Nov. 10, 1959 J. M. BAKER 2,911,789

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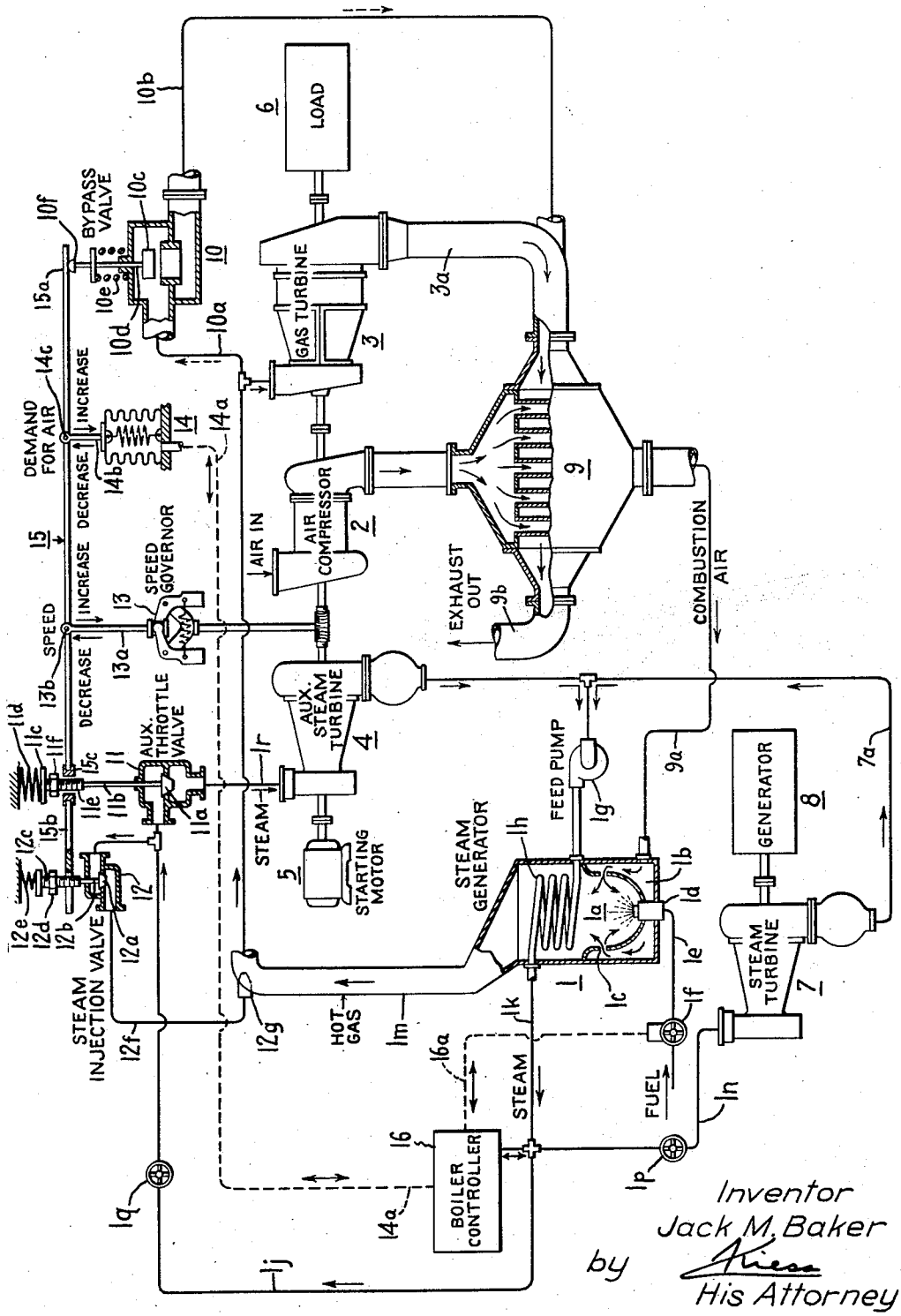
Filed Aug. 27, 1958



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United States Patent Office

2,911,789
Patented Nov. 10, 1959

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REGULATING SYSTEM FOR STEAM-GAS TURBINE POWERPLANT

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Application August 27, 1958, Serial No. 757,487

7 Claims. (Cl. 60—39.18)

This invention relates to steam generating plants, particularly to a plant of the so-called "Velox-boiler" type in which the combustion space is supercharged by a compressor driven by a gas turbine, the motive fluid for which is the hot gases discharged from the combustion space. The invention particularly relates to an improved regulating system for a steam generating plant of this type.

Many years ago, the development of the "Velox-boiler" demonstrated the advantages of a steam generator having a pressurized combustion system. These advantages include improved thermal efficiency due to the increased effectiveness of the heat transfer from the high density hot gases in the combustion space, the very substantially reduced size required for the combustion space, and the reduction in total size, weight, and capital investment required for a steam generating plant of given capacity. Successful commercial exploitation of a steam generating plant of this type depends in large part on a practicable solution to the problem of properly coordinating the air flow requirements of the combustion chamber with the motive fluid requirements of the gas turbine which drives the supercharging compressor, particularly during the starting cycle and during transition periods of significant load change. The gas turbine is ordinarily directly connected to the compressor rotor, which will usually be of the axial flow type, having a substantial number of stages. The result is that the compressor-turbine rotor has a very substantial rotational inertia, rendering it rather insensitive to rapid changes in motive fluid flow. That is, if the boiler suddenly requires a substantially increased rate of combustion air supply, it requires a significant time interval for the increased flow of motive fluid to the turbine to accelerate the compressor-turbine rotor to the new speed required to supply the air called for. In certain ranges of operation, the hot gas discharged from the supercharged combustion space may be inadequate to provide the gas turbine with sufficient available energy to drive the compressor at the new speed called for. Conversely, when the boiler experiences a suddenly reduced load, the rotational inertia of the compressor-turbine rotor will tend to maintain the rate of air supply constant, although the boiler controls will cause a sudden reduction of fuel supply, with a consequent reduction in the temperature of the gases discharged from the combustion chamber and a resultant decrease in energy available to the gas turbine. The net result is an inherent "sluggishness" in response of this type of powerplant to changes in load output.

Accordingly, an object of the present invention is to provide an improved steam generating plant of the supercharged boiler type having auxiliary motor means to assist in starting and accelerating the compressor rotor to obtain quick response and to provide extra power needed when the energy available to the gas turbine is insufficient to generate the power required by the compressor.

Another object is to provide a supercharged boiler plant of the type described with improved means for coordinating the control of the boiler air requirements with

the energy made available to the gas turbine and that required from the auxiliary motor means.

A still further object is to provide a supercharged boiler plant specially adapted for service as a marine powerplant and capable of rapid change in load as required in maneuvering a ship around port.

A still further object is to provide an improved regulating system for a supercharged boiler plant in which a single speed governor effectively controls both the power output of the gas turbine and the power required from the auxiliary prime mover means.

Other objects and advantages will become apparent from the following description taken in connection with the accompanying drawing in which the single figure represents diagrammatically a supercharged boiler plant having an improved regulating system in accordance with the invention.

Generally stated, the invention is practiced by providing a governor responsive to compressor speed and a controller producing a signal representing the steam generator's demand for combustion air, which jointly operate to position a bypass valve which diverts a variable amount of hot gas from the gas turbine and an auxiliary control device which varies the energy supplied to an auxiliary prime mover for furnishing extra power when the energy available to the gas turbine is insufficient to supply the demand for air.

Referring now more particularly to the drawing, the invention is shown as applied to a supercharged boiler type steam generator shown generally at 1, supplied with air from a "supercharging compressor" 2 driven by a gas turbine 3. The auxiliary prime mover is represented by the steam turbine 4, which is also connected to directly drive the air compressor 2. For starting, an additional means shown as an electric motor 5 may also be coupled to the turbine-compressor rotor. A suitable load device, shown at 6, may be used to absorb any excess power developed by the gas turbine 3, steam turbine 4 combination when the thermodynamic cycle of the powerplant justifies its installation.

The steam generator 1 supplies a principal consumer, represented by the steam turbine 7, connected to a load device such as the generator 8, the output of which represents the primary "end product" of the powerplant.

The steam generator 1 comprises a combustion space 1*a* supplied with air under pressure from a plenum chamber 1*b* by way of a plurality of air inlet ports 1*c*. A suitable fuel is injected by nozzle 1*d* supplied through conduit 1*e* containing suitable fuel control valve means 1*f*, which is controlled by a signal from the boiler controller 16, by way of conduit 16*a*. Water is supplied by the feed pump 1*g* to appropriate heating coils 1*h*. The steam is discharged through conduit 1*k*. Conduit 1*n* delivers motive fluid to the steam turbine 7, at a rate determined by the stop and throttle valve gear of this turbine, represented diagrammatically by the valve means 1*p*. Condensate from turbine 7 is returned to the boiler feed pump 1*g* by conduit 7*a*.

The air compressor 2 takes in air from the ambient atmosphere and delivers it under pressure to the regenerator or air preheater 9. Conduit 9*a* delivers combustion air to the plenum chamber 1*b* of the steam generator 1. The hot gases discharged from the steam generator through the discharge conduit 1*m* are delivered to the inlet of the gas turbine 3. The still hot motive fluid exhausted from gas turbine 3 is delivered by conduit 3*a* to the preheater 9 and then discharged to atmosphere through the stack 9*b*.

The energy made available to the gas turbine 3 is regulated by diverting a variable amount of the hot gas from conduit 1*m* through a bypass conduit 10*a* to the bypass valve 10. So as to conserve the energy in the hot

fluid bypassed by valve **10**, it may be returned by way of conduit **10***b* to the gas turbine exhaust conduit **3***a* so that the energy thereof will be recovered in the air preheater **9**.

Steam is supplied to the auxiliary prime mover **4** by conduit **1***j* which contains a suitable stop valve **1***q*. From conduit **1***j*, steam is conveyed to the inlet of the auxiliary steam turbine **4** by way of conduit **1***r*, as controlled by the auxiliary throttle valve **11**.

For supplying an additional increment of available energy to the turbines driving the air compressor, an additional steam injection valve **12** is disposed in conduit **12***f* which communicates from conduit **1***j* and discharges steam into the hot gas conduit **1***m*, as for instance by a suitable nozzle **12***g*. This injected steam adds to the weight flow of hot motive fluid supplied to the gas turbine **3** and thereby increases the energy made available thereto.

In accordance with the invention, integrated control of the bypass valve **10**, the auxiliary throttle valve **11**, and the steam injection valve **12** is effected by only two condition-responsive devices, namely the single speed governor **13**, and a combustion air demand-responsive device, represented as a bellows **14** supplied with a pressure signal by way of conduit **14***a* from the boiler controller **16**. The nature of the boiler control **16** need not be described here since this is a conventional device which senses the temperature and/or pressure of the steam in conduit **1***k* and delivers an appropriate pressure signal to conduit **14***a* similar to the signal sent to fuel valve **1***f* previously described. For example, if steam pressure is the condition measured, increased demand for steam by steam turbine **7** will cause the pressure to fall. This represents an immediate demand for increased air to the combustion chamber in order to increase the heat supplied to the steam coils **1***h*. The signals for air and fuel may be coordinated to maintain a given fuel-air ratio. As indicated by the legend in the drawing, an increase in the pressure signal supplied to bellows **14** represents a decrease in demand for combustion air while a reduction in this pressure signal corresponds to an increase required in the air flow. The speed governor **13** is driven at a speed proportional to that of the air compressor rotor, and is arranged to position its output rod **13***a* upwardly upon a decrease in speed and downwardly with an increase in speed. Although conditions other than those of the steam in conduit **1***k* could be sensed to give a signal representing the demand for air, such as the temperature in combustion chamber **1***a*, the embodiment shown is preferable as it rapidly senses an increase in demand for air.

The details of the control valves **10**, **11**, **12** will now be noted more particularly.

The bypass valve **10** has a fluid control disk member **10***c* carried on rod **10***d* and biased upwardly by a coil spring **10***e*. At its upper end, rod **10***d* has an abutment member **10***f* adapted to be engaged by the main control lever **15** in a manner described more particularly in connection with the method of operation. The air demand control rod **14***b* is pivoted to the lever **15** at **14***c*, and the speed governor control rod **13***a* is pivoted to the lever **15** at **13***b*.

The auxiliary throttle valve **11** and steam injection valve **12** are both arranged to be actuated by the left-hand end portion **15***b* of the main control lever **15**.

The auxiliary throttle valve **11** has a flow control member **11***a* carried on rod **11***b*, the upper end of which is provided with an abutment member **11***c* biased downwardly by spring **11***d*. The upper end portion of rod **11***b* is provided with a threaded portion **11***e* on which is an adjustable abutment member **11***f* adapted to be engaged by an abutment ring member **15***c* which is formed integral with the lever **15**. It is to be understood that the rod **11***b* and the threaded portion **11***e* project freely through the abutment ring **15***c* for all positions of the lever **15**. With this arrangement, the abutment ring member **15***c* engages the adjustable abutment **11***f* so as to raise the valve stem **11***b* only after the left-hand end portion **15***b* of the lever has moved upwardly a preselected amount, determined by the adjustment of abutment **11***f*.

Likewise, the steam injection valve **12** has a flow control member **12***a* carried on a stem **12***b* which has a threaded portion **12***c* carrying an adjustable abutment **12***d*. The valve stem is biased downwardly by a coil spring **12***e*. The forked end portion of lever **15***b* is adapted to engage the abutment **12***d* so as to raise the valve stem **12***b* only after the lever portion **15***b* has moved upwardly a preselected distance, determined by the adjustment of abutment **12***d*. It will be observed that, as shown in the drawing, upward movement of the lever portion **15***b* will result first in opening the auxiliary throttle valve **11** and subsequently open the steam injection valve **12**.

Thus it will be seen that an exceedingly simple interconnecting linkage is employed to connect the two condition-responsive devices **13**, **14** so as to position the three motive fluid control valves **10**, **11**, **12**. The method in which this operation is effected will be seen from the following description of the method of operation.

To start the powerplant, the electric motor **5** is energized to turn the air compressor **2** at the speed necessary to furnish the combustion air required for initiating combustion in the steam generator **1**. When the air supply is adequate, the fuel control valve **1***f* is actuated to admit fuel, and a suitable sparking device (not shown) ignites the fuel-air mixture. As the combustion rate increases, the feedwater supplied by pump **1***g* is vaporized and the steam pressure in conduit **1***k* rises to the rated value which is established by the requirements of the principal consumer steam turbine **7**, for example, 1450 p.s.i.g.—950° F. When sufficient steam pressure and temperature is available, the boiler operator manually initiates acceleration of the unit through the boiler controller **16** by calling for an increase in combustion air flow. This decreases the pressure signal delivered to bellows **14**, causing the pivot **14***c* to descend in the "increase air" direction. Lever **15** pivots clockwise about the point **13***b* so that bypass valve **10** is closed, and the abutment **15***c* engages the adjustable abutment **11***f* and opens the auxiliary throttle valve **11**, so as to admit steam to the turbine **4**. The auxiliary steam turbine now drives the air compressor, and the electric starting motor **5** may be de-energized, or disengaged by suitable clutch means (not shown). By way of example, it may be noted that the starting motor **5** may be designed to drive the compressor at about 10% of rated speed, which is found adequate to furnish the air required to initiate combustion in the steam generator **1**. The auxiliary steam turbine **4** now brings the air compressor **2** up to the desired speed, as determined by the characteristics of speed governor **13** and the "speed setting" demand for air established by the position of pivot **14***c*. Increasing speed of the governor **13** causes the pivot **13***b* to descend so as to partly close the steam throttle valve **11**. The governor **13** will now control the steam valve **11** to keep the compressor speed at the value determined by the setting of the "air demand pivot" **14***c*.

If now the boiler controller **16** calls for a greater air supply, as occasioned for instance by opening the valve **1***p* to admit steam to the consumer **7**, the pressure signal supplied to bellows **14** will cause the pivot point **14***c* to descend still further to a new speed setting and open the steam valve **11** wider. This increases the speed of compressor **2**, and the resulting increased flow of hot gases to the gas turbine **3** will decrease the power required from the auxiliary steam turbine **4**; and any tendency of the compressor rotor to rise above the speed setting determined by the position of pivot **14***c* will cause the speed governor **13** to move the pivot **13***b* downwardly so as to close steam valve **11**. If valve **11** closes completely, and the speed governor **13** is still calling for a decrease in speed, further downward movement of pivot **13***b* will cause lever **15** to pivot counter-clockwise about point **14***c* so the right-hand portion **15***a* of lever **15** rises and spring

10e moves valve stem 10d upwardly and opens the bypass valve disk member 10c. This permits some of the hot gas to be diverted from the gas turbine 3 through the bypass conduit 10b. This diverted flow is discharged into the exhaust conduit 3a so that the thermal energy of this gas is not wasted but is recovered in heat exchanger 9.

Thus the bypass valve 10 acts to control the gas turbine 3 when the power output thereof is sufficient that no power is required from the auxiliary prime mover 4, and the demand for air from the boiler controller 16 is such that the hot gas generated is in excess of that required to drive the compressor 2. This will be the "normal operating condition," with the bypass valve 10 controlling the gas turbine 3 and the auxiliary steam turbine 4 inactive. It is, of course, possible to provide an overrunning clutch (not shown) between the auxiliary steam turbine 4 and the air compressor 2 so that the starting motor and auxiliary steam turbine are mechanically disengaged from the compressor shaft except when they are delivering torque to the compressor rotor.

The plant is now operating at normal "cruising" condition. If a sudden demand is made on the plant for maximum delivery of steam to the turbine 7, the boiler controller 16 quickly delivers an "increase air signal," which is also an "increase speed" setting, to the bellows 14, causing the pivot 14c to descend rapidly. The resulting clockwise rotation of lever 15 about pivot 13b causes the bypass valve 10 to close, and the auxiliary steam valve 11 to open. If the power now delivered to the air compressor is still not adequate to supply the demand for air (with valve 11 wide open), the bellows 14 continues to pull down on pivot 14c and lever 15 pivots further about the point 13b so the left-hand end 15b of the lever engages the adjustable abutment 12d and opens the steam injection valve 12. This admits steam to conduit 1m, and this additional weight flow of hot motive fluid furnishes the additional energy to the gas turbine required to accelerate the unit to supply the air demand called for.

Thus in the event of a transient call for maximum air flow, the throttle valve 11 and the steam injection valve 12 cooperate to increase the flow of motive fluid to the steam and gas turbines so as to provide the compressor power required. When this transient demand is satisfied, the speed governor 13 causes pivot 13b to descend, causing lever 15 to pivot counterclockwise about point 14c. This first closes the steam injection valve 12, then progressively closes the auxiliary throttle valve 11, and finally returns the plant to the normal condition in which the bypass valve 10 is partly opened and controlling the gas turbine, which again furnishes the entire power for driving the compressor at the new steady-state condition.

Conversely, when the boiler controller 16 calls for a reduction in air flow, which means a reduction in speed of the compressor, the bellows 14 will cause the pivot 14c to rise, opening the gas turbine bypass valve 10, without any effect on the auxiliary valve 11 and steam injection valve 12 since the left-hand end of lever 15 merely moves downwardly away from the abutments 11f, 12d. If the cycle is thermodynamically "self-sustaining" at this reduced air flow, the gas turbine bypass valve 10 will remain open sufficiently to maintain the energy balance and drive the gas turbine 3 at the new speed called for by the air demand bellows 14. If, however, the cycle is not now self-sustaining, the gas turbine rotor will decelerate, with the result that speed governor 13 will cause pivot 13b to rise, tending to close the gas turbine bypass valve 10 so as to increase the energy available to the gas turbine. If, with the entire flow of hot gas from conduit 1m going to the gas turbine 3, the power output is still not sufficient to drive the air compressor, the continuing decrease in speed will cause pivot 13b to rise so that the auxiliary steam valve 11 is progressively opened until the combined output of the steam turbine 4 and the gas turbine 3 satisfy the energy requirements of the air compressor 2.

It will, of course, be appreciated that the regulating system will include suitable emergency overspeed trip governors and other safety devices which are conventional and not necessary to an understanding of the present invention. Accordingly, these conventional components are not shown in the drawings.

It will be seen that the invention provides a very simple regulating mechanism employing only a single speed governor and a single air demand responsive device coordinated in a simple but effective manner for controlling the energy made available to the gas turbine and for supplying additional power from an auxiliary prime mover when the flow of hot gas to the turbine 3 is insufficient to furnish the compressor power requirements. The arrangement provides maximum flexibility of operation of the supercharged steam generator, rendering it extremely responsive to calls for sudden changes in air flow, making possible rapid acceleration and deceleration as required for maneuvering in a marine powerplant. Thus the invention helps to overcome the inherent sluggishness of the "supercharged boiler" type of steam generator, giving it such flexibility as to make it readily adaptable for marine propulsion as well as for supplying steam for power generation or industrial process purposes.

While this invention has been illustrated specifically as applied to a steam generating plant with a supercharged combustion chamber, it will be obvious to those skilled in the art that the regulating system may be used in any industrial process where there is a demand for air, and in which heat is added either by the process or by combustion before the air enters the gas turbine, and a separate source of energy is available for the auxiliary prime mover. It will also be obvious that the regulating system may be used in other powerplants where the power requirements of load device 6 and the air compressor 2 may be at times greater than the gas turbine 3 can produce alone, and a separate auxiliary prime mover is provided to supply the extra power required.

While only one preferred embodiment of the invention has been illustrated specifically herein, it will be obvious to those skilled in the art that many modifications and substitutions of equivalents may be made without departing from the invention. The components illustrated in the drawing are of course intended to be purely diagrammatic and may take many alternate forms. Instead of having the lever 15 act directly to operate the bypass valve 10, the steam valve 11, and the steam injection valve 12, it will be appreciated that suitable power amplifying means such as electric, pneumatic, or hydraulic servo-mechanisms could be employed to furnish the mechanical power required to position these valves. It will also be obvious that the electric starting motor 5 may be dispensed with if an auxiliary source of steam other than the steam generator 1 is available to furnish steam to turbine 4 so that it can also serve as the starting motor. Likewise, the auxiliary prime mover 4 could take the form of an electric motor, diesel engine, etc.

It is, of course, intended to cover by the appended claims all such modifications as fall within the true spirit and scope of the invention.

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

1. Regulating means for use in a combined steam generating and gas turbine powerplant having a steam generator including a supercharged combustion chamber, an air compressor connected to supply combustion air under pressure to the combustion chamber, a gas turbine connected to drive the compressor and to be driven by hot gas discharged from the combustion chamber, and auxiliary motor means also connected to drive the compressor, the regulating means comprising speed governor means responsive to compressor speed, bypass valve means connected to divert from the gas turbine a portion of the total flow of hot gas discharged from the combustion chamber, first means connected to said bypass valve means

to control the supply of motive fluid to the gas turbine as a function of combustion air required by the steam generator, second means connected to control said auxiliary motor means to supply additional power to the compressor when gas turbine power is inadequate to furnish the air flow required by the steam generator and to accelerate the compressor to secure desired rate of response upon change in load, and linkage means interconnecting the speed governor with said first bypass valve control means and said second auxiliary motor control means to first progressively close the bypass valve means and then to regulate said auxiliary motor means to increase the power output thereof, upon demand for increased air flow to the steam generator.

2. Regulating means for a combined steam-gas turbine powerplant having a steam generator with a pressurized combustion chamber, an air compressor connected to supply combustion air under pressure to the combustion chamber, a gas turbine driving the compressor and driven by hot gas discharged from the combustion chamber, and at least one auxiliary motor means also connected to drive the compressor when the gas turbine power is insufficient to supply the air demands of the steam generator, the regulating means comprising speed governor means responsive to compressor speed, bypass valve means connected to divert from the gas turbine inlet conduit a portion of the total hot gas discharged from the combustion chamber to vary the motive fluid input to the gas turbine, first control means connected to said bypass valve to control the supply of motive fluid to the gas turbine as a function of combustion air required by the steam generator, second control means connected to vary the power output of said auxiliary motor means to regulate the supply of additional power to the compressor when gas turbine power is insufficient to furnish the air flow required by the steam generator, a steam injection valve connected to supply steam to the gas turbine inlet, and linkage means interconnecting the speed governor with said bypass valve control means and said second control means and said steam injection valve to first progressively close the bypass valve means and then to increase the power output of said auxiliary motor means and then to open said steam injection valve progressively as the demand for air from the compressor increases.

3. In a combined steam-gas turbine powerplant, the combination of a steam generator having a supercharged combustion chamber, a compressor connected to supply air under pressure to the combustion chamber, a gas turbine connected to drive the compressor and to be driven by hot gas discharged from the combustion chamber, variable power output auxiliary motor means also connected to drive the compressor, boiler control means connected to emit a signal as a function of load on the steam generator, and regulating means comprising speed governor means responsive to compressor speed, bypass valve means connected to divert hot gas from the gas turbine inlet to vary the motive fluid supply to the gas turbine, a main control lever member, first control means connected to position said lever member in accordance with the signal from the boiler control means, second control means connected to position a spaced portion of said lever member in accordance with compressor shaft speed, said lever member having a first portion disposed to regulate said bypass valve means to control the supply of hot gas to the gas turbine to keep compressor speed constant at a value determined by said first control means, said lever member having a second spaced portion connected to adjust the power output of said auxiliary motor means, said control lever being connected to first close the bypass valve upon a demand for increased load, and then to increase the power output of the auxiliary motor means.

4. Steam-gas turbine powerplant in accordance with claim 3 and including variable means for injecting steam under pressure into the gas turbine inlet, the main control lever member having also a portion adapted to control said variable steam injection means to supply steam to the gas turbine to increase the power output thereof after the bypass valve is completely closed and the auxiliary motor means is delivering maximum power.

5. Steam-gas turbine powerplant in accordance with claim 3 and including air-preheater means for transferring heat from the exhaust gas discharged from the gas turbine to the compressed air discharged from the compressor, and conduit means for discharging the diverted hot gas from the bypass valve to the air-preheater whereby the thermal energy of the bypassed gas is transferred to the heated air supplied to the combustion chamber.

6. Regulating means for use with a gas turbine powerplant having a compressor connected to supply gas under pressure to a heating device, a gas turbine connected to drive the compressor and to be driven by hot gas discharged from the heating device, and auxiliary motor means also connected to drive the compressor, the regulating means comprising speed governor means responsive to compressor speed, first valve means connected to control the quantity of hot gas discharged from the heating device to the gas turbine, second means connected to said first valve means to control the supply of hot gas to the gas turbine as a function of desired rate of gas flow to the heating device, third means connected to control the auxiliary motor means to supply additional power when the output of the gas turbine is insufficient to drive the compressor, and linkage means connecting the speed governor with said second control means and with said third auxiliary motor control means to progressively regulate the first valve means and then to regulate the third control means to increase the power output of the auxiliary motor means, upon demand for increased gas flow to the heating device.

7. Regulating means for use with a gas turbine powerplant having a compressor connected to supply gas under pressure to a heating device, a gas turbine connected to drive the compressor and to be driven by hot gas discharged from the heating device, load means utilizing a portion of the energy in said compressed gas, and auxiliary motor means also connected to drive the compressor, the regulating means comprising speed governor means responsive to compressor speed, first means connected to control the available thermal energy of the hot gas discharged from the heating device to the gas turbine, second means connected to said first means to control the available thermal energy supplied to the gas turbine as a function of the load on said load means, third means connected to control the auxiliary motor means to supply additional power when the output of the gas turbine is insufficient to drive the compressor, and linkage means connecting the speed governor with said second control means and with said third auxiliary motor control means to progressively regulate the first control means and then to regulate the third control means to increase the power output of the auxiliary motor means, upon increased load on the load means.

No references cited.