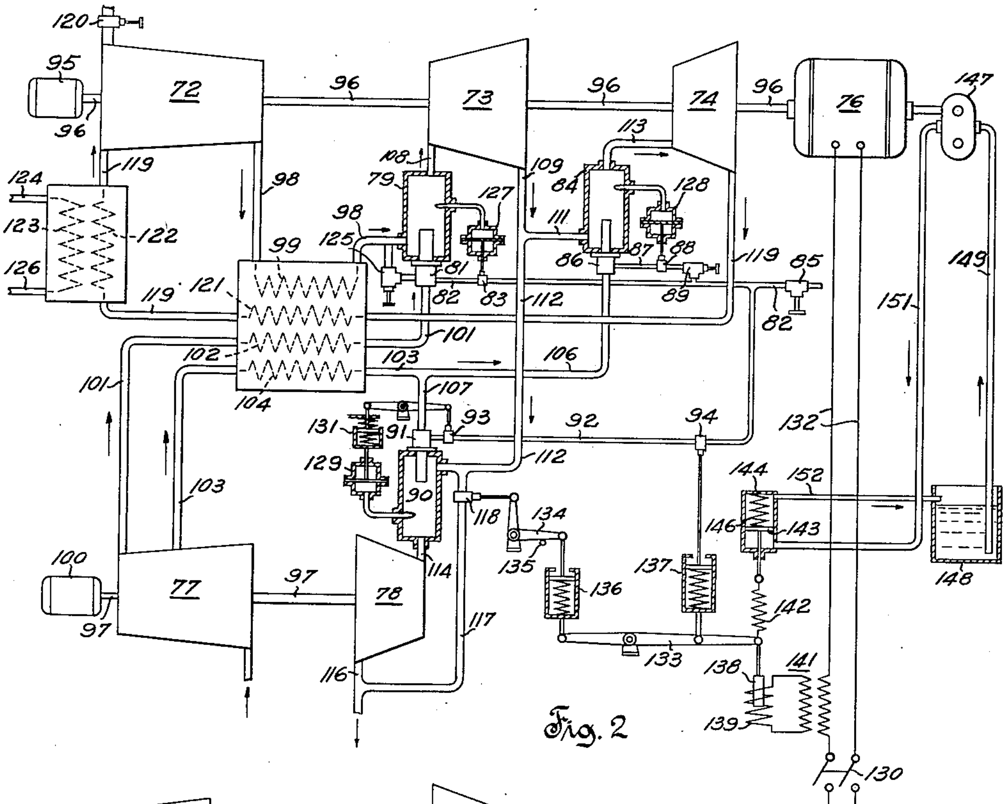

Fig. 2

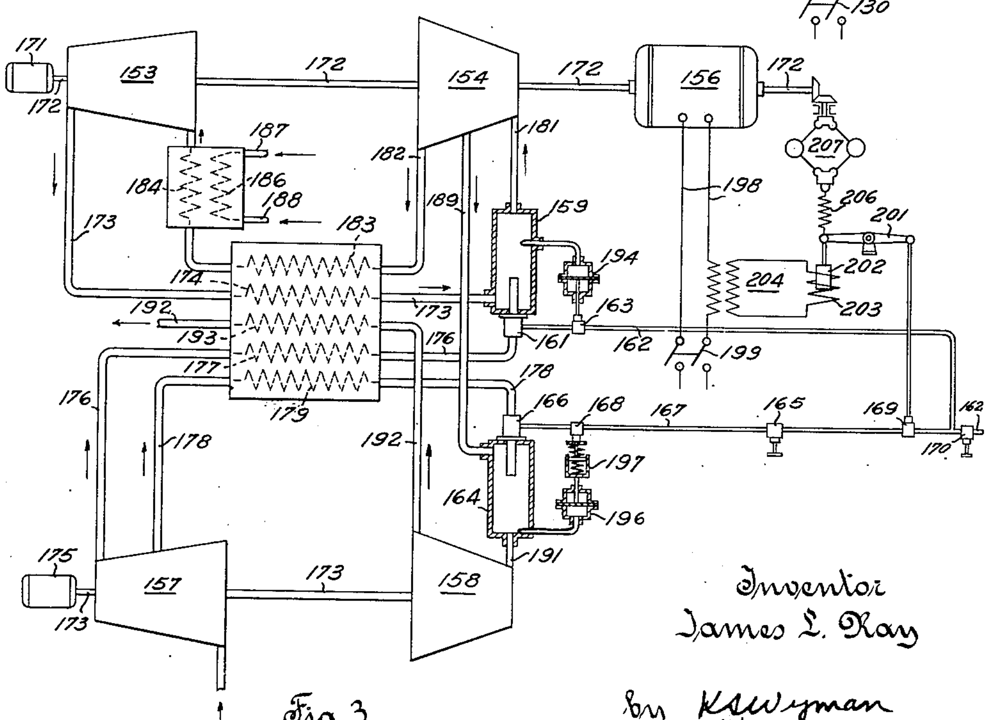

Fig. 3

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GAS TURBINE SYSTEM

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11 Claims. (Cl. 60—41)

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This invention relates to elastic fluid turbine systems for developing power by expanding products of combustion incident to conversion of thermal energy into mechanical energy and more particularly to the type of system embodying apparatus for continuously performing the steps of releasing a portion of the expanded products of combustion, cooling and then recompressing the remaining products of combustion, heating the recompressed products of combustion by combining same with newly formed, highly heated products of combustion obtained by burning fuel in a compressed, combustion supporting elastic fluid either before or after such fluid is partially or wholly mixed with the recompressed products of combustion, and expanding the resulting mixture.

In the known systems of this type, recompression of expanded products of combustion is effected by a main compressing means driven by one of the turbines while compression of the combustion supporting elastic fluid is effected by a separate auxiliary compressing means driven by another turbine which is mechanically independent of the main compressor turbine and also of the power turbine when such a turbine is employed; the auxiliary compressor turbine being connected either in parallel or series flow arrangement with the main compressor and power turbines, that is, it either receives motive fluid from the combustion chamber or chambers supplying the main compressor and power turbines, or it is a low pressure turbine operated by motive fluid exhausting from such other turbines. In either case, both the temperature and the mass flow of motive fluid are similarly, simultaneously varied, usually by varying fuel input to the combustion chamber or chambers in accordance with changes in external load or power transmitted, and as a result, part load efficiencies are objectionably low and regulation sluggish particularly with respect to the handling of rapidly changing loads.

It is therefore an object of this invention to provide a mode of operation for such systems which will afford optimum part load efficiencies and will improve accelerating characteristics.

A further object of this invention is to provide improved correlations of elements for effecting such a mode of operation.

The construction and operation of apparatus embodying the invention will become readily apparent as the disclosure progresses and particularly points out additional features considered of special importance, and accordingly, the invention may be considered as consisting of the methods and of the correlations of elements and arrangements of parts as is more fully set forth in the detailed description and in the appended claims, reference being had to the accompanying drawings, in which:

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Fig. 1 schematically illustrates a gas turbine system embodying the invention;

Fig. 2 schematically illustrates another gas turbine system embodying the invention;

Fig. 3 schematically illustrates still another gas turbine system embodying the invention.

Referring to Fig. 1 of the drawings, it is seen that a gas turbine system embodying the invention may include a combustion chamber 1 having a burner portion 2 to which fuel is supplied from a suitable source (not shown) through a pipe 3 provided with a flow regulating valve 4; a starting motor 6, a first or main compressor 7, a first or compressor turbine 8, an electric generator 9, a second or power turbine 11, an auxiliary compressor 12, and an electric motor 13. Starting motor 6 and turbines 8 and 11 may be drivingly connected with main compressor 7 and with generator 9 by any suitable means such as a common shaft 14, and electric motor 13 may be drivingly connected with auxiliary compressor 12 by any suitable means such as a common shaft 16.

A main conduit 17 and branch conduits 18 and 19 severally connect the inlets of turbines 8 and 11 with the discharge end of combustion chamber 1, and a conduit 21, which includes heat exchanging portions 22, 23 and 24, connects the exhaust of turbine 8 with the inlet of main compressor 7. Turbine 11 exhausts to atmosphere through a conduit 25. A conduit 26, which includes a heat exchanging portion 27 operatively associated with heat exchanging portion 22 of conduit 21, connects the discharge of compressor 7 with the burner end of combustion chamber 1 and a conduit 28, which includes a heat exchanging portion 29 operatively associated with heat exchanging portion 23 of conduit 21, connects the discharge of auxiliary compressor 12 with the burner portion 2 of combustion chamber 1. The inlet of compressor 12 communicates with the atmosphere through a conduit 31. A cooling coil or the like 32 is operatively associated with the heat exchanging portion 24 of conduit 21. Water or other suitable cooling fluid passes into and out of coil 32 through pipes 33 and 34, respectively.

Excess power developed by the system is converted into electrical energy in generator 9 and is transmitted for use where desired by means of a power line 35 including a switch 36. The armature of motor 13 is connected across power line 35 by means of conductors 37 and 38, the latter including a switch 39. Motor 13 is preferably separately excited by means of field windings 41 and 42 which are in turn separately energized by any suitable means such as batteries 43 and 44, respectively. Starting from one side of battery 43, the energizing circuit for field winding 41 comprises conductor 46, field winding 41, conductor 47, rheostat 48, and conductor 49. Starting from one side of battery 44, the energizing circuit for field winding 42 comprises conductor 51, field winding 42, conductor 53, a pair of parallel circuits one of which includes a conductor 54, a rheostat 56 and a conductor 57 and the other of which includes a conductor 58, a rheostat 59 and a conductor 61, and a conductor 62 connecting conductors 57 and 61 with the other side of battery 44.

The position of the movable element 50 of rheostat 48 is controlled by means of a load responsive device comprising a solenoid 63 subjected to oppositely acting forces by means of a spring 64 and a coil 65 forming a part of the secondary circuit of a current transformer 66 associated with power line 35, the arrangement of these parts being such that the field produced by the flow of current through winding 41 is automatically increased and decreased as the load on generator 9, i. e., the electrical energy transmitted through power line 35, decreases and increases, respectively. It should therefore be obvious that the control of rheostat 48 in this manner operates to increase and decrease the speed of motor 13 as the load on generator 9 increases and decreases, respectively.

The position of the movable element 55 of rheostat 56 is controlled by a speed governor 67 operatively associated with shaft 14 and is thereby operated to automatically vary the flow of current through field winding 42 as the speed of compressor 7, turbine 8, etc. increases and decreases. Rheostat 59 is controlled by a speed governor 68 driven from shaft 16 and is operatively associated with the movable element 60 of rheostat 59 by means of a speed-limiting lost-motion connection 69. Consequently, rheostat 59 is operated to automatically vary the flow of current through field winding 42 only in the event the speed of motor 13 exceeds a predetermined maximum. In this connection, it should be noted that since rheostats 56 and 59 are connected in parallel relation between field winding 42 and battery 44, these two rheostats are jointly and severally operative to vary the flow of current through field winding 42 as determined by the movements of their actuating governors 67 and 68, respectively.

The relation of field windings 41 and 42 and the energizing control thereof afforded by rheostats 48, 56 and 59 is such that the speed of motor 13 and thereby the quantity of air delivered by auxiliary compressor 12 to the burner portion 2 of combustion chamber 1 is normally increased and decreased as the load on the system, represented in this case by the transmission of electrical energy through power line 35, increases and decreases, respectively, that in the event the speed of compressor 7, turbine 8, etc. varies in response to a change in the quantity of air being delivered to combustion chamber 1 by auxiliary compressor 12, or for any other reason, rheostat 56 is operated by governor 67 to effect a compensating change in the speed of motor 13 and compressor 12, that in the event the speed of motor 13 and compressor 12 should for any reason exceed a predetermined maximum, rheostat 59 is operated by governor 68 to effect a reduction in the speed of motor 13, and that when the load on generator 9 is zero or the switch 36 in power line 35 is opened, the movable element of rheostat 48 is positioned against stop 70 by the action of spring 64 to maintain motor 13 operating at a minimum speed rendering auxiliary compressor 12 effective to supply combustion chamber 1 with a quantity of air sufficient for idling or no load operation.

Operation of this system is initiated in the usual manner by means of starting motor 6, and once the system is up to speed and motor 13 energized by closing switch 39, combustion may be initiated and the operation of the starting motor, which may be of any desired type, terminated. During normal operation, the temperature of the mixture of newly formed and recompressed products of combustion leaving combustion chamber 1 through conduit 17 is maintained substantially constant at the highest value permissible for continuous operation by means of a temperature responsive device 71 operatively connected with fuel flow regulating valve 4 by any suitable means, such as a lever 75, to effect compensating changes in its position and thereby corresponding changes in the temperature of the newly formed products of combustion. Obviously, a variation in the temperature of the newly formed products of combustion effects a corresponding change in the resulting mixture of newly formed and recompressed products of combustion. Moreover, it should also be obvious that since the speed of auxiliary compressor 12 is varied in accordance with changes in load, the quantity and the pressure of the combustion supporting air delivered to combustion chamber 1 is likewise varied as is also the pressure and density of the resulting motive fluid.

Consequently, it should now be apparent that in operation, the quantity of compressed combustion supporting elastic fluid and thereby the mass flow of the mixture of recompressed and newly formed products of combustion are varied in accordance with changes in load or power requirements, and the fuel input is also varied substantially simultaneously so as to maintain the temperature of the mixture prior to expansion substantially constant throughout the normal range of power development.

Referring to Fig. 2, it is seen that another embodiment of the invention may include a main compressor 72, a high pressure main compressor turbine 73, a low pressure power turbine 74, an electric generator 76, an auxiliary compressor 77, a low pressure auxiliary compressor turbine 78, a main combustion chamber 79 having a burner portion 81 to which fuel is supplied from a suitable source (not shown) through a pipe 82 provided with a flow regulating valve 83, a first reheat combustion chamber 84 having a burner portion 86 to which fuel is supplied through a branch 87 of pipe 82 which is provided with a flow regulating valve 88 and with a normally open manual valve 89, and a second reheat combustion chamber 90 having a burner portion 91 to which fuel is supplied through another branch 92 of pipe 82 which is also provided with a pair of flow regulating valves 93 and 94. Branch pipes 87 and 92 are connected with pipe 82 on the upstream side of valve 83 and on the downstream side relative to a manually operative main valve 85. A starting motor 95 and the turbines 73 and 74 may be drivingly connected with main compressor 72 and generator 76 by any suitable means such as a common shaft 96. Turbine 78 may be drivingly connected with auxiliary compressor 77 by any suitable means such as a common shaft 97.

A conduit 98, which includes a heat exchanging portion 99, connects the discharge of compressor 72 with the burner end of combustion chamber 79 and a conduit 101 which includes a heat exchanging portion 102, connects the high pressure discharge of auxiliary compressor 77 with the burner portion 81 of combustion chamber 79. A conduit 103, which includes a heat exchanging portion 104 and branches 106 and 107 severally connects the burner portions of reheat combustion chambers 84 and 90 with a low pressure discharge portion of auxiliary compressor 77. A conduit 108 connects the discharge end of primary combustion chamber 79 with the inlet of high pressure turbine 73 and a conduit 109 which includes branch conduits 111 and 112, severally connects the exhaust of high pressure turbine 73 with the burner ends of reheat combustion chambers 84 and 90, respectively. A conduit 113 connects the discharge end of reheat combustion chamber 84 with the inlet of low pressure turbine 74 and a conduit 114 connects the discharge end of reheat combustion chamber 90 with the inlet of low pressure turbine 78 which in turn exhausts to atmosphere through a conduit 116. A bypass conduit 117 connects branch conduit 112 with exhaust conduit 116 and is provided with a flow regulating valve 118. A conduit 119, which includes a first heat exchanging portion 121 operatively associated with the heat exchanging portions 99, 102 and 104 of conduits 98, 101 and 103, respectively, and a second heat exchanging portion 122 operatively associated with a cooling coil 123 provided with fluid inlet and outlet connections 124 and 126, respectively, connects the exhaust of low pressure turbine 74 with the inlet of main compressor 72. In addition, main compressor 72 is provided with a valve controlled atmospheric air inlet 120 and conduit 98 is provided with a valve controlled branch 125 connecting same with the burner portion 81 of primary combustion chamber 79. The valves in inlet 120 and in branch conduit 125 are maintained closed during normal operation.

Fuel flow regulating valves 83 and 88 are operatively connected with temperature responsive devices 127 and 128 which are in turn operatively associated with primary and reheat combustion chambers 79 and 84, respectively, the arrangement of these parts being such that flow regulating valves 83 and 88 are positioned to effect compensating changes in fuel input to their associated combustion chambers in order to maintain the temperature of the mixture of newly formed and recompressed products of combustion entering high pressure turbine 73 and the temperature of that portion of the partially expanded, reheated mixture entering low pressure turbine 74 substantially constant at selected maximum values commensurate with optimum thermal efficiency. Fuel flow regulating valve 93 is normally maintained in its fully open position and is closed or partially closed in the event the temperature of that portion of the reheated mixture of newly formed and partially expanded products of combustion entering turbine 78 exceeds a predetermined maximum by means of temperature responsive device 129 which is operatively associated with reheat combustion chamber 90 and operatively connected with valve 93 by means including a lost-motion connection 131.

The position of fuel flow regulating valve 94 and of motive fluid bypass valve 118 are controlled by the joint action of speed and load responsive devices operatively associated with shaft 96 and with generator power line 132, respectively, the control apparatus comprising in this case a lever 133 fulcrumed intermediate its ends and having one end operatively connected with valve 118 by means of a bell crank lever 134 and a lost-motion connector 136 permitting a further movement of lever 133 in a clockwise direction after valve 118 is fully closed and having a portion intermediate its fulcrum point and other end operatively connected with valve 94 by means including a lost-motion connector 137 permitting a further movement of lever 133 in a counterclockwise direction after valve 94 is fully closed, a solenoid 138 operatively connected with the other end of lever 133 and operatively associated with a coil 139 forming part of the secondary circuit of a current transformer 141 which is in turn operatively associated with power line 132, and a spring 142 having one end also connected with the other end of lever 133 in opposite force-producing relation with respect to solenoid 138 and having its other end connected with a piston 143 operatively enclosed in a cylinder 144.

One side of piston 143 is subjected to the action of a compression spring 146 and its opposite side is subjected to the action of fluid under a pressure which varies as a function of the speed of compressor 72, turbine 73, etc., the fluid being supplied to cylinder 144 by means of a pump 147 driven by shaft 96 and having its inlet connected with a reservoir 148 by means of a pipe 149 and its discharge connected with cylinder 144 by means of a pipe 151. Cylinder 144 is provided with a drain pipe 152 leading to reservoir 148. Consequently, it should now be apparent that a downward movement of solenoid 138 is resisted by spring 142, that the tension of spring 142 increases and decreases as the speed of shaft 96 and thereby the pressure of the fluid delivered by pump 147, increases and decreases, respectively, that an increase in the power transmitted through line 132 results in a clockwise movement of lever 133, that a decrease in the power transmitted through line 133 results in a counterclockwise movement of lever 133, and that if a change in load, i. e., a change in the power transmitted through line 132, is accompanied by a change in speed, piston 143 moves and modifies the action of solenoid 138. In this connection, the opening movement of bypass valve 118 is preferably limited by means of a suitably arranged stop 135.

When the system is shut down, the manually operated main and auxiliary fuel flow control valves 85 and 89 are closed, fuel valve 94 in pipe 92 is also closed, bypass valve 118 in conduit 117 is partially open, and switch 130 in power line 132 is open. All that has to be done in order to start the system is to energize starting motor 95 (the valve in atmospheric air inlet 120 of main compressor 72 and in branch conduit 125 connecting conduit 98 with the burner portion 81 of primary combustion chamber 79 may be opened to thereby increase the initial supply of combustion supporting elastic fluid to burner 81) and when the unit comprising compressor 72, turbine 73, etc., attains a self-operative speed, open main fuel valve 85 and initiate combustion in primary chamber 79 whereupon operation of starting motor 95 may be terminated. Low pressure turbines 74 and 78 are both developing power due to the passage therethrough of the combustion gases issuing from high pressure turbine 73 and consequently auxiliary compressor 77 is now delivering combustion supporting elastic fluid to the burner portions of primary and reheat combustion chambers 79, 84 and 90. Consequently manually operated fuel flow control valve 89 in pipe 87 can now be opened and combustion initiated in reheat combustion chamber 84. If the valves in atmospheric inlet 120 and branch conduit 125 have been opened, they may be closed either before or after initiating combustion in reheat chamber 84. The system is now operating under idling or no load conditions with the temperature responsive devices 127 and 128 operating to maintain the temperature of the mixture of newly formed and recompressed products of combustion entering high pressure turbine 73 and the temperature of the mixture of newly formed and partially expanded products of combustion entering low pressure turbine 74 substantially constant at values commensurate with optimum thermal efficiency.

As previously indicated, automatically actuated fuel valve 94 is closed and bypass 118 in conduit 117 is partially open to the extent determined by the position of stop 135 which is in turn preferably so located that the flow of motive fluid through low pressure turbine 78 and the power and speed developed thereby is sufficient for stable idling operation and that the system can be started, if desired, without the aid of the valve controlled atmospheric inlet 120 to main compressor 72 and of the valve controlled branch conduit 125 connecting conduit 98 with the burner portion 81 of primary combustion chamber 79. If desired, an auxiliary starting motor 100 on shaft 97 may also be utilized for starting purposes. If it is now desired to carry load, switch 130 in power line 132 is closed whereupon the resulting movement of solenoid 138 is rendered operative to actuate lever 133 in a clockwise direction as the load increases thereby moving bypass valve 118 to its fully closed position and opening fuel valve 94 to increase reheat input to the partially expanded motive fluid entering reheat combustion chamber 90, the maximum temperature of the fluid entering low pressure turbine 78 being limited by temperature responsive device 129. Upon a decrease in load, the combined action of spring 142 and piston 143 moves lever 133 in a counterclockwise direction thereby moving fuel valve 94 toward its fully closed position, and if the decrease in load is sufficient, valve 94 is fully closed and bypass valve 118 is opened until a further opening movement is prevented by stop 135.

Consequently, both the quantity and the temperature of the motive fluid passing through low pressure turbine 78 and thereby its speed and power and the quantity and pressure of the air delivered to the burner portions 81, 86 and 91 of combustion chambers 79, 84 and 90 by auxiliary compressor 77 is varied in accordance with changes in load. i. e., in accordance with power requirements. Moreover, temperature responsive device 127 operates to vary fuel input to primary combustion chamber 79 so as to maintain the temperature of the mixture of newly formed and recompressed products of combustion substantially constant prior to the expansion thereof, and it should therefore be obvious that in general the system of Fig. 2 affords at least all of the advantages present in the system of Fig. 1.

Referring to Fig. 3, it is seen that still another embodiment of the invention may include a main compressor 153, a main turbine 154, an electric generator 156, an auxiliary compressor 157, a low pressure auxiliary compressor turbine 158, a primary combustion chamber 159 having a burner portion 161 to which fuel is supplied from a suitable source (not shown) through a pipe 162 provided with a flow regulating valve 163, and a reheat combustion chamber 164 having a burner portion 166 to which fuel is supplied through a branch pipe 167 provided with a flow regulating valve 168 and a manually operated valve 165. Branch pipe 167 is also provided with an additional flow regulating valve 169 and is connected with pipe 162 on the upstream side of valve 163 whereby the flow of fuel to burner portions 161 and 166 can be severally controlled as desired. Pipe 162 is also provided with a manually operative main control valve 170 disposed in upstream relation with respect to branch pipe 167. A starting motor 171 and the turbine 154 may be drivingly connected with main compressor 153 and generator 156 by any suitable means such as a common shaft 172. Auxiliary turbine 158 may be drivingly connected with compressor 157 by any suitable means such as a common shaft 173.

A conduit 173 which includes a heat exchanging portion 174, connects the discharge of main compressor 153 with the burner end of combustion chamber 159 and a conduit 176, which includes a heat exchanging portion 177, connects the high pressure discharge portion of auxiliary compressor 157 with the burner portion 161 of primary combustion chamber 159. A conduit 178, which includes a heat exchanging portion 179, connects a low pressure discharge portion of auxiliary compressor 157 with the burner portion 166 of reheat combustion chamber 164. A conduit 181 connects the discharge end of primary combustion chamber 159 with the inlet of high pressure turbine 154 and a conduit 182, which includes a heat exchanging portion 183 operatively associated with the heat exchanging portions 174, 177 and 179 of conduits 173, 176 and 178 and a heat exchanging portion 184 operatively associated with a cooling coil 186 having inlet and outlet connections 187 and 188, respectively, connects the exhaust of high pressure turbine 154 with the inlet of main compressor 153. A bleeder conduit 189 connects an intermediate pressure exhaust of high pressure turbine 154 with the burner end of reheat combustion chamber 164 and a conduit 191 connects the discharge of reheat combustion chamber 164 with the inlet of low pressure auxiliary turbine 158. A conduit 192, which includes a heat exchanging portion 193 operatively associated with one or more of the heat exchanging portion 174, 177, 179 of conduits 173, 176 and 178, places the exhaust of low pressure turbine 158 in communication with the atmosphere.

Fuel flow regulating valve 163 is operatively connected with a temperature responsive device 194 which is in turn operatively associated with primary combustion chamber 159, the arrangement of these parts being such that flow regulating valve 163 is positioned to effect compensating changes in fuel input to the burner portion

161 of combustion chamber 159 in order to maintain the temperature of the mixture of newly formed and recompressed products of combustion entering high pressure turbine 154 substantially constant at a selected maximum value commensurate with optimum thermal efficiency. Fuel flow regulating valve 168 is normally maintained in its fully open position and is closed or partially closed in the event the temperature of the reheated mixture of newly formed and partially expanded products of combustion entering turbine 158 exceeds a predetermined maximum by means of a temperature responsive device 196 which is operatively associated with reheat combustion chamber 164 and operatively connected with valve 168 by means including a lost-motion connection 197.

The position of fuel flow regulating valve 169 is controlled by the joint action of speed and load responsive devices operatively associated with shaft 172 and with generator power line 198 which includes a control switch 199, respectively, the control apparatus in this case comprising a lever 201 fulcrumed intermediate its ends and having one end pivotally connected with valve 169, a solenoid 202, which is operatively associated with a coil 203 forming part of the secondary circuit of a current transformer 204 which is in turn operatively associated with power line 198, has one end pivotally connected with the other end of lever 201, a spring 206 having one end also connected with the other end of lever 201 in opposite force-producing relation with respect to solenoid 202 and having its opposite end connected with a speed governor 207 which is in turn operatively associated with shaft 172. The arrangement of these parts is such that a downward movement of solenoid 202 is resisted by spring 206, that the tension of spring 206 increases and decreases as the speed of shaft 172 increases and decreases, respectively, that an increase in the power transmitted through line 198 results in a clockwise movement of lever 201, that a decrease in the power transmitted results in a counterclockwise movement of lever 201, and that if a change in load, i. e., a change in the power transmitted through line 198, is accompanied by a change in the speed of shaft 172, governor 207 modifies the action of solenoid 202.

When the system is shut down, manually operated fuel valves 165 and 170 are closed as is also fuel flow regulating valve 169 and the switch 199 in power line 198 is open. Consequently, all that has to be done in order to start the system is to energize starting motor 171 and bring the main unit comprising compressor 153 and high pressure turbine 154 up to a self-operating speed whereupon manual fuel valve 170 can be opened and combustion initiated in the burner portion 161 of primary combustion chamber 159 which is supplied with combustion supporting air due to the operation of auxiliary compressor 157 effected by the passage of partially expanded gas through low pressure turbine 158, and if desired, by the aid of an auxiliary starting motor 175 on shaft 173. The initiation of combustion increases the energy content of the motive fluid and thereby the power developed by turbines 154 and 158 sufficient for self-operation under no load or idling conditions without the aid of reheat combustion chamber 164, and consequently, the operation of starting motor 171 may be terminated as soon or shortly after combustion has been initiated in primary chamber 159. All that now has to be done in order to condition the system for carrying load is to open manual valve 165 in fuel line 157, which renders governor 207 effective to control fuel input to reheat combustion chamber 164 and thereby the speed of low pressure turbine 158 and auxiliary compressor 157 so as to maintain the speed of the main unit comprising main compressor 153, high pressure turbine 154 and generator 156 substantially constant at a predetermined desired value, and to then close switch 199 in power line 198.

The closure of switch 199 places valve 169 under the joint control of speed governor 207 and load responsive solenoid 202 and consequently the speed of low pressure turbine 158 and of auxiliary compressor 157 will be normally varied in accordance with the speed and power requirements of the main unit. However, if for any reason the temperature of the motive fluid entering low pressure turbine 158 should become excessive, temperature responsive device 196 will effect a closing or partial closing of fuel valve 168. During normal operation, the temperature of the motive fluid entering high pressure turbine 154 will be maintained substantially constant at the maximum value permissible for continuous operation by the action of temperature responsive device 194, and it should therefore be obvious that this system also operates to vary the quantity of compressed, combustion supporting elastic fluid delivered to the burner portion 161 of primary combustion chamber 159 and thereby the mass flow of the mixture of recompressed and newly formed products of combustion in accordance with power requirements, and to substantially simultaneously vary the fuel input to the primary combustion chamber so as to maintain the temperature of such mixture substantially constant prior to its expansion in high pressure turbine 154.

In both the systems shown in Figs. 2 and 3, the compressed, combustion supporting elastic fluid delivered to the reheat combustion chamber or chambers is maintained at a pressure commensurate with the pressure of the partially expanded mixture of newly formed and recompressed products of combustion supplied to such chambers from the high pressure turbine or turbines. Moreover, in all of the systems herein described, the main compressor and power turbine or turbines are operated at a substantially constant speed and temperature, the power developed being varied by changing the mass flow and density of the motive fluid in accordance with changes in load. Consequently, the overall thermal efficiency of the main unit is maintained substantially constant throughout the normal load range, and since the power developed and utilized by the main unit may be as much or more than 0.8 of the total power developed by both the main and auxiliary units, the overall thermal efficiency of the system is materially improved by maintaining conditions conducive to obtaining optimum thermal efficiency for the main unit. In addition, the provision of an auxiliary, makeup compressor unit which operates independently of the main unit with respect to power and speed developed affords better regulation particularly with respect to part load operation and with respect to the handling of rapidly changing loads.

The invention embodies features of general application although of particular advantage when applied to systems embodying apparatus for continuously performing the steps of releasing a portion of the expanded products of combustion, cooling and then recompressing the remaining products of combustion, heating the recompressed products of combustion by combining same with newly formed, highly heated products of combustion obtained by burning fuel in a compressed, combustion supporting elastic fluid either before or after such fluid is partially or wholly mixed with the recompressed products of combustion, and expanding the resulting mixture, and it should therefore be understood that it is not desired to limit the invention to the exact modes of operation and systems herein shown and described for purposes of illustration as various modifications within the scope of the appended claims may occur to persons skilled in the art.

It is claimed and desired to secure by Letters Patent:

1. In a method of developing power by expanding products of combustion incident to conversion of thermal energy into mechanical energy including the continuously performed steps of releasing a portion of the expanded products of combustion, cooling and then recompressing the remaining products of combustion, heating the recompressed products of combustion by combining same with newly formed, highly heated products of combustion obtained by burning fuel in a compressed, combustion supporting elastic fluid before or after such fluid is partially or wholly mixed with the recompressed products of combustion, and expanding the resulting mixture; the improvement comprising the steps of directly varying only the quantity of compressed, combustion supporting elastic fluid and thereby the mass flow of the mixture of recompressed and newly formed products of combustion in accordance with power requirements, and substantially simultaneously varying fuel input so as to maintain the temperature of such mixture prior to the expansion thereof approximately constant throughout the normal range of power development.

2. In a method of developing power by expanding products of combustion incident to conversion of thermal energy into mechanical energy including the continuously performed steps of releasing a portion of the expanded products of combustion, cooling and then recompressing the remaining products of combustion, compressing a combustion supporting elastic fluid, combusting fuel in at least a portion of such fluid, mixing the newly formed products of combustion with the recompressed products of combustion to heat the latter, and expanding the resulting mixture; the improvement comprising the steps of directly varying only the quantity of compressed combustion supporting elastic fluid and thereby the mass flow of the mixture of recompressed and newly formed products of combustion in accordance with changes in power requirements, and substantially simultaneously varying fuel input so as to maintain the temperature of such mixture prior to the expansion thereof approximately constant throughout the normal range of power development.

3. In operating a power developing system embodying a main elastic fluid compressing means, a plurality of turbine means including at least one turbine or turbine section having its exhaust connected with the inlet of the main compressing means and at least another turbine or turbine section exhausting to atmosphere, a driving connection between at least one of the turbines or turbine sections and the main compressing means, a separately driven auxiliary compressing means having its inlet connected with a source of combustion supporting elastic fluid, means for conducting elastic fluid discharged from the main and auxiliary compressing means to all of said turbines, and means for heating the compressed elastic fluid passing into said turbines or turbine sections by combusting fuel in such fluid or a constituent thereof; the method of improving thermal efficiency and accelerating characteristics comprising the steps of directly varying only the speed of the auxiliary compressing means in accordance with changes in power requirements of said turbines, and substantially simultaneously varying the heat input to the compressed elastic fluid so as to maintain the temperature of at least that portion of the fluid entering the turbine or turbine section driving the main compressing means approximately constant prior to the expansion thereof throughout the normal range of power development.

4. In operating a power developing system embodying a main elastic fluid compressing means, a plurality of turbine means including at least one turbine or turbine section having its exhaust connected with the inlet of the main compressing means and at least another turbine or turbine section exhausting to atmosphere, a driving connection between at least one of said turbines or turbine sections and the main compressing means, means for conducting recompressed elastic fluid discharged from the main compressing means to all of said turbines or turbine sections comprising at least one combustion chamber having a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with recompressed elastic fluid, and an auxiliary compressing means mechanically independent of said turbine means and having an inlet connected with a source of combustion supporting elastic fluid and an outlet connected with the burner portion of said combustion chamber; the method of improving thermal efficiency and accelerating characteristics comprising the steps of directly varying only the speed of the auxiliary compressing means in accordance with changes in the power requirements of said turbines, and substantially simultaneously varying the temperature of the newly formed products of combustion and thereby the temperature of the mixture of newly formed products of combustion and recompressed elastic fluid entering said turbines or turbine sections so as to maintain the inlet temperature of such mixture approximately constant prior to the expansion thereof throughout the normal range of power development.

5. In an elastic fluid turbine power system embodying a main elastic fluid compressing means, a plurality of turbine means including at least one turbine means having its exhaust connected with the inlet of said main compressing means and at least another turbine means exhausting to atmosphere, a driving connection between at least one of said turbine means and said main compressing means, means for conducting recompressed elastic fluid discharged from said main compressing means to all of said turbine means comprising at least one combustion chamber including a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with recompressed elastic fluid, an auxiliary compressing means operable separately from the turbine means which is drivingly connected with said main fluid com-

pressing means and having an inlet communicating with a source of combustion supporting elastic fluid and an outlet connected with the burner portion of said combustion chamber, and means for delivering fuel to the burner portion of said combustion chamber means, means for improving thermal efficiency and accelerating characteristics comprising a first control responsive to changes in the excess power being developed by said turbine means for increasing and decreasing the speed of the auxiliary compressing means as the power developed increases and decreases respectively, and a second control responsive to the temperature of the elastic fluid passing into the turbine means for varying fuel input to said burner portion so as to maintain the temperature of the mixture of newly formed products of combustion and recompressed elastic fluid approximately constant prior to the expansion thereof as the power developed varies throughout the normal load range.

6. An elastic fluid turbine power system comprising a main elastic fluid compressing means, a plurality of separately operable turbines including a first turbine having an exhaust portion connected with the inlet of said main compressing means and a second turbine exhausting to atmosphere, a driving connection between said first turbine and said main compressing means, a separate auxiliary compressing means having an inlet communicating with a source of combustion supporting elastic fluid, a driving connection between said second turbine and said auxiliary compressing means, means for conducting recompressed elastic fluid discharged from said main compressing means to said first and second turbines for expansion in succession therein comprising separate combustion chambers respectively disposed in upstream relation to said turbines, said combustion chambers each including a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with recompressed elastic fluid, means for conducting compressed combustion supporting elastic fluid discharged from said auxiliary compressing means to the burner portion of each of said combustion chambers, and means for delivering fuel to the burner portion of each of said combustion chambers, means for improving thermal efficiency and regulating characteristics comprising a first control responsive to changes in the excess power developed by the system for increasing and decreasing the quantity of fuel delivered to the burner portion of the combustion chamber in direct association with said second turbine so as to vary the speed of said auxiliary compressing means as the excess power developed increases and decreases, respectively, and a second control responsive to the temperature of the elastic fluid passing into said first turbine for varying the quantity of fuel delivered to the burner portion of the combustion chamber in direct association with said first turbine so as to maintain the temperature of the mixture of newly formed products of combustion and recompressed elastic fluid entering said first turbine approximately constant as the excess power developed by the system varies throughout the normal range of operation.

7. An elastic fluid turbine power system comprising a main elastic fluid compressing means, a separate auxiliary compressing means having an inlet communicating with a source of combustion supporting elastic fluid, a plurality of first turbine means including at least one turbine or turbine section drivingly connected with said main compressing means, a second turbine means exhausting to atmosphere and operable separately from said first turbine means, a driving connection between said second turbine means and said auxiliary compressing means, means severally connecting the inlet of said main compressing means and the inlet of said second turbine means with exhaust portions of said first turbine means, said connection between said first and second turbine means including a combustion chamber having a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with motive fluid exhausting from said first turbine means, means for conducting recompressed motive fluid discharged from said main compressing means to said first turbine means comprising at least one combustion chamber including a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with recompressed motive fluid, and means connecting relatively high and low pressure discharge portions of said auxiliary compressing means with the burner portions of the combustion chambers supplying motive fluid to the inlets of said first and second turbine means, respectively.

8. An elastic fluid turbine power system comprising a main elastic fluid compressing means, a separate auxiliary compressing means having an inlet communicating with a source of combustion supporting elastic fluid, a plurality of first turbine means including at least one high pressure turbine or turbine section and at least one low pressure turbine or turbine section, a driving connection between at least one of said first turbine means and said main compressing means, a second turbine means exhausting to atmosphere and operable separately from said first turbine means, a driving connection between said second turbine means and said auxiliary compressing means, means connecting the exhaust of said low pressure turbine or turbine section with the inlet of said main compressing means, means severally connecting the inlet of said low pressure turbine or turbine section and the inlet of said second turbine means with an exhaust portion of said high pressure turbine or turbine section, said connection between said high pressure turbine or turbine section and said second turbine means including a combustion chamber having a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with motive fluid exhausting from said high pressure turbine or turbine section, means for conducting recompressed motive fluid discharged from said main compressing means to said first turbine means comprising at least one combustion chamber including a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with recompressed motive fluid, and means connecting relatively high and low pressure discharge portions of said auxiliary compressing means with the burner portions of the combustion chambers associated with said first and said second turbine means, respectively.

9. An elastic fluid turbine power system comprising a main elastic fluid compressing means, a separate auxiliary compressing means having an

inlet communicating with a source of combustion supporting elastic fluid, a plurality of first turbine means including at least one high pressure turbine or turbine section and at least one low pressure turbine or turbine section, a driving connection between at least one of said first turbine means and said main compressing means, a second low pressure turbine means exhausting to atmosphere and operable separately from said first turbine means, a driving connection between said second turbine means and said auxiliary compressing means, means connecting the exhaust of said low pressure turbine or turbine section with the inlet of said main compressing means, means including separate combustion chambers severally connecting the inlet of said low pressure turbine or turbine section and the inlet of said second turbine means with an exhaust portion of said high pressure turbine or turbine section, said separate combustion chambers each having a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with motive fluid exhausting from said high pressure turbine or turbine section, means for conducting recompressed motive fluid discharged from said main compressing means to said high pressure turbine or turbine section comprising at least one combustion chamber including a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with recompressed motive fluid, and means connecting relatively high and low pressure discharge portions of said auxiliary compressing means with the burner portions of the combustion chambers associated with said high and low pressure turbine portions, respectively, of said first and second turbine means.

10. An elastic fluid turbine power system comprising a main elastic fluid compressing means, a high pressure turbine or turbine section, at least two low pressure turbines or turbine sections including at least one turbine or turbine section which exhausts to atmosphere, means connecting the exhaust of at least another one of said low pressure turbines or turbine sections with the inlet of said main compressing means, means including a primary combustion chamber connecting the discharge of said main compressing means with the inlet of said high pressure turbine or turbine section, means including a reheat combustion chamber connecting the exhaust of said high pressure turbine or turbine section with at least said one of said low pressure turbines or turbine sections exhausting to atmosphere, said combustion chambers each including a burner portion adapted to produce newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with the motive fluid delivered thereto, an auxiliary compressing means having

an inlet connected with a source of combustion supporting elastic fluid, and means connecting relatively high and low pressure discharge portions of said auxiliary compressing means with the burner portions of said primary and reheat combustion chambers, respectively.

11. In an elastic fluid turbine power system embodying a main elastic fluid compressing means, a plurality of turbine means including at least one turbine means having its exhaust connected with the inlet of said main compressing means and at least another turbine means exhausting to atmosphere, a driving connection between at least one of said turbine means and said main compressing means, means for conducting recompressed elastic fluid discharged from said main compressing means to all of said turbine means comprising at least one combustion chamber including a burner portion adapted to product newly formed products of combustion and a mixing portion in which newly formed products of combustion are combined with recompressed elastic fluid, an auxiliary compressing means operable separately from the turbine means drivingly connected with said main fluid compressing means and having an inlet communicating with a source of combustion supporting elastic fluid and an outlet connected with the burner portion of said combustion chamber, a separate source of power for driving said auxiliary compressing means, means for delivering fuel to the burner portion of said combustion chamber means, and means for improving thermal efficiency and accelerating characteristics of the system comprising a first control responsive to changes in the excess power being developed by said turbine means for separately controlling said separate source of power to increase and decrease the speed of the auxiliary compressing means as said excess power developed increases and decreases respectively, and a second control responsive to the temperature of the elastic fluid passing into the turbine means for varying fuel input to said burner portion so as to maintain the temperature of the mixture of newly formed products of combustion and recompressed elastic fluid approximately constant prior to the expansion thereof as the power developed varies throughout the normal load range.

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