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(71) Applicant(s):
David Andrew Johnston
280 Ovington Grove, FENHAM, Newcastle Upon Tyne, Tyne and Wear, NE5 2QH, United Kingdom

(72) Inventor(s):
David Andrew Johnston

(74) Agent and/or Address for Service:
David Andrew Johnston
280 Ovington Grove, FENHAM, Newcastle Upon Tyne, Tyne and Wear, NE5 2QH, United Kingdom

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(54) Title of the Invention: **Solar-powered gas turbine with optical concentration of radiation engine into the turbine engine**
Abstract Title: **Solar-powered gas turbine engine with direct heating**

(57) A solar powered gas turbine engine receives solar radiation 2 through windows 5 into heating zone 7. The turbine engine has a compressor 10 and turbine 9. The turbine 9 may receive further solar radiation 2 which heats parts of the turbine such as blades 8, to provide turbine re-heat. The radiation may be provided by a solar concentrator with a first concave mirror, a second convex mirror (1, 3, figure 1) and third mirrors or prisms (4, figure 2) to distribute the light to appropriate parts of the gas turbine engine.

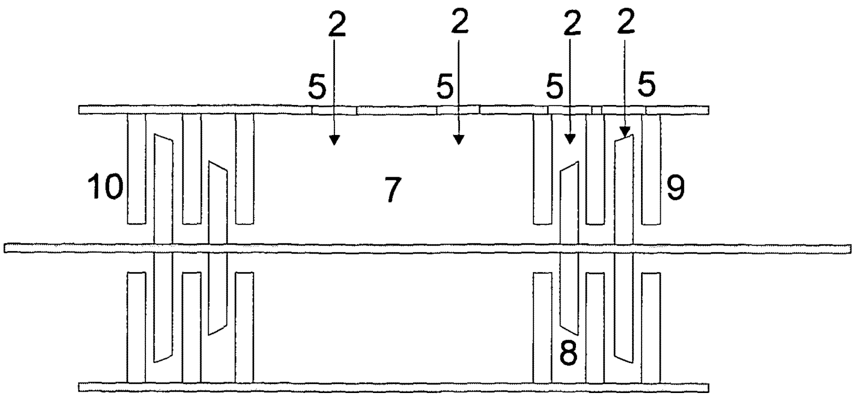

Figure 3.

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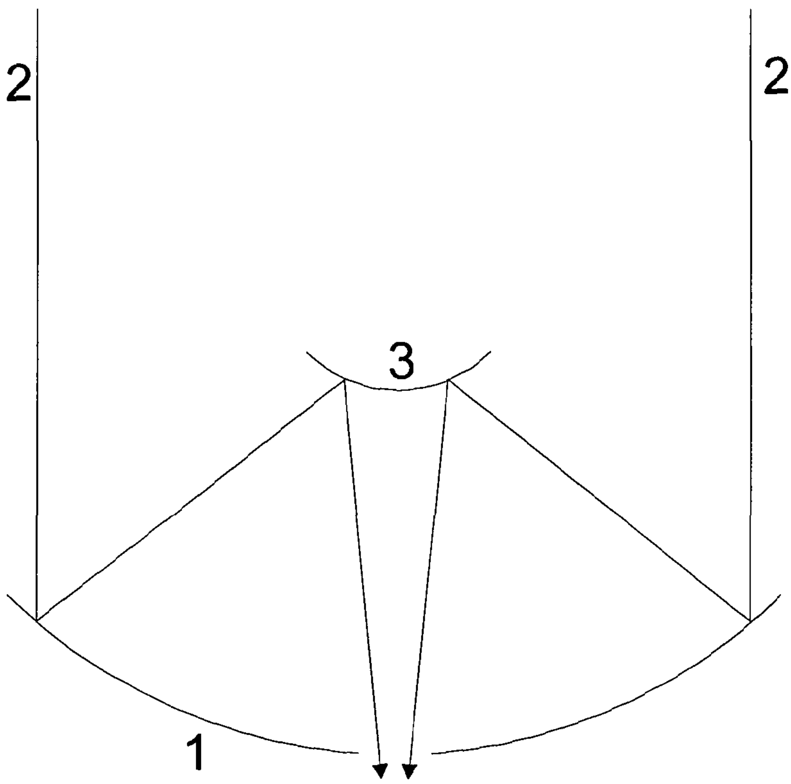

Figure 1.

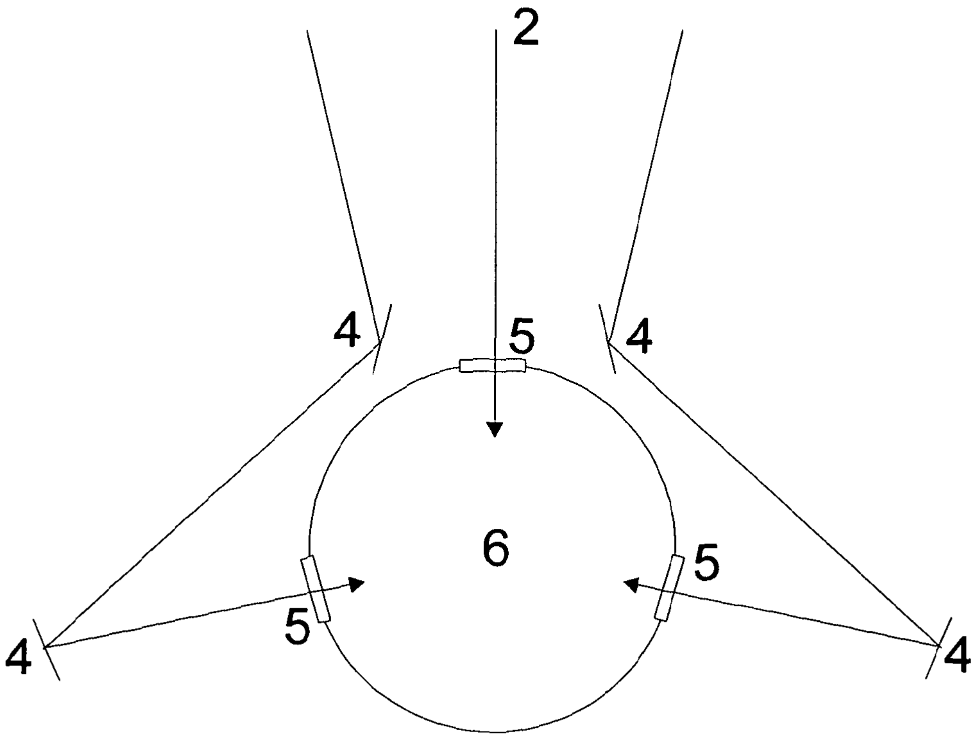

Figure 2.

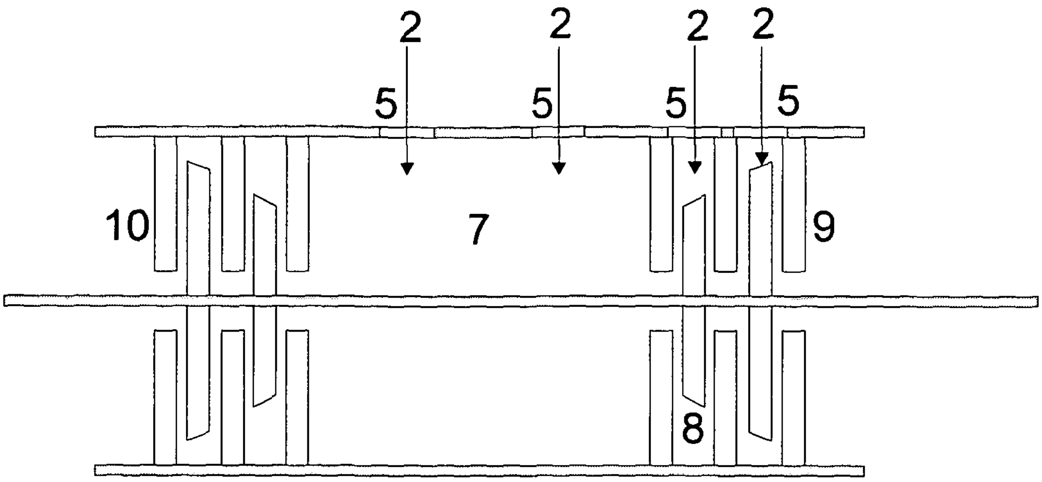

Figure 3.

Solar-powered gas turbine engine with optical concentration of radiation into the turbine engine.

This invention relates to a solar-powered gas turbine engine, in which a large diameter optical concentrator and additional optics focus solar radiation into a gas turbine engine, such that it heats the flowing gas inside the turbine engine, thus allowing this gas to transfer power to the turbine, from whence it is used to perform useful work. (For clarity, the term "turbine engine" refers to the entire assembly of compressor, heating zone, turbine discs and the casing in which they are enclosed. The term "turbine" refers to the set of turbine discs, which are turned by the heated gas.)

In current solar-thermal generators, a large-area optical concentrator – a concave mirror or a lens (usually a Fresnel lens) focuses solar radiation onto a collector located at the focal point of the optical concentrator. The incident solar radiation heats a fluid which passes through this collector. This fluid may be a liquid (generally water) which is heated to form vapour (steam, in the case of water), which is used to drive a vapour-cycle turbine engine. Alternatively, gas may be heated in the collector, and then used to drive a gas turbine engine.

For each of these variations, there are factors which tend to reduce the energy conversion efficiency. In transferring the heat from the collector to the turbine engine, heat is lost due to conduction, etc. The use of a heat exchanger in this transfer incurs additional losses. A steam turbine engine has a maximum operating temperature of a few hundred degrees, which is much lower than the temperature which can be obtained in the solar collector. The second law of thermodynamics thus limits the efficiency to well below that obtainable if the collector temperature could be used. A gas turbine engine can operate at higher temperatures, approaching that of the solar collector. The Ericsson cycle has an efficiency close to the limit (Carnot cycle efficiency) for a given operating temperature. However, practical implementation of the Ericsson cycle involves very large turbine engines. Most gas turbine engines are based on the Brayton cycle, which has a lower efficiency, but is easier to implement practically. Heat recovery techniques, such as regeneration and recuperation, produce a working cycle which more closely resembles the Ericsson cycle, with a corresponding improvement in efficiency. Higher efficiencies can be achieved in a combined cycle gas turbine (engine) (CCGT), in which the exhaust gas from the gas turbine engine (which is still at a high temperature) is used to heat water in a boiler, to generate steam which drives a steam turbine engine. The resulting increase in efficiency comes at the expense of a more complicated system involving two cascaded turbine engines.

To overcome the limitations stated above, the present invention incorporates a solar concentrator and additional optics, which directs solar radiation into the turbine engine, where it heats a working fluid to high temperature, such that it can drive a turbine and produce output power on the shaft to which the turbine discs are mounted. This shaft can be used to drive an electrical generator, or to perform other forms of useful work.

By concentrating solar radiation directly into the turbine engine, rather than a collector at the focal point of the concentrator, the heat losses in transferring a high temperature fluid from the collector to the turbine engine are avoided. This allows potentially higher conversion efficiencies. The high working temperature of a gas turbine engine can be used. The basic operation is based on the Brayton cycle, allowing for a practicable design. Direction of a fraction of the solar radiation onto the turbine discs (and other surfaces as required) can be used to add turbine reheat to the cycle. In addition, recuperation and equivalent or similar modifications can result in a working cycle, which is closer to the Ericsson cycle, with a corresponding improvement in efficiency. Optionally, the gas turbine engine can be coupled to a steam turbine engine to form a combined cycle gas turbine engine, for a further improvement in efficiency.

A particular implementation of the invention is described with reference to the accompanying drawings.

Figure 1 shows the primary and secondary optics.
Figure 2 shows the tertiary optics and a transverse section (relative to the axis) of the turbine engine.
Figure 3 shows the tertiary optics and a longitudinal section of the turbine engine.

In figure 1, the primary optical concentrator is a concave mirror 1. This directs the incoming solar radiation 2 onto the secondary mirror 3, positioned just before the focal point of the primary mirror 1. This secondary mirror 2 directs the radiation 2 through a hole in the primary mirror 1. In this particular implementation, the primary mirror 1 and the secondary mirror 2 form a Cassegrain optical system. This system is steerable to follow the apparent daily and seasonal motion of the sun.
In figure 2, solar radiation 2 from the secondary mirror 3 is directed by tertiary mirrors 4 through windows 5 in the casing of the turbine engine 6. A number of such tertiary mirrors may be used to achieve a reasonably uniform angular distribution of radiation entering the turbine engine casing, to provide even heating of the circulating gas.
In figure 3, the solar radiation 2 is shown entering the windows 5 located on the top surface of the casing of the turbine engine 6. Some of the solar radiation 2 enters the turbine engine 6 via windows into the heating zone 7, where it raises the circulating gas to high temperature, producing a thermodynamic cycle, and allowing the turbine engine 6 to produce useful work. The remainder of the solar radiation 2 may optionally be directed onto the turbine rotor discs 8 and/or stator discs 9, to provide turbine reheat, for improved efficiency. The compressor 10 may incorporate intercooling, for a further improvement in efficiency.
The primary application of the turbine engine is to provide the mechanical shaft power to drive an electrical generator. In general, the shaft speed of a gas turbine engine (typically over 10,000 rpm) is much higher than the shaft speed of an electrical generator producing electrical power at typical grid frequencies (50 or 60 cycles per second (Hertz, Hz), requiring shaft speeds of 3000 or 3600 rpm for a two-pole generator). Two alternative approaches can be used to produce the required frequency from the high speed turbine engine.
In the first option, a reduction gearbox can be used to reduce the high shaft speed of the turbine engine to the lower shaft speed required for the generator to produce a frequency of 50 or 60 Hz. This further requires that the shaft speed is accurately controlled, to maintain the correct electrical output frequency, subject to fluctuations in the level of solar radiation, and hence the power being converted by the turbine engine/generator.
In the second option, the turbine engine directly drives the generator at high shaft speed. The electrical output of this generator is therefore at a high frequency. This electrical output is rectified to direct current, and then re-converted by an inverter to alternating current at the grid frequency. This does not require control of the shaft speed of the turbine engine for the purpose of electrical frequency control.
A secondary application of the turbine engine is to provide power for specialised industrial processes. This may require electrical power (via a generator), or mechanical power directly via the shaft or a reduction gearbox, or a combination of the two. Heat may also be required for the industrial process, and the rejected heat from the thermodynamic cycle in the turbine engine (which would otherwise be wasted) can be used for this purpose.

Claims

1. A solar-powered turbine engine in which a set of optics concentrates solar radiation, and transfers it through windows in the casing of a turbine engine, to absorbing surfaces, where the resultant energy heats the fluid flowing through the engine to high temperature, thus allowing the hot fluid to rotate a set of turbine discs, which can then provide mechanical work to an external system.
2. A solar-powered turbine engine according to Claim 1, in which the primary optical component is a concave mirror.
3. A solar-powered turbine engine according to Claim 1, in which the primary optical component is a lens system.
4. A solar-powered turbine engine according to Claim 1 and Claim 3, in which the primary optical component is a Fresnel lens system.
5. A solar-powered turbine engine according to Claim 1, and Claim 2 or Claim 3, in which a secondary optical component is located at the focal point of the primary optical component.
6. A solar-powered turbine engine according to Claim 1, and Claim 2 or Claim 3, and Claim 5, in which the secondary optical component is a convex mirror.
7. A solar-powered turbine engine according to Claim 1, and Claim 2 or Claim 3, and Claim 5, and Claim 6, in which tertiary optics directs solar radiation from the secondary optics onto the windows in the casing of a turbine engine.
8. A solar-powered turbine engine according to Claim 1, and Claim 2 or Claim 3, and Claim 5, and Claim 6, and Claim 7, in which the tertiary optics consists of a set of mirrors.
9. A solar-powered turbine engine according to Claim 1, and Claim 2 or Claim 3, and Claim 5, and Claim 6, and Claim 7, in which the tertiary optics consists of a set of prisms.
10. A solar-powered turbine engine according to Claim 1, and Claim 2 or Claim 3, and Claim 5, and Claim 6, and Claim 7, and Claim 8 Claim 9, in which the tertiary optics consists of a combination of mirrors and prisms.
11. A solar-powered turbine engine according to Claim 1, and Claim 2 or Claim 3, and Claim 5, in which the secondary optical component is a light pipe or a set of light pipes.
12. A solar-powered turbine engine according to Claim 1, in which the turbine engine is a gas turbine engine.
13. A solar-powered turbine engine according to Claim 1, and Claim 12, in which the gas turbine engine implements the Ericsson cycle.
14. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 13, in which the gas turbine engine implements the Ericsson cycle, modified by additional heat transfer and/or work transfer processes.
15. A solar-powered turbine engine according to Claim 1, and Claim 12, in which the gas turbine engine implements the Brayton cycle.
16. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 15, in which the gas turbine engine implements the Brayton cycle, modified by additional heat transfer and/or work transfer processes.
17. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 15, and Claim 16, in which turbine reheat is incorporated into the Brayton cycle.
18. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 15, and Claim 16, and Claim 17, in which turbine reheat is implemented by appropriate distribution of the solar radiation entering the turbine engine via the windows and being absorbed on appropriately located heating surfaces.

19. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 15, and Claim 16, and Claim 17, and Claim 17, in which the appropriately located heating surfaces include the turbine blades mounted on the turbine discs.
20. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 15, and Claim 16, in which intercooling is incorporated into the Brayton cycle.
21. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 15, and Claim 16, in which recuperation is incorporated into the Brayton cycle.
22. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 15, and Claim 16, and Claim 17 and Claim 20 and Claim 21, in which a combination of these modifications are incorporated into the Brayton cycle.
23. A solar-powered turbine engine according to Claim 1, in which the turbine engine is a steam turbine engine.
24. A solar-powered turbine engine according to Claim 1, and Claim 23, in which the steam turbine engine implements the Rankine cycle.
25. A solar-powered turbine engine according to Claim 1, and Claim 23, and Claim 24, in which the steam turbine engine implements the Rankine cycle, modified by additional heat transfer and/or work transfer processes.
26. A solar-powered turbine engine according to Claim 1, and Claim 12, and Claim 23, in which a gas turbine engine and a steam turbine engine are cascaded to form a combined cycle gas turbine engine.
27. A solar-powered turbine engine according to Claim 1, in which the output power of the turbine shaft is used to drive an electrical generator.
28. A solar-powered turbine engine according to Claim 1, and Claim 27, in which a reduction gear system is incorporated to drive the generator at a lower rotational speed than the turbine shaft.
29. A solar-powered turbine engine according to Claim 1, and Claim 27, and Claim 28, in which the speed of the turbine shaft and generator shaft are controlled, such that the electrical power generated is at the voltage and frequency of the transmission grid to which the generator is connected.
30. A solar-powered turbine engine according to Claim 1, and Claim 27, in which the turbine shaft directly drives the electrical generator.
31. A solar-powered turbine engine according to Claim 1, and Claim 27, and Claim 30, in which a rectifier converts the alternating current output of the generator into direct current.
32. A solar-powered turbine engine according to Claim 1, and Claim 27, and Claim 30, and Claim 31, in which the electrical power supplies a local load with direct current at a voltage suitable for operation of that load.
33. A solar-powered turbine engine according to Claim 1, and Claim 27, and Claim 30, and Claim 31, in which an inverter converts the direct current from the rectifier into alternating current.
34. A solar-powered turbine engine according to Claim 1, and Claim 27, and Claim 30, and Claim 31, and Claim 33, in which output at the voltage and frequency of the transmission grid to which the inverter is connected.
35. A solar-powered turbine engine according to Claim 1, and Claim 27, and Claim 30 and Claim 31, and Claim 33, in which the electrical power supplies a local load at a voltage and frequency suitable for operation of that load.
36. A solar-powered turbine engine according to Claim 1, in which the turbine shaft provides mechanical power for direct application to an industrial process.
37. A solar-powered turbine engine according to Claim 1, in which heat recovered from the turbine engine is used for an industrial process.

38. A solar-powered turbine engine according to Claim 1, and Claim 27, and Claim 37, in which electrical power from a generator coupled to the turbine engine and heat recovered from the turbine engine are used for an industrial process.
39. A solar-powered turbine engine according to Claim 1, and Claim 27, and Claim 36, and Claim 37, in which any combination of electrical power, mechanical power and heat recovered from the turbine engine is used for an industrial process.

Application No: GB1114951.5 **Examiner:** Mr Peter Middleton
Claims searched: 1-22, 26-39 **Date of search:** 6 December 2012

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	1-17, 20-39	US2011/233940 A1 (MITSUBISHI) see abstract and figures: solar powered CCGT system
X	1-17, 20-22, 26-39	US6141949 A (DEUTSCH) see abstract and figures: CCGT system with air heated directly in solar collector 38
X	1-17, 20-22, 27-39	US4403601 A (HUNT) see abstract and figures: gas turbine with recuperator and direct solar heating
X	1-17, 20-22, 27-39	US2009/261592 A1 (KAY) see abstract and figures: example of gas turbine with direct solar heating
X	1-17, 20-22, 27-39	FR2844561 A1 (MILLION) see EPODOC abstract and figures: gas turbine heated directly by concentrated solar radiation
A	1	WO2010/149277 A1 (ETH) see abstract and figures: example of solar powered engine with light received through windows
A	2, 5-10	US2009/134748 A1 (PULSAR) see figures and note paragraph 0022: optical system with concave 104 and convex 106 reflectors, and mirrors 128
A	11	US2008/184989 A1 (MECHAM) see abstract and figures: example of light pipe to transport/absorb solar energy

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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&	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:

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Worldwide search of patent documents classified in the following areas of the IPC

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WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
F03G	0006/06	01/01/2006