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(71) Applicant(s):
Bowman Power Systems Limited
(Incorporated in the United Kingdom)
Ocean Quay, Belvidere Road,
SOUTHAMPTON, SO14 5QY,
United Kingdom

(72) Inventor(s):
Martin Eyre
David Ainsworth
Steven David Butt

(74) Agent and/or Address for Service:
Kilburn & Strode
20 Red Lion Street, LONDON, WC1R 4PJ,
United Kingdom

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GB 2274880 A **GB 1103948 A**
FR 002456847 A **US 4492085 A**

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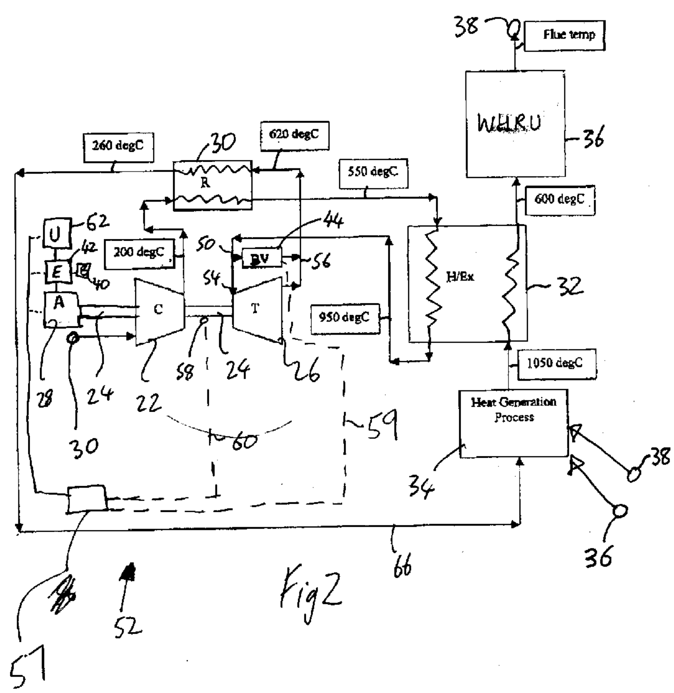
(54) Abstract Title: **Generator system**

(57) A micro turbine generator 52 has a compressor 22 for compressing air. The compressed air passes through a recuperator 30 and a heat exchanger 32, before passing through a turbine 26 which drives the compressor 22 and an alternator 28. A heat generator 34 provides heat so as to indirectly power the turbine 26, via the heat exchanger 32. A waste heat recovery unit 36 is provided. During startup, the alternator 28 is used as a motor to spin the compressor 22 and turbine 26. At a given motoring speed and turbine inlet temperature, a bypass dump valve is closed to provide gases to the turbine 26 to rapidly accelerate the shaft 24 through its first critical speed. Shaft speed may be maintained constant by varying electrical load on the alternator 28.



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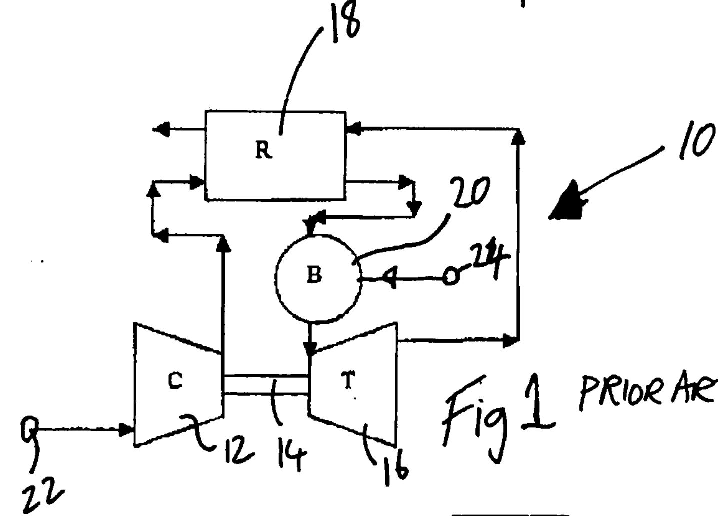

Fig 1 PRIOR ART

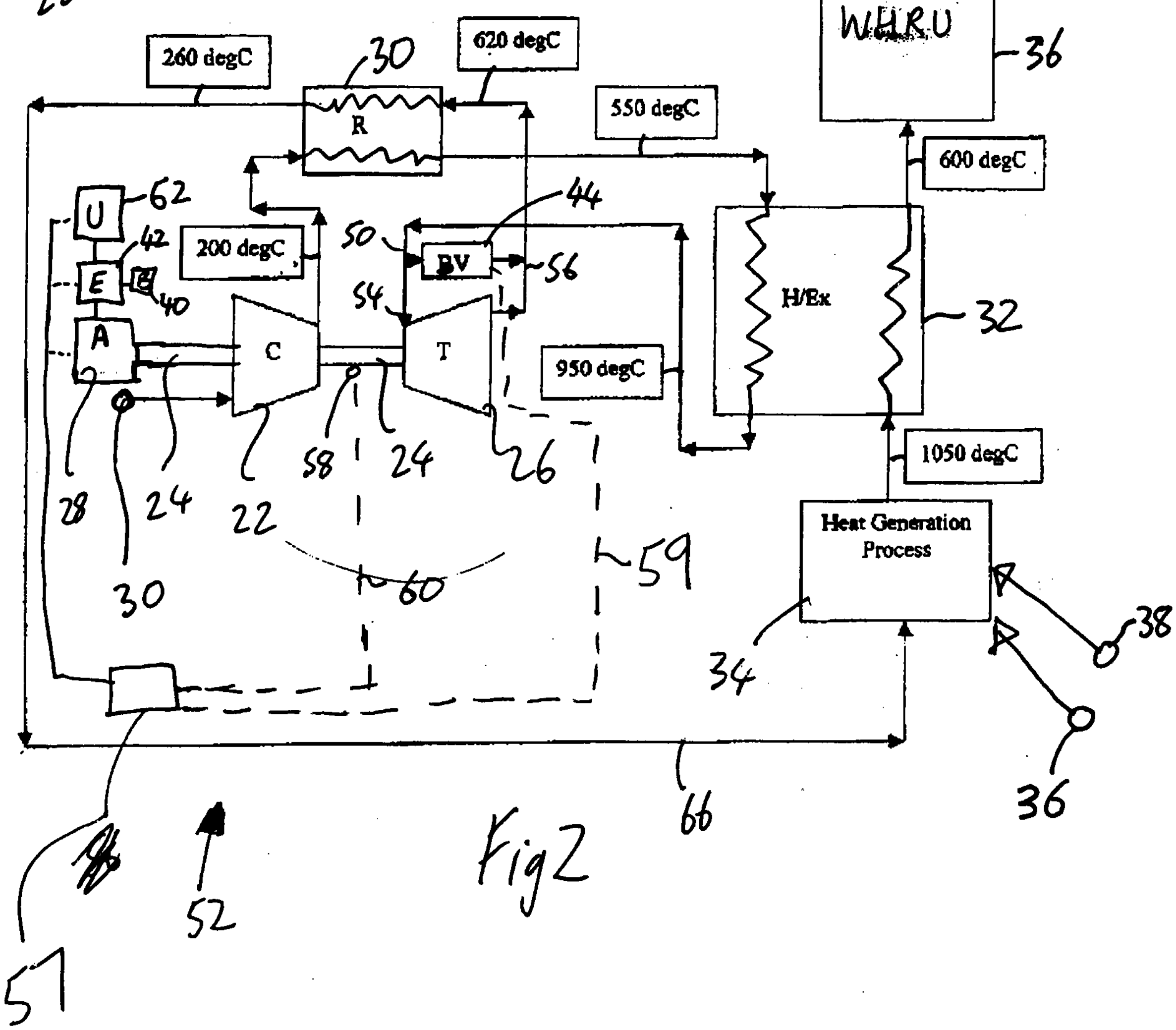

Fig2

GENERATOR SYSTEM

The present invention relates to a micro turbine generator system and to generator systems more generally. The invention also relates to methods of starting generator systems and methods for controlling generator systems.

A micro turbine generator is a small generator for generating up to no more than about 250, 300 or 500 kW of rated electrical power. Traditional micro turbines include a combustor for combusting fuel such as natural gas with compressed air provided to the combustor by a main air compressor of the generating system. Such generator systems are highly effective, particularly when recuperated, but they cannot normally be used for all types of fuels since some fuels do not burn cleanly and the combustor exhaust gases might damage the turbine of the generating system.

The present invention aims to address this problem and to provide a generating system capable of operation on fuels other than standard micro turbine fuels, such as diesel and natural gas which are often used in micro turbines.

According to a first aspect of the present invention there is provided a method of starting a generator system with the features of claim 1. This starting method enables the starting of a generator system when powered by a large heat exchanger with hot gases powered by fuels such as cardboard, MDF, garden or household waste. Thus, a combustion process in the heat generator may be started, the alternator may be used as a motor to start the compressor and turbine rotation and, once at a sufficient speed, a valve may be operated to cause the turbine to drive the compressor in lieu of the motor and, once at a self-sustaining speed, the alternator may be reconfigured as a generator to produce electricity at a load.

Preferably, the running speed is higher than the first critical speed of the shaft. It has been found that by starting the heat generator and then operating a turbine bypass valve to a non-turbine bypassed position the turbine may be used to accelerate the shaft at a high acceleration rate through the first critical speed of the shaft without dwelling on that speed causing potential damage to the generator. This is a useful feature on super critical systems.

Preferably the method includes providing rotors of each of the generator, compressor and turbine on the same shaft for rotation in unison.

The method may comprise: the flow path from the compressor passing through the heat exchanger to a turbine bypass valve, and operating the bypass valve to bypass all or substantially all of the hot air flow past the turbine while the shaft is motored at the initial speed, and then closing the bypass valve in order to pass all of the gases in the flow path from the compressor through the turbine in order to accelerate the shaft to the running speed.

According to a second aspect of the invention there is provided a method of operating a gas turbine generation system, the method being as set out in claim 5. This is advantageous since the method of operating the gas turbine is largely independent of the method of heat generation, enabling simple design for the gas turbine components, and only limited communication between the gas turbine engine system and combustor system is required.

Another aspect is set out in claim 6.

Preferably, the method includes providing a rotor of each of the generator, compressor and turbine on the shaft for rotation in unison.

Preferably, the method includes varying the electrical load to maintain shaft speed substantially constant, such as within plus or minus 1% and up to ±5% of a predetermined nominal value.

According to a further aspect of the present invention there is provided a micro turbine generator with the features of claim 11.

A further aspect of the present invention provides a generator system adapted to produce no more than 500 kW of electrical power, preferably not more than 300 or 250 kW of electrical power, the generator system comprising:

a generator; a compressor; a turbine for driving the compressor; a heat generator; and a heat exchanger for transferring energy from a flow path from the heat generator to a flow path to the turbine. Accordingly, the fluid, e.g. gas such as air, in a flow path through the compressor and turbine may be indirectly heated and may, for example, be air. The air may be heated in the heat exchanger by heat produced by a heat generator, the heat generator itself being provided for the combustion of fuel such as cardboard, MDF, household, industrial or garden waste, or wood or coal, to name some examples only. Accordingly, it is important to note that the combustion products from the heat generator will not pass through the turbine, only the working fluid, such as air, compressed by the compressor.

Preferably, a bypass valve is provided for selectively bypassing the turbine. The bypass valve when open may bypass the turbine. The turbine may be bypassed upon startup, then be non-bypassed for normal operation. The valve may failsafe by bypassing the turbine, for example, upon control power failure. A control system may be provided for opening/closing the valve.

Preferably, the rotor of each of the generator, compressor and turbine are mounted on a shaft for rotation in unison. Preferably, the compressor and turbine are of the radial flow type.

The generator preferably comprises an alternator. Preferably, the generator is operable as a motor for motoring the shaft as desired. Preferably the alternator is adapted to operate as a motor to drive the compressor and turbine during startup. The alternator may be re-configurable after startup as a generator for providing electricity to a load. Preferably, the system includes a recuperator for recuperating heat from fluid which has passed through the heat exchanger and/or the turbine and for transferring such heat to fluid, e.g. gas such as air, exhausted from the compressor.

Preferably, the generator system includes a bypass valve for selectively bypassing the turbine in a fluid flow path from the heat exchanger to the recuperator. The bypass valve may be adapted to be selected in an open position thereof upon system failure. Accordingly, the turbine may be bypassed such that the shaft slows down upon system failure.

If a connected grid fails, the system may be shut down rapidly to prevent overspeed. The valve can thus be opened to remove power, the engine driven electrically, e.g. by the alternator, to provide cooling flow.

An exhaust flow path from the turbine may be directed to the heat generator. Accordingly fuel in the heat generator may be pre-warmed for easier combustion, such as of heavy fuels. By using hot clean compressed air with potential fuels such as cardboard, MDF, and other fuels, the use of pre-heated fuel may reduce the formation of volatile organic compounds.

Preferably, the generator system includes a heating gases path passing from the heat generator, through the heat exchanger to an exhaust flue. Preferably, a waste heat recovery unit is located in the heating gases path downstream of the heat exchanger. Accordingly, the overall efficiency of the system may be improved. The waste heat recovery unit may comprise a steam generator, hot water generator, chiller, such as a direct fired chiller, or other power bottoming device.

Preferably, the generator system includes a load varying device for varying electrical load on the generator for maintaining a constant shaft speed in the generator system.

Accordingly, a system which is convenient for distributed power generation and grid connection purposes may be provided.

The present invention may be carried out in various ways and one example of a method of starting, operating and offloading a generator system and a generator system in accordance with the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a view of a known prior art micro turbine generator system; and

Figure 2 is a schematic system arrangement for a preferred embodiment of a generating system in accordance with the present invention.

As shown in Figure 1, a known micro turbine generator system 10 includes an air compressor 12 connected by a shaft 14 to a turbine 16. A recuperator 18 is also provided. A combustor/burner 20 is included for combusting air taken from air inlet 22 with fuel taken from fuel inlet 24. Such an arrangement may be suitable for burning conventional gas turbine fuels such as diesel and natural gas.

A preferred embodiment of a micro turbine generator in accordance with the present invention is shown in Figure 2 where a compressor 22 is connected by a shaft 24 to a turbine 26 and an alternator 28. Atmospheric air from an air source 30 is compressed by a compressor 22 and passes through a recuperator 30 to a heat exchanger 32 then back to the turbine 26, through the recuperator 30 to a heat generator 34 where it combines with atmospheric combustion air 36 from an atmospheric air source 36 and fuel such as cardboard, MDF or wood for combustion. The combustion products then pass through the heat exchanger 32 to a waste heat recovery unit 36 and then to an exhaust flue 38. The recuperator 30 is an optional feature.

The heat generator 34 which may also be considered a combustor, has a large volume and may have a slow response. Due to this and the large volume of the gas turbine between the compressor and turbine, the overall transient response of the system may be slow. Thus, start time for the overall system may be prolonged and the response of the system to combustion temperature transients needs careful attention. During starting, the alternator 28 is used as a motor powered by a battery 40 or mains power via electronic/electrical system 42 in order to motor the shaft 24 to a high speed, nominally 40% of rated shaft speed. This motoring takes place with a dump bypass valve 44 open, such that gases from the heat exchanger 32 from the compressor 24 are bypassed around the turbine 26, passing straight from the heat exchanger 32 to the recuperator 30 via the bypass valve 44. Bypass valve 44 is arranged to "fail" open, thus being controlled open upon a power or other failure. The combustion process is started in the heat generator 34 and the air at the turbine/bypass valve entry is gradually heated up as the combustion process increases the temperature. At the predetermined engine speed, nominally 40% of rated operation speed, and a predetermined turbine entry temperature, i.e. the temperature at point 50 shown in Figure 2, this temperature nominally being 650°C, the bypass valve 44 is closed. This provides a generally instantaneous increase in turbine entry pressure and allows the shaft 24 of the generator system/engine 52 to accelerate rapidly across the first critical speed thereof, without dwelling on the first critical speed causing potential damage to the engine. This is a useful feature for a super critical micro turbine engine.

The bypass valve 44 is configured so that it is normally (i.e. when uncommanded or unpowered) open, so that if the system fails, it fails safe, i.e. with no shaft power. Therefore, if a catastrophic failure of the electronics 42 or similar failure occurs, the bypass valve 44 linking the turbine entry port 54 to the exhaust side 56 of the turbine can be opened. This dumps all of the hot pressurised gas past the turbine 26, limiting the amount of power the turbine can produce and, in some embodiments, restricting this to zero.

To overcome the response issues of the system, the system is adapted to control the engine shaft speed by varying the power exported. A control unit 57 linked to a speed sensor 58 by signal path 60 and linked also to the alternator 28, electronics/electrical system 42 and load 62 is provided for this purpose. Therefore, this arrangement is ideal for distributed power generation and grid connection. Control unit 57 is connected by control path 59 to valve 44 for controlling the same. The system may be used in standalone generation, although it may have limited applications in this field due to the relatively slow transient response. As heat from the combustion process rises, this will tend to increase engine speed and, once the engine has attained its rated design speed, which for example may be about 60,000 to 150,000 rpm, the electrical load may be applied to the engine to reduce speed. As the process increases in temperature, the load may be increased, controlling the speed to a fixed value with a dead band plus or minus 1% to ±5% either side of a nominal running speed. Conversely, the load may be reduced in a controlled manner when the heat generation process in the heat generator 34 is cooling down.

The excess heat emitted downstream of the heat exchanger 32 may still contain significant energy. This may be further recovered by passing the hot gases through the additional waste heat recovery unit 36, which may take the form of a hot water heat exchanger, direct fired chiller, steam generator or other power bottoming device. The routing of the air (which is passed through the turbine 26 and recuperator 30 to the heat generator 34) along preheated air path 66 is optional. Thus, after expansion across the turbine, the air may be fed into the combustion process using the combustor re-generatively. In some instances, by using the hot clean compressed air with potential fuels such as cardboard and MDF, the use of preheated air can reduce the formation of volatile organic compounds. The use of preheated compressed air to pre-warm the fuel in the heat generator may also be beneficial for easier combustion of heavy fuels, etc.

The heat generator 34 may comprise a fuel cell, or in other embodiments may comprise a traditional combustor for combusting wood, cardboard, MDF, household, industrial and garden waste, coal or other fuels. Although such fuels may, once combusted, produce contaminants, such as tar, soot or corrosive compounds not suitable for gas turbine use, such gases will not pass through the turbine 26, but will provide energy to gases (e.g. clean air) to be passed through the turbine 26 indirectly, by way of the heat exchanger 32.

The construction in this embodiment is very flexible because, although the method and rate of fuel feed to the combustor 34 may vary greatly dependent upon the design authority of the heat generator/combustor 34 designer, the method of gas turbine control makes the gas turbine system independent of the method of heat generation and limited communication between the engine system, provided by the turbine 26, compressor 22, recuperator 30, alternator 28, electronics 42, and the combustor system, provided by the combustor 34 and heat exchanger 32 is required.

The bypass valve 44 may be subject to proportional control and may thus be a modulated bypass valve and, in other embodiments, may be modulated in addition to or as an alternative to electrical load control, in order to control the gas turbine shaft speed.

As shown in Figure 2, the temperature of atmospheric air at the air inlet 30 is raised by the compressor to 200°C. The temperature may further be increased, when running at a steady state, by the recuperator to 550°C, being further increased in temperature in the heat exchanger 32 to 950°C. Downstream of the turbine 26, the air temperature may be reduced to 620°C. The exhaust from the heat generator 34 may enter the heat exchanger 32 at 1,050°C exiting the heat exchanger 32 at 600°C. Downstream of the waste heat recovery unit 36, the temperature of the exhaust gases may be reduced to a relatively low flue temperature, of about 20 to 100°C.

Modifications may be made to the embodiment described without departing from the scope of the invention as defined by the claims hereof as interpreted under patent law.

CLAIMS

1. A method of starting a generator system having a compressor, a turbine, a generator, a heat generator, and a heat exchanger for transferring heat from a heating gases path to a flow path; the method comprising: motoring a shaft of the generator system to an initial speed, then applying gas from the compressor and heated by the heat exchanger to the turbine to accelerate the shaft to a running speed.

2. A method as claimed in claim 1 in which the running speed is higher than the first critical speed of the shaft.

3. A method as claimed in claim 1 or claim 2 which includes providing rotors of each of the generator, compressor and turbine on the shaft for rotation in unison.

4. A method as claimed in claim 1 or claim 2 or claim 3 in which the flow path for the compressor passes through the heat exchanger to a turbine bypass valve, and which includes operating the bypass valve to bypass the turbine while the shaft is motored at the initial speed, and then closing the bypass valve in order to pass gases in the flow path from the compressor through the turbine in order to accelerate the shaft to the running speed.

5. A method of operating a gas turbine generator system, the gas turbine having a compressor, a generator for powering an electrical load, a turbine for driving the compressor and generator, a heat generator and a heat exchanger for transferring energy from a flow path from the heat generator to a flow path to the turbine, the method comprising varying the electrical load upon the generator to control the speed of a shaft of the generator system.

6. A method of operating a gas turbine generator system, the gas turbine having a compressor, a generator for powering an electrical load, a turbine for driving the compressor and generator, a heat generator and a heat exchanger for transferring energy from a flow path from the heat generator to a flow path to the turbine, wherein a bypass valve is provided for selectively bypassing the turbine in a fluid flow path from the heat exchanger.

7. A method as claimed in claim 5 or claim 6 which includes providing a rotor of each of the generator, compressor and turbine on the shaft.

8. A method as claimed in claim 5 or claim 6 or claim 7 which includes varying the electrical load to maintain the shaft speed substantially constant.

9. A method as claimed in claim 8 which includes varying the shaft speed to maintain the shaft speed within plus or minus 5% of a predetermined value.

10. A method as claimed in any preceding claim which includes using the generator as a motor to motor the shaft.

11. A micro turbine generator system comprising: a generator; a compressor; a turbine for driving the compressor; a heat generator; and a heat exchanger for transferring energy from a flow path from the heat generator to a flow path to the turbine.

12. A generator system as claimed in claim 11 in which a rotor of each of the generator, compressor and turbine are mounted on a common shaft for rotation in unison.

13. A generator system as claimed in claim 11 or claim 12 in which the generator is operable as a motor for motoring the shaft at the initial speed.

14. A generator as claimed in claim 13 in which the alternator is adapted to operate as a motor to drive the compressor and turbine during startup.

15. A generator system as claimed in any one of claims 11 to 14 which includes a recuperator for recuperating heat from fluid which has passed through the heat exchanger and/or the turbine and transferring such heat to fluid exhausted from the compressor.

16. A generator system as claimed in claim 15 which includes a bypass valve for selectively bypassing the turbine in a fluid flow path from the heat exchanger to the recuperator.

17. A generator system as claimed in any one of claims 11 to 14 which includes a bypass valve for selectively bypassing the turbine in a fluid flow path from the heat exchanger.

18. A generator system as claimed in claim 16 or claim 17 in which the bypass valve is adapted to select an open position thereof upon a system failure.

19. A generator system as claimed in any one of claims 16 to 18 in which a control system is provided for maintaining the valve open then closing the valve during system startup.

20. A generator system as claimed in claim 18 or claim 19 in which the bypass valve, when open, is arranged to bypass fluids around the turbine.

21. A generator system as claimed in any one of claims 11 to 20 in which an exhaust flow path from the turbine is directed to the heat generator.

22. A generator system as claimed in any one of claims 11 to 21 which includes a heating gases path passing from the heat generator through the heat exchanger to an exhaust flue.

23. A generator system as claimed in claim 22 which includes a waste heat recovery unit in the heating gases path downstream of the heat exchanger.

24. A generator system as claimed in any one of claims 11 to 23 which includes a load varying device for varying electrical load on the generator for maintaining a substantially constant shaft speed in the generator system.

25. A generator system as claimed in claim 24 in which the load varying device is adapted to maintain the shaft speed to within plus or minus 5% of a fixed speed.

26. A generator system as claimed in claim 25 in which the load varying device is adapted to maintain the shaft speed within plus or minus 1% of the fixed speed.

27. A generator system substantially as described herein with reference to Figure 2 of the drawings.

28. A method of starting a gas turbine generator system substantially as designed herein with reference to Figure 2 of the accompanying drawings.

29. A method of operating a gas turbine substantially as described herein with reference to figure 2 of the accompanying drawings.

Application No: GB 0312467.4 **Examiner:** Tom Roberts
Claims searched: 1-29 **Date of search:** 14 November 2003

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Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-3, 5, 7-15, 21, 22, 24-26	GB2274880 (SHELL INT RESEARCH) See fig. 1, abs,
X	1-3, 5, 7-15, 21, 22, 24-26	GB1103948 (CLARKE CHAPMAN) See fig. 1, abs,
X	1-3, 5, 7-15, 21, 22, 24-26	US4492085 (GENERAL ELECTRIC) See fig. 1, abs,
X	1, 4, 6, 11, 17	FR2456847 (CURTISS WRIGHT CORP) See abs, fig. 1.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{V}:

F1G

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

F02C

The following online and other databases have been used in the preparation of this search report:

EPODOC, PAJ, WPI