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[54] **CONTROL SYSTEM FOR A GAS-TURBINE INSTALLATION**

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[58] **Field of Search**...60/39.3, 39.12, 39.18 B, 39.14, 60/39.25

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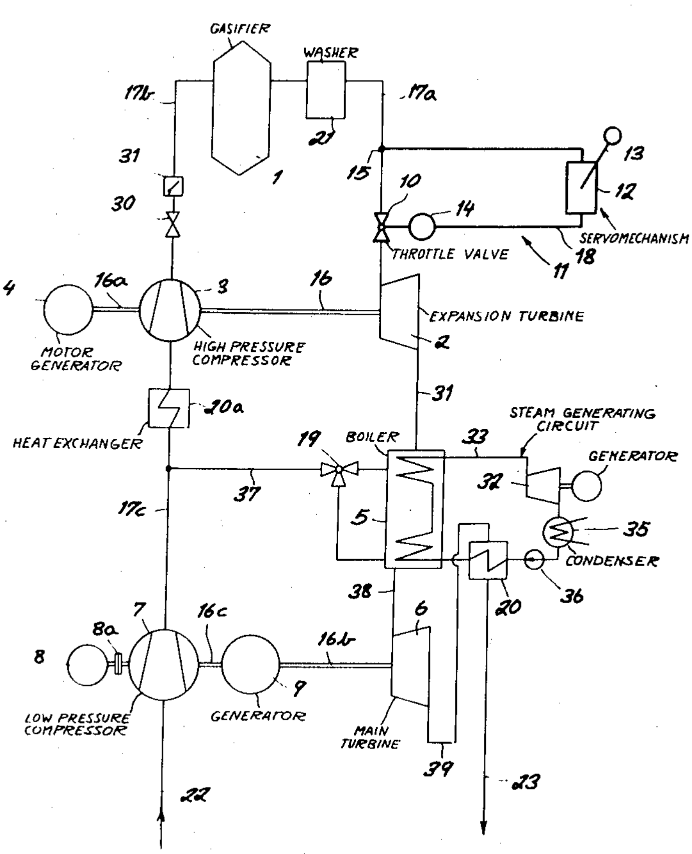
[57] **ABSTRACT**

A gas-turbine electricity-generating installation has a pressurized-air fuel (coal) gasifier for producing a high-pressure combustible gas which drives a high-pressure turbocompressor, the low-pressure combustible gases emerging from this turbocompressor being delivered to a boiler for driving a steam-generating circuit. The turbogenerator supplies compressed air to the gasifier and is, in turn, fed with low-pressure compressed air from a low-pressure turbocompressor driven by the exhaust gases emerging from the boiler. The control system comprises a regulating valve between the gasifier and the gas-inlet to the turbine of the high-pressure turbocompressor which is responsive to the output pressure at the gasifier to maintain the same substantially constant.

5 Claims, 1 Drawing Figure



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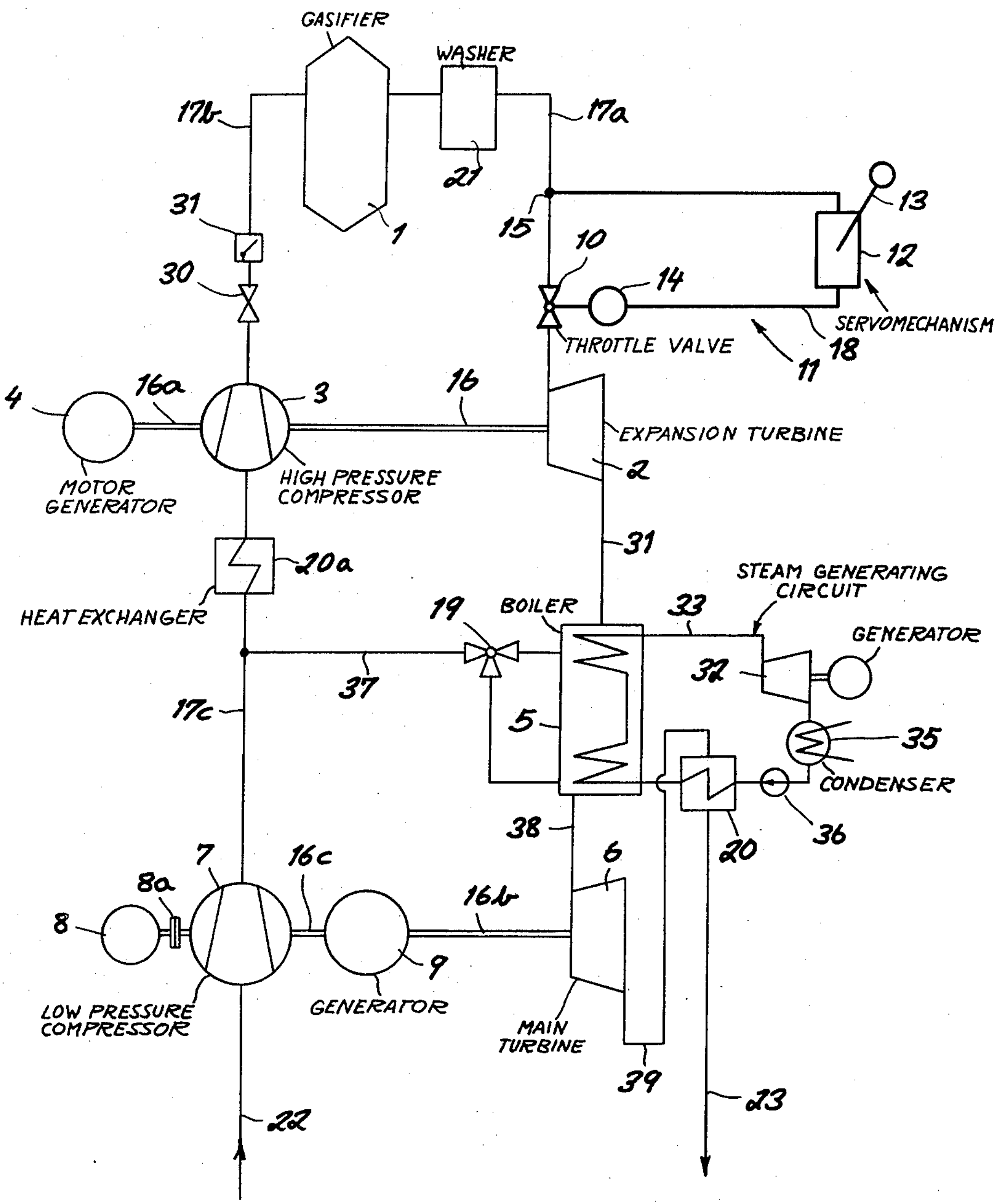

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CONTROL SYSTEM FOR A GAS-TURBINE INSTALLATION

FIELD OF THE INVENTION

Our present invention relates to a gas-turbine installation, especially for the generation of electricity and, more particularly, to a control system for such an installation.

BACKGROUND OF THE INVENTION

It has been proposed heretofore to provide gas-turbine installations in which a turbocompressor generates compressed air for supplying a gasifier or combustor, the output of which is used, in turn, to supply the generator turbine or compressor turbine to which the generator is coupled. It has also been proposed to use the gas to operate a steam-generating cycle in which, for example, steam is produced in a boiler by combustion of the gas and is used to operate a steam-driven turbine which is coupled, in turn, to a generator.

A major problem arising in connection with such installations is the control of the process where countervailing forces are involved. For example, the pressure in the gasifier should be approximately 20 atmospheres if gasification is to proceed efficiently. However, when the combustible gas is to be introduced into the boiler, it should have a pressure of at most 10 atmospheres. Conventional control systems have involved a modification of the operation of the compressors and a reduction of the pressure at the gasifier in an effort to limit the pressure developing at the boiler or bypass or like arrangements at the input to the boiler ro relieve excessive pressures. These have provided to be inefficient and insufficient.

OBJECTS OF THE INVENTION

It is the principal object of the present invention to provide an improved plant for the generation of electrical energy using gas-turbine principles.

It is another object of the invention to provide an improved gas-turbine installation operating with greater efficiency than earlier systems.

Another object of the invention is to provide an improved control system for a gas-turbine installation.

SUMMARY OF THE INVENTION

These objects and others which will become apparent hereinafter are attained in accordance with the present invention, with a gas-turbine installation which comprises a fuel gasifier (coal gasifier) operating at elevated pressure and supplied with compressed air from a high-pressure compressor driven by a respective turbine (high-pressure turbocompressor), the gasifier producing high-pressure combustible gases at a pressure above the operating pressure of the boiler, i.e. well above 10 atmospheres. The gasifier output is introduced, according to the principles of this invention, into the expansion turbine of the high-pressure compressor which drops the pressure of the emerging combustible gases (low-pressure combustible gases) to the level necessary in the boiler. The combustible gases are then introduced into the boiler and are burned in the presence of oxygen (e.g. low-pressure compressed air) to operate a conventional generating cycle in which steam is the power fluid. Exhaust gases emerge from the boiler and are used, in turn, to drive the turbine of a low-pressure compressor (low-pressure turbocompressor) which preliminarily compresses the air which is fed into the high-pressure compressor, preferably to a level equal to that at which the boiler is operated. A portion of this low-pressure compressed air is bypassed to the boiler for use as the combustion air. Advantageously, the low-pressure compressor is provided with a starting motor to enable the installation to be brought into operation from standstill.

According to an important feature of this invention, a control valve is provided in the line between the gasifier and the high-pressure turbine and is provided with a control network for adjusting the valve. The principle of this control system is that it is responsive to the pressure ahead of the valve, i.e. the output pressure of the gasifier, to maintain this pressure substantially constant and thereby permit the gasifier to operate at maximum efficiency. With falling power demand or increasing power demand, the volume output rate of the coal gasifier must decrease or increase so that the variable gas-flow rate supplied to the high-pressure turbine must be more or less throttled to maintain the constant pressure ahead of the valve. With varying gas volume (throughput of the turbine), there is a modification of the pressure drop across the turbine and therefore of the power of the turbine measured in terms of the product of the pressure drop and volume flow rate. The combustible gases delivered to the boiler similarly fluctuate in volume flow rate and the steam generation rate is similarly modified. Consequently, the output in power of the steam-burbine cycle is also modified. Finally, since the exhaust gases or waste gases from the boiler are of a volume determined by the rate at which combustible gas is supplied, the volume flow rate through the low-pressure turbine is modified with modification of the power output thereof in accordance with the newly established product of pressure drop and volume flow rate of the waste gas therethrough. The rate at which low-pressure compressed air is supplied to the high-pressure compressor, is similarly diminished.

According to the present invention, moreover, the control circuit is provided with means for adjusting the level of the constant pressure maintained ahead of the control valve in accordance with the power demand. A simple adjustment at this point adjusts practically all of the components of the installation and the control system has minimum complexity.

We, in addition, prefer to provide the high-pressure turbine with a motor-generator set designed to operate as a motor during start of the installation and operating as a generator during normal running thereof. Start-up may be facilitated by the use of a compressed-air tank selectively connectable to the output of the high-pressure compressor and the gasifier in accordance with the principles enunciated in the commonly assigned concurrently filed copending application Ser. No. 109,358 entitled STARTING SYSTEM FOR A GAS-TURBINE INSTALLATION. The steam cycle may include, according to the present invention, a steam-driven turbine operated with the steam produced by the boiler and driving the main electrical generator, the steam being condensed at the output side of the turbine with the condensate being preheated by waste heat derived from the exhaust gases upon their traversal of the low-pressure turbine. A secondary generator may be coupled with this latter turbine.

DESCRIPTION OF THE DRAWING

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which the sole FIGURE is a flow diagram of a as-turbine installation embodying the present invention.

SPECIFIC DESCRIPTION

In the drawing, we show a gas-turbine installation which comprises a pressurized-air coal gasifier **1** operating preferably at a pressure of about **20** atmospheres. The high-pressure combustible gas emerging at **17***a* from the gasifier, after washing at **21** in a washer to eliminate corrosive components, is introduced to an expansion turbine **2**. A shaft **16** connects the high-pressure turbine **2** with a high-pressure compressor **3** the output of which is applied via line **17***b*, a control valve **30** and a flow indicator **31** to the gasifier **1**. The turbine **2** also drives a motor generator **4** via the mechanical connection **16***a*, this unit operating as a motor during startup of the installation and as a generator during normal running operation.

The low-pressure combustible gases emerging from the turbine **2** are delivered at **31** to a boiler **5** which connects the gas-turbine installation with the steam-driven generator circuit. The steam-generating circuit includes a steam turbine **32**, receiving steam via line **33** from the boiler **5** and mechanically coupled to the main electrical generator **34**. Depleted steam may be condensed at a heat exchanger **35**. A condensate pump **36** delivers the power medium to a preheater **20** in which sensible heat of the exhaust gas is utilized to preheat the condensate before it is discharged to the atmosphere at **23**.

In the boiler **5**, the low-pressure compressed combustible gases are burned with air supplied by a shunt line **37**, the exhaust gases emerging at **38** from the boiler at approximately the pressure of the combustion chamber thereof. This pressure is sufficient to drive the expansion turbine **6** (low-pressure turbine), the expanded hot gas being delivered at **39** to the waste-gas heat exchanger **20**.

The turbine **6** is mechanically coupled at **16***b* to a secondary electrical generator **9** and at **16***c* to a low-pressure compressor **7**. The compressor **7** draws ambient air at **22** and delivers it with precompression at **17***c* via a heat exchanger **20***a* to the high-pressure compressor **3**. The shunt line **37** bypasses a limited proportion of this low-pressure air to the boiler **5** as previously mentioned. A motor **8** (starting motor) is coupled by a releasable clutch **8***a* to the low-pressure compressor **7** and is used during starting in accordance with conventional practices.

In the line **17***a* between the gasifier **1** and the turbine **2**, we provide a controllable valve **10** operated by a servomotor **14** from a servoamplifier or controller **12** connected by control line **18** with the servomotor **14**. The amplifier responds to the pressure at point **15** via a conventional transducer and a set-point value may be introduced at **13**. The servomechanism may be that described at pages 37 ff. of SERVOMECHANISM PRACTICE, McGraw-Hill Book Co., New York, 1960. In principle, the transducer **15** produces a measured signal which is compared with a set-point or reference signal at **12** to yield an error signal at **18** upon deviation of the measured pressure value from the reference pressure value associated with a particular electrical load. The error signal, in turn, operates the valve **10** via the servomotor **14**. Should the pressure rise at **15**, the valve **10** will be opened correspondingly and, should the pressure fall at **15**, valve **10** will further throttle the flow of gas to the turbine **2**. When the electrical load varies, e.g., is reduced, it is merely necessary to change the set-point or reference value at **13** to throttle the flow to turbine **2**. The immediate response is a reduction of the power product of this turbine, a reduction in the delivery rate of its turbine **3**, a reduction of the steam production in boiler **5** and a corresponding drop in the steam-generating rate, and a lowering of the power product of the turbine **6** and the outputs of its generator **9** and compressor **7**. The servomechanism, of course, reacts to maintain the new pressure setting ahead of the turbine **2**.

OPERATION AND SPECIFIC EXAMPLE

The installation illustrated in the drawing, once started as described in the aforementioned copending application, via motors **4** and **8** and a compressed air source, provides **22** atmospheres gauge of compressed air to the gasifier **1** at a rate of 35.4 kg/sec, a temperature of 225°C and a heat content of 54.5 Kcal/kg. The output of the gasifier is a high-pressure combustible-gas stream at a pressure of 19 atmospheres absolute, a rate of 79.5 kg/sec, heat content of 1,320 Kcal/kg and a temperature of 200°C. This high-pressure combustible gas drives the turbine **2** and emerges from the latter as a low-pressure combustible gas at 9.62 atmospheres absolute, a flow rate of 79.5 kg/sec, a heat content of 340 Kcal/kg and a temperature of 162°C. In the boiler **5**, the low-pressure combustible gas is burned with 284.1 kg/sec of air delivered at 9.62 atmospheres gauge from the low-pressure compressor **7**, the output of the low-pressure compressor **7**, the output of the low-pressure compressor corresponding to the operating pressure of the boiler **5**.

About 340 tons/hour of steam at 130 atmospheres absolute and a temperature of 525°C is generated by the boiler **5** to operate the steam turbine **32** and the main generator **34** which has an output of 96 megawatts.

The waste gas emerges from the boiler **5** at a pressure of 9.5 atmospheres absolute, a temperature of 804°C at a rate of 363.6 kg/sec with a heat content of 300 Kcal/hour. The waste gas is used to drive the expansion turbine **6** whose generation **9** has an output of 74 megawatts and the compressor **7** having an output of 340 kg/sec of air at a pressure of 9.62 atmospheres gauge and a temperature of 307°C, starting with ambient air (760 torr) supplied at a rate of 340 kg/sec at a temperature of 15°C.

The waste gases emerging from the compressor **6** with a heat content of 1,078 Kcal/kg and a temperature of 399°C is used to heat the condensate at **20** and then discard it with a loss of only 26.6 Kcal/kg. During startup, the motor **8** is driven at 600 rpm with a power consumption of 2.2 megawatts. The motor generator **4**, which can be operated at 3,000 rpm, produces 0.445 megawatts, one operating as a generator and consumes 1.8 megawatts when operating as a motor. When the total power output of the generating units **34** and **9** is reduced to 155 megawatts, the valve **10** is throttled to increase the gasifier pressure behind valve **10** to 21 atmospheres absolute.

The improvement described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the invention except as limited by the appended claims.

We claim:

1. In a method of operating an electricity-generating plant wherein compressed air is supplied to a gasifier by a high-pressure turbocompressor to produce a high-pressure combustible gas, the high-pressure combustible gas drives the high-pressure turbocompressor and is transformed into a low-pressure combustible gas, which is fed to a boiler for operating a steam-driven generator circuit by combustion of the low-pressure combustible gas, thereby producing a waste gas, and the waste gas drives a low-pressure turbocompressor supplying low-pressure air to the high-pressure turbocompressor, the improvement which comprises detecting the high-pressure combustible gas pressure upon emergency of the high-pressure combustible gas from the gasifier and adjustably throttling the flow of the high-pressure combustible gas to the high-pressure turbocompressor to maintain said pressure substantially constant for a given electrical load on the plant, and selectively varying the substantially constant pressure of the combustible gas emerging from said gasifier in accordance with the electrical load on said plant, said gasifier being operated at a pressure of about 20 atmospheres and said boiler being operated at a combustion pressure of about 10 atmospheres.

2. A plant for the generation of electricity, comprising:

a. a pressurized-air fuel gasifier for producing a high-pressure combustible gas;
b. a high-pressure turbocompressor connected with said gasifier and driven by expansion of said high-pressure combustible gas for feeding high-pressure air to said gasifier;
c. a steam-driven generating circuit including a boiler connected to said high-pressure turbocompressor for receiving low-pressure combustible gas therefrom and producing high-pressure steam by combustion of the gas received from said high-pressure turbocompressor, thereby producing a waste gas;
d. a low-pressure turbocompressor connected to said boiler and driven by expansion of said waste gas for supplying low-pressure compressed air to said high-pressure turbocompressor;
e. adjustable throttle means between said gasifier and said high-pressure turbocompressor for controlling the flow of said high-pressure combustible gas to the latter; and
f. means responsive to the pressure between said gasifier and said throttle means for controlling said throttle means to maintain said pressure substantially constant for a give electrical load on the plant, said throttle means being provided with a servomechanism responsive to said pressure and having a set-point pressure settable in accordance with the electrical load on said plant, said circuit including:

a steam-driven turbine connected to said boiler,
a first electrical generator mechanically coupled with said turbine,
a condenser communicating with said turbine for forming a condensate from steam expended in said turbine,
a pump for feeding said condensate to said boiler, and
heat-exchange means supplied with expanded waste gas from said low-pressure turbocompressor for heating said condensate prior to its introduction into said boiler, said low-pressure turbocompressor comprising:
a first expansion turbine,
a low-pressure compressor mechanically connected to said first expansion turbine for generating low-pressure air of a pressure substantially equal to that at which said low-pressure combustible gas is introduced into said boiler,
a second electrical generator mechanically connected to said first expansion turbine, and
a starting motor mechanically connectable to said low-pressure compressor.

3. The plant defined in claim **2**, further comprising bypass means connecting the output side of said low-pressure compressor to said boiler for supplying combustion air thereto.

4. The plant defined in claim **3** wherein said high-pressure turbocompressor comprises a second expansion turbine connected to said throttle means, a high-pressure compressor mechanically connected to said second expansion turbine and receiving low-pressure air from said low-pressure compressor, and a motor generator set mechanically connected to said high-pressure compressor and said second expansion turbine.

5. The plant defined in claim **4**, further comprising a gas washer between said gasifier and said throttle means and a heat exhanger between said low-pressure compressor and said high-pressure compressor, said gasifier converting coal into said high-pressure combustion gas.

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