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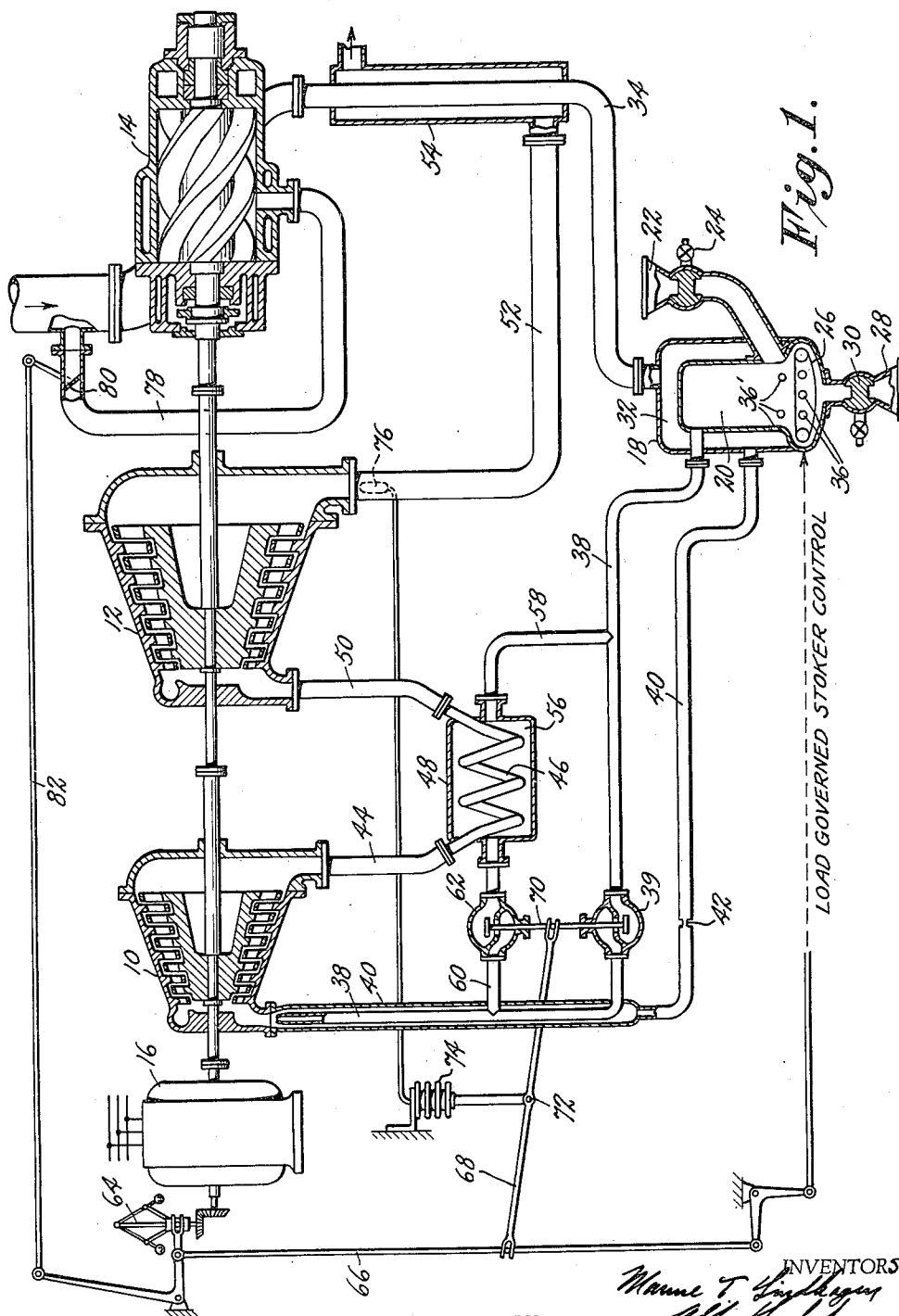
M. T. LINDHAGEN ET AL

2,225,310

GAS TURBINE SYSTEM

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2 Sheets-Sheet 1



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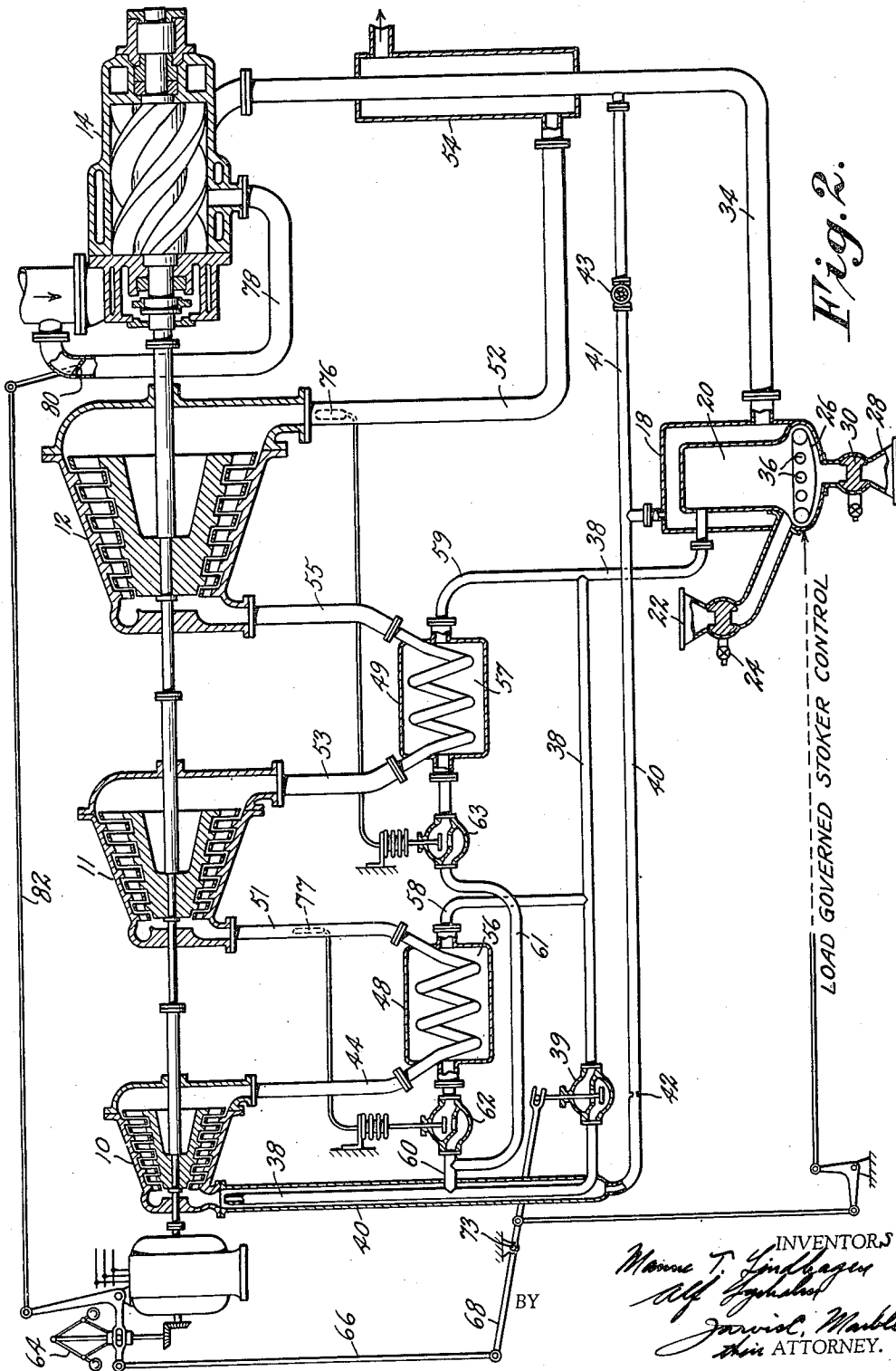
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UNITED STATES PATENT OFFICE

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GAS TURBINE SYSTEM

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The present invention relates to gas turbine systems of the continuous combustion type and has particular reference to systems of this type employing a plurality of turbines or turbine stages arranged serially with respect to flow of motive fluid and employing reheating between the turbines or turbine stages.

In systems of the above described kind, it is disadvantageous from the standpoint of cost and other factors to provide a plurality of combustion chambers for forming or for reheating the gaseous motive fluid and a principal object of the present invention is the provision of a novel gas turbine system and method of operation thereof whereby multiple stage expansion, with reheating, may be employed without requiring a multiplicity of combustion chambers, while at the same time employing only simple apparatus which will permit the system to be operated with high efficiency under variable load conditions.

The manner in which the above general object and other and more detailed objects of the invention are attained and the advantages to be derived from its use may best be understood from the ensuing description of suitable embodiments of apparatus for carrying the invention into effect, illustrated in the accompanying drawings forming a part hereof in which:

Fig. 1 is a more or less diagrammatic view of a gas turbine system illustrative of the invention; and

Fig. 2 is a similar view of another form of such apparatus.

The invention is particularly useful in connection with gas turbine systems of the kind in which the motive fluid is formed in gas producing apparatus from solid fuel, since the nature of such apparatus is such that it would be more expensive to construct a multiplicity of units than combustion chamber apparatus for forming and reheating motive fluid with liquid or gaseous fuels. The invention is consequently illustrated with this type of apparatus for producing motive fluid, but it will be understood that it is not limited to this specific kind of combustion apparatus.

Referring now to the apparatus shown in Fig. 1, the system illustrated includes a high pressure turbine 10, a low pressure turbine 12, an air compressor 14 and a generator 16. The turbines illustrated are of the axial flow type and in the embodiment shown, these turbines, the compressor and the generator are shown connected so as to operate together at the same speed. It will be understood, however, that in so far as the

invention is concerned, the type and arrangement of the turbines and the manner in which the compressor and generator drive is effected by the turbines, may be varied.

Gaseous motive fluid for operation of the turbines is formed in a gas producer indicated generally at 18 and having a combustion chamber 20 to which fuel is admitted through the feed hopper 22 under the control of valve 24. The fuel is burned on grate 26 which in the present instance has been indicated as a traveling chain grate, ashes being removed from time to time through the discharge 28 which is under the control of valve 30.

The chamber 20 is advantageously surrounded by a jacket 32 to which compressed air delivered from compressor 14 through conduit 34 is admitted and from which it may pass to the interior of chamber 20 for combustion purposes through any suitable apertures such as those indicated at 36 in the grate structure, or at 36' above the grate. The combustion chamber 20 is connected by means of conduit 38 with the inlet of the high pressure turbine 10, flow through this conduit being under the control of valve 39. Advantageously, a part of the compressed air from the jacket space 32 is conducted through conduit 40 to the inlet of the turbine for the purpose of sheathing the conduit 38 through which the high temperature gases flow and also for the purpose of reducing the temperature of these gases at the inlet of the turbine to the desired temperature for admission to the turbine in the event the temperature is too high.

For purposes of clarity, the conduit 40 has been shown as sheathing only a portion of conduit 38 but it will be understood that if desired this jacketing with air may be employed for all of the piping conducting the high temperature motive fluid delivered from producer 18. The proportion of the total amount of compressed air employed for this purpose, if it is so used, is relatively small and may advantageously be determined by a restriction in conduit 40 as indicated at 42.

The high pressure turbine exhausts motive fluid through conduit 44 to a coil 46 in a reheating surface type exchanger 48. From this coil motive fluid is delivered through the conduit 50 to the inlet of the low pressure turbine 12 and from the latter the motive fluid is exhausted through conduit 52 to a regenerator 54 through which the delivery conduit 34 leading from the compressor passes.

The casing of the reheating heat exchanger or

reheater 48 provides a chamber 56 to which is admitted a portion of the high temperature motive fluid through conduit 58. The motive fluid discharged from chamber 56 is delivered to the inlet of the high pressure turbine, advantageously by means of a conduit 60 connecting this chamber with the main conduit 38, flow through conduit 60 being under the control of valve 62. It will be evident that the chamber 56 and the conduits 58 and 60 constitute a by-pass with respect to the direct path of flow through conduit 38 from the gas producer to the turbine inlet.

Control of the above described system in order to compensate for variations in load may be effected in numerous different specific ways but for purposes of illustration one advantageous form of control system has been diagrammatically indicated and will now be described.

A governor 64 is provided which is responsive to changes in load on the system, this governor being connected as by means of the linkage consisting of link 66 and lever 68 in a manner such that as the load on the system decreases, valve 38 will be moved toward fully opened position and valve 62 moved toward closed position. These valves may advantageously be directly interconnected as indicated by the link 70 but obviously may be separately controlled.

For purposes which will hereinafter be more fully explained, the lever 68 is advantageously pivoted at 72 about an adjustable fulcrum, the position of which is changed by the action of a bellows 74 or like arrangement which is under the control of a thermostat 76 located in the exhaust conduit of the low pressure turbine.

The gas producer 18 is also under the control of governor 64 and as indicated this control may be effected by any suitable arrangement of known kind for varying the speed of operation of the stoker in accordance with changes in load on the system.

The compressor illustrated is of the rotary screw type, a characteristic of which is that the quantity of air supplied is proportional to the speed of operation. If the system is of the constant speed type, this type of compressor would compress more air than would be required under partial or low load operating conditions, involving among other things loss of efficiency due to unnecessary work of compression. In order to avoid this, the compressor has been shown as provided with a by-pass 78 controlled by valve 80. This valve is connected as by link 82 with the governor so that it will open upon decrease in load on the system, thus by-passing a part of the air entering the compressor before any work of compression has been done thereon.

The operation of the above described system is as follows: Air admitted to compressor 14 and compressed therein is delivered to the gas producer after having been preheated by passage through the regenerator 54. In the gas producer the air is burned with fuel to form hot gaseous products of combustion. A portion of this motive fluid is delivered directly to the high pressure turbine through conduit 38 and a portion is by-passed through the reheater to reheat, by surface heat exchange, the exhaust motive fluid from the high pressure turbine. Advantageously, the temperature of the motive fluid exhausted from turbine 10, which has decreased in temperature during its passage and expansion through this turbine, is reheated in the reheater 48 to approximately the admission temperature of the motive fluid supplied to turbine

10. This reheating to substantially initial inlet temperature may be effected in spite of the fact that there must necessarily be some temperature differential between the temperature of the gas in chamber 56 and the outlet temperature 5 of the reheated gas leaving the coil 46, because of the fact that the admission temperature of the entire motive fluid supply admitted to turbine 10 is less than the temperature of the motive fluid discharged from conduit 58, owing to the admixture in conduit 38 of cooled motive fluid which has passed through the heat exchanger. Also, if jacketing air is employed, this will also tend to produce an initial temperature at the inlet of turbine 10 of lower value than the temperature of the gas delivered from the producer to the heat exchanger.

It will be understood that for normal full load operation of the system, valves 38 and 62 will be set so that the portion of motive fluid by-passed through the reheater will be an amount sufficient to produce the desired reheating effect.

If the load on the system drops, the total quantity of the motive fluid produced will be reduced through reduction of the amount of air and fuel burned in the producer and for such reduced load conditions, the amount of motive fluid by-passed through the heat exchanger will be reduced so as to change the proportion of the total amount produced flowing through the reheater. This will result in a decreased amount of reheating and consequent reduction in temperature of motive fluid flowing to the low pressure turbine.

It is characteristic of gas turbines exhausting to constant back pressure that if they are supplied with motive fluid at substantially constant inlet temperature, the exhaust temperature will rise as the load on the turbine decreases and this rise may cause the exhaust gases to reach dangerous temperatures if the load drops to a small fraction of the normal full load or to idling load.

In order to avoid any possibility of damage to the low pressure turbine because of this operating characteristic, the normal load control of the system is advantageously modified by the apparatus illustrated which is under the control of the thermostat 76. From the drawings, it will be seen that upon rise in exhaust gas temperature, the fulcrum point of the control lever 72 will be moved in a direction tending to close valve 62 and this apparatus is adjusted in such manner that in the event the exhaust gas temperature approaches the dangerous range upon low load operation, valve 62 will be entirely closed so as to cut off all flow of heating fluid through the reheater, with consequent substantial reduction in inlet temperature of motive fluid admitted to turbine 12 so that the dangerous condition of excessive exhaust gas temperature may be avoided.

Referring now to Fig. 2, the system therein illustrated is similar in many respects to the system previously described and like parts have been correspondingly designated.

In the present embodiment, three turbines are employed consisting of the high pressure turbine 10, intermediate pressure turbine 11, and low pressure turbine 12.

Motive fluid delivered to the high pressure turbine through conduit 38 is exhausted therefrom through conduit 44 to the reheater 48 as previously described, the reheated motive fluid being admitted to the inlet of the intermediate pressure turbine 11. A second reheater 49 re-

ceives the motive fluid exhausted from the intermediate pressure turbine through conduit 53 and through conduit 55 delivers reheated motive fluid to the low pressure turbine 12. The latter exhausts through conduit 52 to the regenerator 54 as previously described.

The motive fluid delivered from the gas producer 18 through conduit 38 is as previously described under the control of valve 39 and a certain amount of this fluid is diverted through the by-pass comprising conduits 58, chamber 56, and conduit 60, under the control of valve 62.

For supplying heating fluid to the chamber 57 of reheater 49, a second by-pass is provided which is formed by the conduit 59 leading from the main supply conduit 38 to chamber 57 and the conduit 61 placing the outlet of this chamber in communication with the supply conduit 38, conduit 61 being controlled by valve 62.

For control of air and fuel supplied to the producer, control apparatus similar to that previously described may be employed and has been indicated.

In the apparatus shown, the control is different in some respects from that previously described. Valve 39 is controlled from governor 64 in the same manner as in the preceding embodiment except that in the present instance the fulcrum 73 is fixed and the by-pass controls are independent of the control of this valve.

The thermostat 76 in the low pressure exhaust conduit in this instance controls valve 63, closing this valve upon rise in temperature in the exhaust conduit 52.

Valve 62 controlling flow of heating fluid through the reheater 48 is in this instance under the control of a thermostat 77 which in the illustrated embodiment is located in the conduit 51 leading to the intermediate pressure turbine 11.

Further, in this embodiment a by-pass conduit 41 under control of valve 43 is provided through which, if desired, compressed air may be bypassed directly to conduit 40 without passing through the jacket of the producer 18.

It will be noted that the by-pass for supplying heated fluid to the reheaters 48 and 49 are arranged in parallel so that normally and with the control valves fully opened, which is desirable in order to avoid throttling losses, the pressure drops through these by-passes will be substantially the same and there will normally be supplied therethrough substantially the same amounts of heating fluid.

The manner in which the control of the system operates will be largely evident from the drawings and from the description of the operation of the control for the embodiment shown in Fig. 1. In the present instance the two reheaters are independently controlled and thermostats 76 and 77 and the valves controlled thereby are adjusted so that upon decrease in load on the system to a certain value, reheating of motive fluid flowing to the low pressure turbine is cut out and upon further decrease in load or no load, which would result in increase in the admission temperature of the motive fluid flowing to the intermediate pressure turbine 11, reheating effected in the reheater 48 is cut out.

In both of the previously described embodiments the principle of decreasing the amount of reheating effected upon decrease in load on the system is followed, and from the foregoing it will be evident that the manner in which this is accomplished, in so far as the specific control mechanism employed, may vary widely within the

scope of the invention and it will also be evident that within the principles of the invention, manual control for the various elements may be resorted to.

For clarity of illustration, the expansion of the motive fluid has been indicated as occurring in separate turbine structures between which reheating occurs, but it will be understood that such reheating may equally well be employed between any desired stages of a multiple stage turbine system in which the motive fluid is expanded from its initial to its final pressure in a single multi-stage turbine structure. It is therefore to be understood that as here employed, the term turbine is to be considered as applying generally to separate turbines or turbine stages between which reheating may be effected.

While in compliance with the patent statutes, specific embodiments of apparatus have been described by way of example, it will be readily appreciated by those skilled in the art that many variations in the structures illustrated may be made without departing from the scope of the invention, which is to be understood as embracing all forms of apparatus and modes of operation falling within the scope of the appended claims.

What is claimed is:

1. In the operation of a gas turbine system of the continuous combustion type having multiple stage expansion with reheating of motive fluid between expansion stages, that improvement which includes producing high temperature motive fluid by combustion of fuel, conducting a portion of the motive fluid directly to the inlet of a high pressure turbine of the system for initial expansion, conducting another portion of the motive fluid produced at the same source as the first mentioned portion in heat exchange relation with motive fluid partially expanded in the system to reheat said partially expanded motive fluid for further expansion in the system, thereafter conducting the second mentioned portion of the motive fluid to a high pressure expansion stage in the system for initial expansion therein, and decreasing the quantity of the portion of the motive fluid utilized for reheating as the load on the system drops.

2. In a gas turbine system of the continuous combination type having a high pressure turbine and a low pressure turbine, the improved method of operation which includes forming heated gaseous motive fluid by combustion, conducting a portion of said motive fluid directly to the inlet of the high pressure turbine for expansion therein, by-passing a second portion of said motive fluid in heat exchange relation with motive fluid exhausted from the high pressure turbine to reheat the same prior to further expansion in the system, delivering said second portion to the inlet of the high pressure turbine for initial expansion therein, reducing the quantity of said second portion upon decrease in load on the system and entirely eliminating reheating of motive fluid supplied to the low pressure turbine when the load on the system drops below a predetermined value.

3. In a gas turbine system of the continuous combustion type having a high pressure turbine and a low pressure turbine, the improved method of operation which includes forming at a single source heated gaseous motive fluid by combustion of solid fuel with air compressed in the system, conducting a portion of the motive fluid directly from said source to the inlet of a high pressure

turbine for initial expansion in the system, by-passing a second portion of said motive fluid in heat exchange relation with motive fluid exhausted at an intermediate pressure to reheat the same prior to further expansion in the system, delivering said second portion to the inlet of a high pressure turbine for initial expansion in the system, and controlling the system in response to variations in load thereon by decreasing the quantity of motive fluid by-passed upon decrease in the load on the system.

4. In a gas turbine of the continuous combustion type having a high pressure turbine, an intermediate pressure turbine and a low pressure turbine, the improved method of operation which includes forming heated gaseous motive fluid by combustion at a single source, conducting a first portion of said motive fluid directly from said source to the inlet of the high pressure turbine for expansion therein, by-passing a second portion of said motive fluid in heat exchange relation with fluid exhausted from the high pressure turbine to reheat the same for expansion in the intermediate pressure turbine, delivering said second portion to the inlet of the high pressure turbine for expansion therein, by-passing a third portion of said motive fluid in heat exchange relation with fluid exhausted from the intermediate pressure turbine to reheat the same for expansion in the low pressure turbine, delivering said third portion to the inlet of the high pressure turbine for expansion therein and controlling the system in response to variations in load by first reducing the quantity of said third portion of motive fluid as the load decreases and then decreasing the quantity of said second portion of motive fluid as the load further decreases.

5. In a gas turbine system of the continuous combustion type, a plurality of turbines including a high pressure turbine and a low pressure turbine arranged for serial expansion of motive fluid, compressor means, means providing a combustion chamber for forming gaseous motive fluid, means for conducting air from said compressor means to said combustion chamber, means for conducting motive fluid directly from said cham-

ber to the inlet of the high pressure turbine, a surface type heat exchanger, means for conducting motive fluid exhausted from the high pressure turbine to said heat exchanger, means for by-passing a second portion of said motive fluid from said combustion chamber through said heat exchanger to the inlet of the high pressure turbine whereby to reheat the motive fluid exhausted from the high pressure turbine, and means for controlling the quantity of motive fluid by-passed through said heat exchanger.

6. In a gas turbine system of the continuous combustion type, a plurality of turbines including a high pressure turbine, an intermediate stage turbine, and a low pressure turbine, means providing for serial flow of motive fluid through said turbines, said means including a plurality of surface type reheaters, a compressor, means providing a combustion chamber for forming motive fluid with air from said compressor, means for conducting a portion of said motive fluid directly from the combustion chamber to the inlet of the high pressure turbine, means for by-passing motive fluid from said chamber through said reheaters to the inlet of the high pressure turbine and means for controlling the flow of the by-passed motive fluid.

7. In a gas turbine system of the continuous combustion type, a plurality of turbines including a high pressure turbine, an intermediate stage turbine, and a low pressure turbine, means providing for serial flow of motive fluid through said turbine, said means including a plurality of surface type reheaters, a compressor, means providing a combustion chamber for forming motive fluid with air from said compressor, means for conducting a portion of said motive fluid directly from the combustion chamber to the inlet of the high pressure turbine, means for separately by-passing different portions of said motive fluid in separate streams respectively through said reheaters and in parallel between said chamber and the inlet of the high pressure turbine, and means for separately controlling the quantities of motive fluid by-passed through the different reheaters.

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