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(56) Documents Cited:
GB 2069065 A **EP 3023617 A1**
EP 0462724 A1 **DE 003016817 A1**
DE 102011000420 A1 **US 6397577 B1**
JP S59120701

(58) Field of Search:
INT CL **B22F, C04B, C22C, F01D, F02C**
Other: **WPI, EPODOC, Patent Fulltext**

(54) Title of the Invention: **An axial turbine**
Abstract Title: **Axial turbine with stationary shaft and rotating outer casing, and combustor for said turbine**

(57) An axial turbine (104, figs 3, 4) having a stationary shaft 8 with stator blades 6 and a rotating outer casing 4 with rotor blades 2. Also claimed is an axial turbine having a rotating outer casing comprising rotor blades, where the rotating outer casing is cooled externally. Also claimed is an axial turbine comprising an axially arranged series of rotor sections 10, each section having an outer ring and rotor blades. Preferably, said turbine also has an axially arranged series of stator sections 12, each comprising an inner hub and stator blades. Also claimed is a combustor 100 suitable for any of said turbines, said combustor having a stationary combustor casing 108, which at least partially encloses the turbine, thereby forming a combustion chamber between the turbine and the casing. The combustor allows rotational motion of the turbine. The combustor may have fuel and/or air injection ports 102 arranged circumferentially and a primary air intake 106.

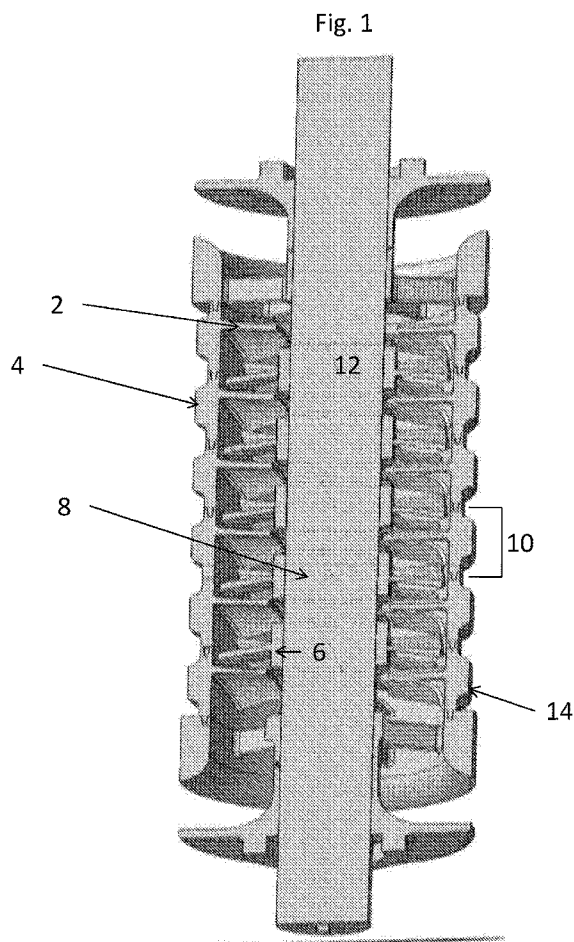


Fig. 1

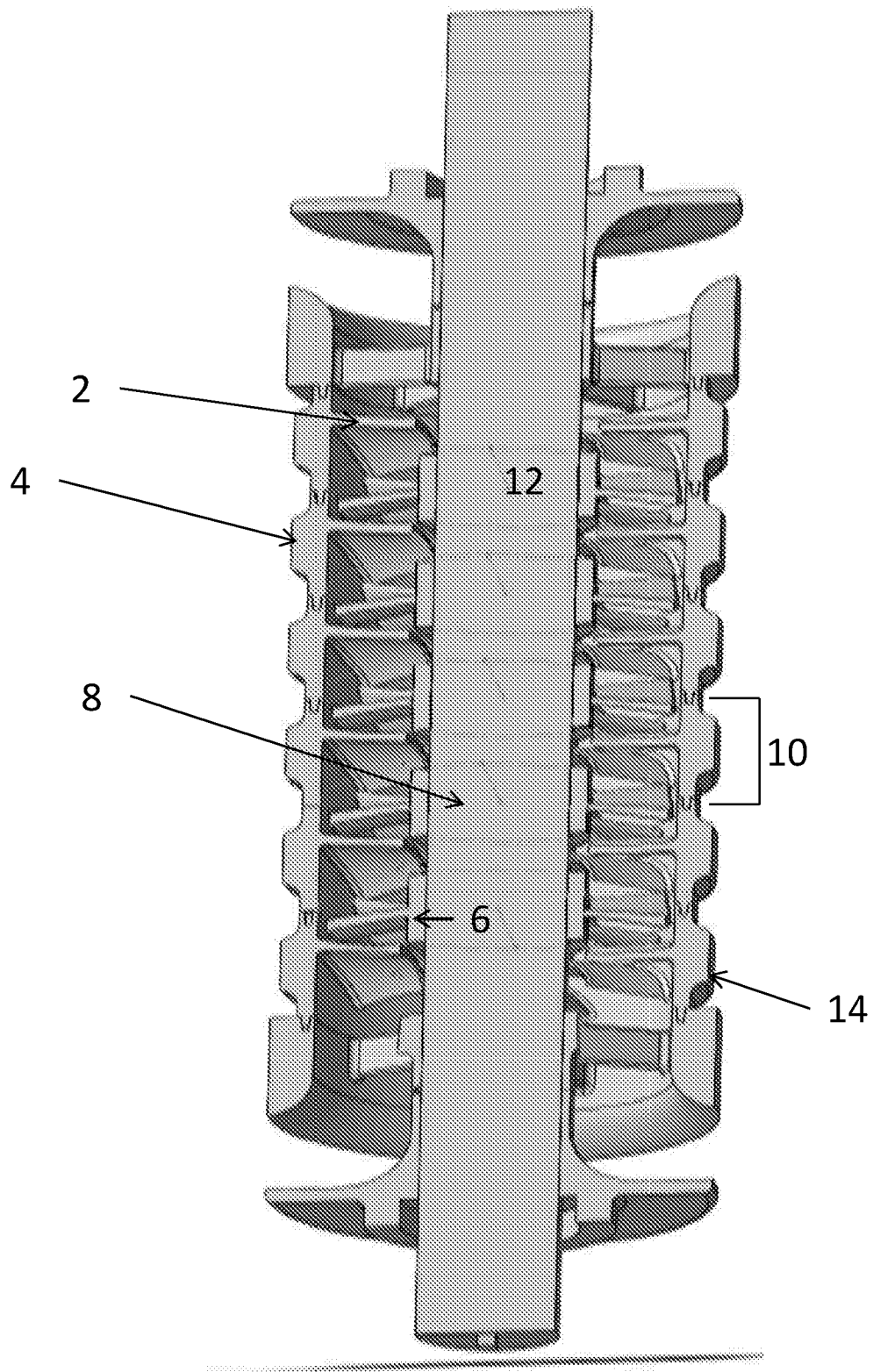


Fig. 2

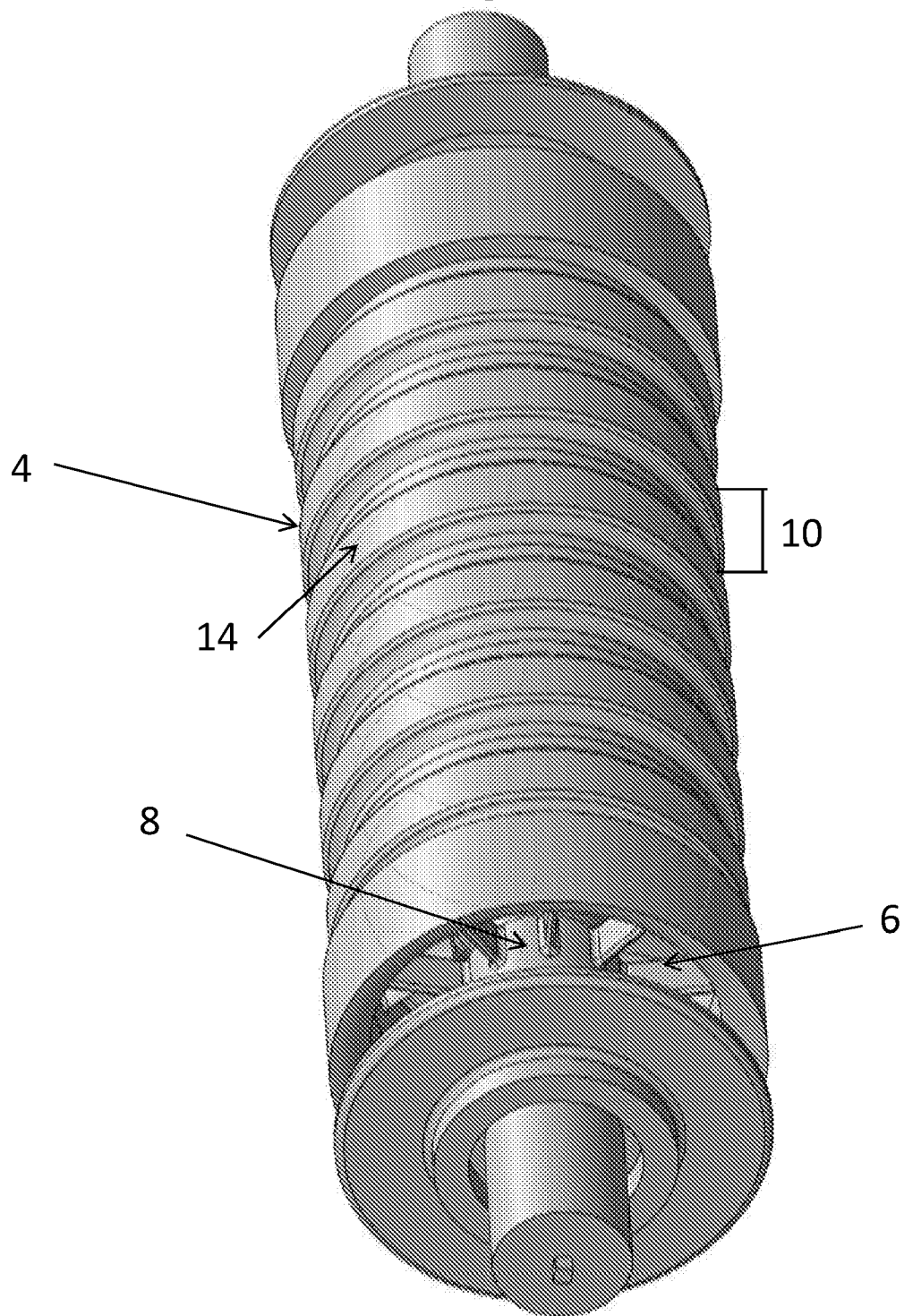


Fig. 3

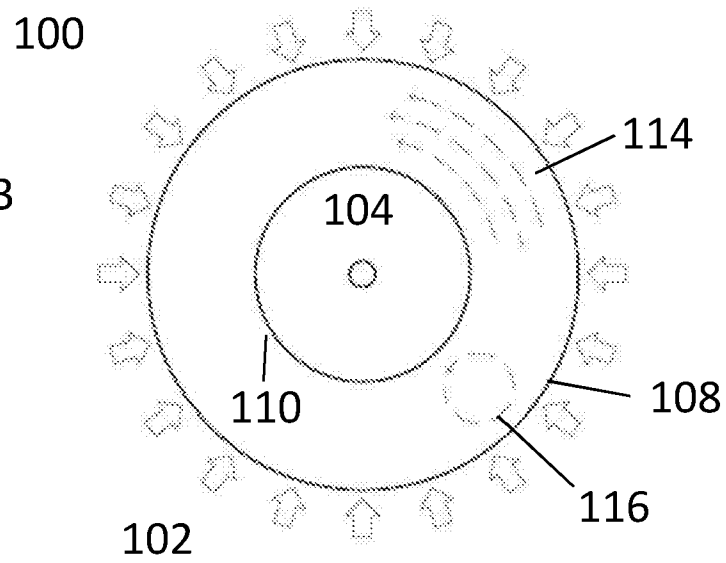
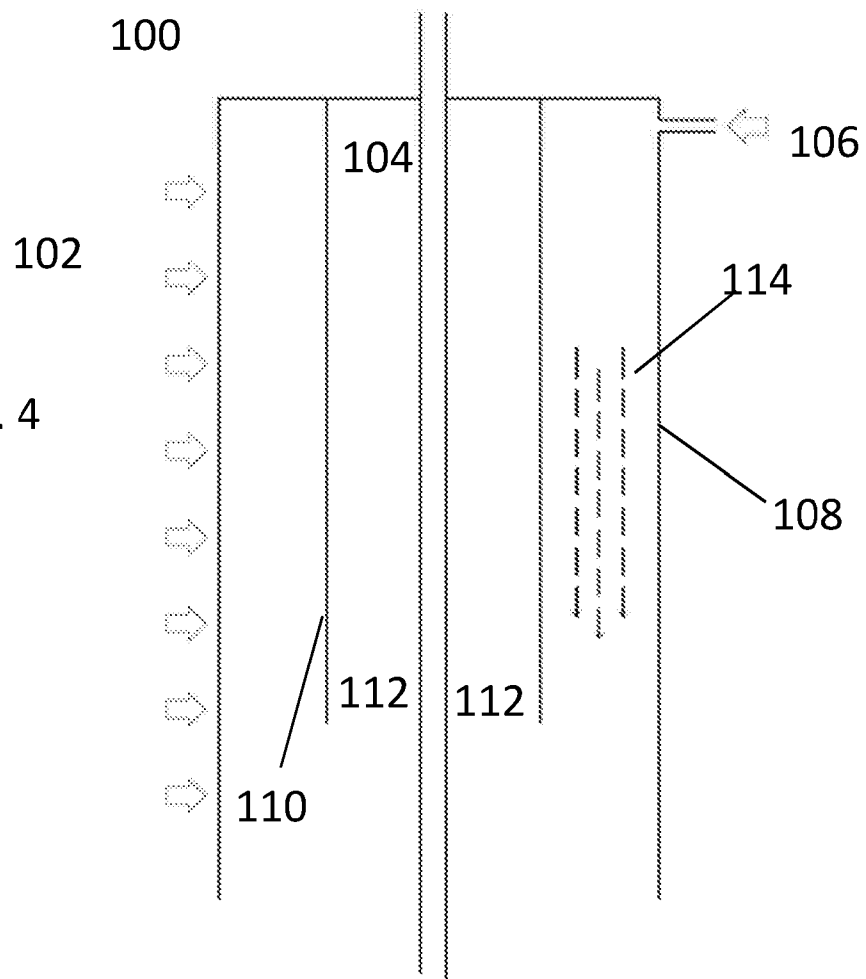


Fig. 4



An Axial Turbine

Field of the Invention

The featured devices are a type of axial turbine, and a combustor suitable for use with such a turbine.

Background

An axial turbine is a rotating machine which extracts useful shaft work from a motive fluid which is supplied to the turbine typically at high pressure and temperature, flowing generally axially along the device. Typical axial turbines use conventional aerodynamics, including stationary (stator) and rotating (rotor) blades, the stators converting the supplied pressure into swirl velocity and the rotors extracting that velocity due to the aerodynamic blade forces acting through a rotational movement. It is customary that such turbines consist of many stages of alternate rotor and stator sections, and that the rotors are affixed to a rotating central shaft and the stators are affixed to a stationary casing.

PCT application WO 2013/113324 depicts a statorless gas turbine with a rotating casing, with the rotors mounted to that casing instead of being mounted to a central shaft. This makes it more viable to use ceramic materials in the rotor blades, since it means that whereas hub-mounted rotor blades would be under high tensile stress due to centrifugal force, casing-mounted rotor blades would instead be under compressive stress. There is a modern trend in using ceramics to allow a very high temperature inlet flow, thereby boosting the efficiency and power density of a power generation cycle.

Turbines are often used in conjunction with combustors. Combustors are devices which ignite and burn a fuel to raise the temperature of a working fluid, ideally with little pressure loss and low formation of undesirable gas species such as carbon monoxide (CO) and mono-nitrogen oxides (NO_x).

A flame is a cascading oxidation reaction of a fuel whereby local exothermic heat (from either an ignition source or a prior flame) perpetuates local ignition only. This creates large spatial gradients in properties such as temperature and combustion air-fuel ratio, and hence can create undesirable products than a theoretical ideal process. It also requires relatively low working fluid velocities (typically on the order of 5-10 m/s) and hence a large volume (and hence mass) and requires very careful design to ensure flame stability.

Various forms of “flameless” combustion abound in the literature under names such as FLOX (flameless oxidation), CDC (colourless distributed combustion) and asymmetric whirl combustion. In all cases, the necessary activation energy for combustion is provided by means other than a conventional flame front, for example the combustion gases are greatly recirculated and/or preheated.

Summary of the Invention

The invention is according to the accompanying claims.

Description of Figures

Fig. 1 depicts a cross-section of an axial turbine.

Fig. 2 depicts an exterior view of the axial turbine of Fig. 1.

Fig. 3 depicts a conceptual diagram of the function of the combustor as viewed along the axis of rotation.

Fig. 4 depicts a conceptual diagram of the function of the combustor

Detailed Description

Unlike conventional axial turbines, which use rotor blades attached to a rotating shaft with stator blades attached to the surround casing, the turbine depicted in Fig. 1 and 2 reverses this by attaching the rotor blades 2 to an outer casing 4 which itself rotates, and attaching the stator blades 6 to a shaft 8 which does not rotate.

The turbine in Fig. 1 and 2 comprises rotor sections 10 and stator sections 12. The rotor sections comprise aerodynamic rotor blades 2 are positioned radially inside an outer circular ring 14. When fitting adjacent rotor sections 10 together, the outer rings 14 connect to form a continuous outer cylinder, the casing 4, all of which rotates together. Space is left between the rotor blades 2 for the stator blades 6. The stator sections 12 comprise the stator blades 6 comprised on an inner hub. The inner hubs of the stator sections 12 fit together to form the shaft 8 which is locked from rotation. (The shaft 8 may be locked from rotation by the casing

4). Typically, the process of assembly involves placing the rotor sections 10 and stator sections 12 alternately, to form two concentric assemblies with blades.

The arrangement of a stationary shaft 8 and a rotating outer casing 4, with the rotor blades 2 on the outer casing 4, means that in operation a compressive centrifugal force operates on the rotor blades 2, rather than putting them under tension as they would be if mounted on a rotating central shaft as in a conventional turbine. This is preferable if producing rotor blades 2 from ceramic materials, since ceramics tend to be more prone to fracture and creep when under tension. The placement of the rotor blades 2 on the outer casing 4 therefore reduces the mechanical demands on the rotor blades compared with a conventional arrangement.

Under the rotational loading, the casing 4 is in tension, which permits for a much simpler blade geometry to be used and hence a superior structural efficiency – that is, in operation a greater proportion of the turbine approaches the maximum limit for allowable stress, so that no material is needlessly operating below capacity. It is also easier to grind to a smooth finish, minimising the effect of surface flaws in potential crack initiation.

These features (placement of the rotor blades 2 on the casing 4 and having the casing under tension) allow the blades to be spun at higher speeds, increasing the stage work and thus reducing the number of stages, and hence weight, required for the same power (ie, the power to weight ratio is improved), with consequent benefits for material cost. It also allows the same aerodynamic load to be obtained from thinner blades - perhaps as little as 1mm thick - allowing the use of more blades per stage. Higher blade counts provide an optimal ratio of blade axial length to pitch when coupled with a reduced axial length, so using thinner blades reduces the overall length and weight of the turbine without affecting efficiency, which is particularly useful for vehicle applications.

In some embodiments of this invention, rotor sections 10 and stator sections 12 are formed as monolithic pieces, each incorporating many blades – preferably 20 to 60. Alternatively, some embodiments of the invention may allow for the attachment of individual blades, or the attachment of an assembly of a small number of blades, to a common hub for ease of manufacture.

Torque can be extracted from the rotating portions of the turbine in various ways, including but not limited to belts or gears attached to the rotating portion, or cantilevering the stator shaft 8 at one end and connecting the rotor back to a rotating shaft at the other end, or having the stator assemblies as two separate cantilevers, allowing the middle rotor stage to connect to a rotating central shaft.

Optionally, the outer rings 14 of the rotor sections 10 and/or the inner hubs of the stator sections 12, may comprise shrouds to limit tip leakage. Optionally, shrouds may instead be provided by the provision of additional ring and/or hub sections designed so as to interface with the rotor sections 10 and/or stator sections 12 accordingly to limit tip leakage and annular losses.

Either of the rotor sections 10 or stator sections 12 may or may not facilitate annular flare of the flow path, thereby creating conical assemblies, as is customary to retain a constant axial velocity as the flow reduces in pressure through the turbine.

Optionally, the outer casing 4 can be cooled externally to reduce the ceramic operating temperatures, provided that the resulting thermal stress does not offset this benefit. Conventional axial turbines use cooling via micro-channels embedded in the blades; providing exterior cooling to the outer casing 4 instead means that the rotor blades 2 and stator blades 6 do not require such channels, thus simplifying the design considerations and manufacturing process.

As far as ceramic turbine materials are concerned, it is preferred that reaction bonded silicon nitride (RBSN) is used. Reaction Bonded Silicon Nitride (RBSN) is unique amongst ceramics. One manufacturing method for RBSN is to machine shapes from a suitable silicon solid billet (said billets formed by cold-pressing a suitable silicon powder) prior to conversion to a nitride form via firing in a pure nitrogen atmosphere. Machining in the soft and ductile metal silicon phase greatly reduces the tooling cost compared with diamond grinding in a harder, more brittle ceramic phase. The nitride heating process causes minimal shrinkage compared with other sintering processes, thus requiring no further machining after firing. Alternatively, the silicon material (such as silicon powder) can be injection moulded, and due to the low shrinkage again requires no or very little further machining after firing. The product, however, tends to remain porous, so has inferior mechanical properties to higher density silicon nitrides such as those formed by sintering, which generally have far greater manufacturing costs due to expensive

grinding and more process steps (necessitated by the greater degree of shrinkage), or otherwise the substantial cost and time of adjusting injection moulds to correctly compensate for shrinkage. Optionally, the rotor sections 10 and stator sections 12 are made from RBSN.

- 5 Optionally, a sheath manufactured from a higher strength material may optionally slide on outside the said rotor sections 10, thereby adding substantial strength by resisting the centrifugal load in tension. Preferably, this sheath is cylindrical to make grinding the inner diameter easier. Other conical forms may also suffice in this role, adding cost but allowing the annulus to flare outwards in the latter stages, being aerodynamically preferable.

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The sheath material will preferably but not necessarily have similar thermal-mechanical properties to the material from which the rotor sections 10 are produced; where the rotor sections are produced from RBSN, examples of suitable materials include (but are not limited to) ceramics such as Silicon Nitride 282 (SN282) as provided by Kyocera, NT154 (as provided
15 by Coorstek), Sintered Silicon Nitride (SSN), Gas-Pressure-Sintered Silicon Nitride (GPS-SN), or High Gas-Pressure-Sintered Silicon Nitride (HGPS-SN). (Alternatively, the casing could be formed from metals, whether high temperature metals such as nickel alloys or high strength metals such as rolled steels, but with an insulating inner layer or suitable cooling strategy (if a metal casing is used, the sheath will typically be made out of nickel alloys). Metal cylinders
20 and cones are easy to manufacture, so could also be suitable for the casing if using a suitable interference fit to compensate for differential thermal expansion. Various graphite based materials may also work in role either as a rotor section or sheath without departing from the scope of the invention herein described.)

- 25 The higher strength material comprised in the sheath would generally be chosen to have superior, more reliable and/or better documented mechanical properties, thus being more capable of taking tension than the rotor hub components.

Since the sheath need only be a simple shape such as cylinder or cone, perhaps with some taper
30 in thickness, the grinding costs for materials such as SN282 or GPS-SN are much lower than would be the case for the highly complex aerodynamic blade shapes since grinders can be easily inserted axially along the internal faces, using less specialist grinding tools and using fewer machine axes. Accurate measurements of the sheath inner diameter can be used to grind the rotor hub outside diameters to suit, thereby taking advantage of the ease of grinding an outside

diameter and in the generally weaker of the two materials, thereby reducing the cost of grinding. The use of RBSN rotor pieces which may be cheaply manufactured despite possessing a complex geometry, arranged to favour compression, alongside a geometrically simple (and hence relatively low-cost) sheath comprised of stronger material arranged to favour tension, thus takes advantage of the favourable properties of both materials whilst mitigating the drawbacks.

Optionally, said sheath can be interference fit over the RBSN rotor section 10, putting the latter into residual compression and thereby reducing the tensile load in the weaker RBSN rotor sections 10 when spinning. Alternatively, the tolerance can be left sliding or using a transitional fit by applying a moderate temperature difference during assembly. In this case, it may be acceptable to allow the rotor hubs, generally the weaker material, to creep until an interference fit forms by itself, rather than machining the necessary fine tolerances before assembly.

Optionally, the rotor can be placed within a vacuum to prevent windage losses and effectively insulate the turbine casing, thereby reducing conductive losses and thermal transient stresses in the casing 4. The vacuum can be sealed towards the bearings via rotating seals, and the vacuum may be need to be maintained via a separate pumping system.

Optionally, the turbine may be used in conjunction with a combustor. To this end, there is herein described a novel combustor considered especially suitable for use with turbines according to the present invention, though it is also an inventive contribution to the art in its own right and may be used separately. The combustor described herein is a low weight, low NO_x , low CO recuperated air combustor, designed to provide a form of flame-less combustion with the ability to use a high temperature oxidiser (for example recuperated air) whilst keeping NO_x and CO levels low (i.e. lessens the need for secondary removal methods).

This is achieved by creating a stationary outer casing around some or all of the turbine rotor (including the sheath, if present) to create an annular space which can act as a combustion chamber which the turbine can rotate within. The specific dimensions of the outer casing will be condition and input dependent and this invention does not limit the dimensions to any specific figure. Flow passing along this annulus will thus form a 'Couette flow' whereby the circumferential velocity varies almost linearly between the inner and outer diameters. If air and fuel pass axially along this annulus, the conditions of flame-less combustion can be

achieved due to the exceptionally high recirculation and mixing, and/or the high air-fuel ratio achieved by reducing the fuel consumption required to ensure the flow reaches the desired combustor outlet temperature by using pre-heated air from a recuperator and/or conventional pre-combustor, and/or by the heat transfer coming from the turbine. The combusted air can then pass to the turbine inlet directly reducing the requirement for ducting.

No current flame-less technologies exploit a rotating inner diameter in this way since, in the absence of the featured turbine's unique layout, it would be difficult to otherwise justify the power-offtake, cost, weight and complexity of a rotational device for this purpose alone. Without it, the whirling flow would need to be sustained via an eccentric inlet, which would require using a nozzle to impart a velocity to the flow, resulting in a nozzle pressure loss, and the flow pattern would be difficult to control over much axial distance without spiral baffles, adding weight and further pressure loss.

In addition, the well-studied phenomenon of Taylor-Couette flow can be exploited. This can occur when a Couette flow rotates beyond a critical Taylor number, being a function of rotational speed, annular size and fluid properties. The resulting flow pattern exhibits toroidal vortices, known also as Taylor vortex flow. This flow pattern encourages a degree of mixing in the axial direction, helping to provide a further mechanism for the recirculation of heat and oxygen, achieving more uniform chemistry, and thus improving the conditions for flame-less combustion.

Optionally fuel and or oxidiser injection can occur axially and/or circumferentially along the whole outer surface of the combustion chamber, via methods well known to those experienced in the art, where desired in order to control the fluid temperature such that it matches that of the turbine to reduce thermal stress. This allows combustion temperatures can be controlled.

This type of combustor will result in reduced NO_x and CO formation due to a number of different factors. The excellent mixing of oxidiser and fuel reduces the tendency for hot zones in the combusted fluid such that thermal NO_x formation will be reduced. Additionally, excellent mixing and flame-less combustion results in no specific fuel-rich locations, thus resulting in low CO formation. As the combustor does not need cooling fluid, recuperated air can be used as the oxidiser - this means the fuel:air ratio can be decreased to provide the desired final temperature for the turbine. This reduces NO_x formation and CO formation by providing

sufficient oxygen for complete, rapid oxidation. The ability to control fluid and combustion temperature via variable fuel injection ports means that, even with recuperated air, the fluid temperature can be controlled by providing an approximate axially smooth heat distribution. Therefore, fluid temperatures will not reach greater than the turbine inlet temperatures and can be kept well below typical NO_x formation temperatures. The control of combustion temperatures and the use of recuperated air means that the temperature of the fluid can be kept sufficiently high resulting in reduction of CO formation.

Although the use of Taylor-Couette flow in a combustor has previously been envisaged in academia around the late 1990s by for example Vaezi, Aldredge, and Ronney, this has not been linked directly to flame-less combustion, for which the relevant literature is generally subsequent, but rather to turbulent flames which generally require far lower velocities than the featured turbine casing, as would be required for flame stability. Nor has it been linked to small scale gas turbines, let alone with turbines of the form herein described.

Optionally, the combustor can incorporate a separate chamber to initiate conventional combustion at lower speeds isolated from most of the effect of the turbine rotation. This has two purposes: 1) to bring the combustion inlet temperature up to that of the turbine exit temperature, thereby reducing radial thermal stresses, and 2) to begin combustion during the start-up process, which otherwise would not initially provide pre-heated air or not yet have as high a turbine rotational speed.

The turbine sheath would need to be exposed to combustion conditions, which is not classically preferable for a crucial structural part since surface degradation or deposition could promote cracking or cause imbalance. However, the high combustion temperatures should inhibit soot production, which would affect the turbine interior anyway, and the flame-less and highly lean nature of the combustion should not impinge on the sheath to cause local heating and corrosion. Optionally, a flame-retardant surfacing spray (of which countless variants exist) can be applied to the turbine sheath lest any conventional flames form, say, at low speeds during start-up or shut-down.

The two primary aims of this combustor are 1) to reduce NO_x production, as claimed by almost every paper on flame-less combustion, and 2) to minimise weight by incorporating parts of the turbine design such as the outer casing which would exist anyway. The turbine described above

can be operated with or without the aforementioned combustor, and while the described combustor utilises the turbine as the rotating inner diameter, any rotating inner diameter can be used (which would have the benefit of variable inner diameter rotation speeds).

- 5 Any combination of combustor, turbine, or both combined will have the ability to use a multitude of fuels with a range of Calorific values using the same basic geometric configuration. Both liquid and gaseous fuels can be utilised, including but not limited to biomethane, other biogas mixtures, landfill gas, natural gas, and kerosene.
- 10 Fig. 3 and Fig. 4 provide a conceptual diagram of a combustor 100 according to the present invention, with the turbine 104 positioned centrally and able to rotate and a stationary outer combustor casing 108 placed around the turbine. The distance between the stationary outer combustor casing and the casing 110 of the turbine may be optimised based on fuel mass and air mass. The combustor may optionally have fuel or air or fuel/air injection ports 102 arranged
- 15 circumferentially along its length, and may optionally have a primary air intake 106. Where a primary air intake is used, this may optionally deliver air to the combustor from a pre-combustor.

The turbine has inlets 112. The system depicted in these figures can incorporate any inlet

20 geometry. Beyond the inlets there is potential to provide extra space for pre-turbine combustion products. If one considers the axis of rotation of the turbine in Fig. 4 as an x -axis, the turbine may be located anywhere along that x -axis, either fully or partially inside the combustor and facing in either direction, so the air flow 114 within the combustor can pass axially in the positive or negative x -axis direction. The air flow 114 will also tend to flow circumferentially,

25 as shown in Fig. 3, with rapid recirculation following a Couette flow velocity distribution. It is also possible for Taylor-Couette recirculation 116 to take place.

Various embodiments and features have been described above. It should be recognized that these embodiments are merely illustrative of the invention presently claimed and may

30 themselves separately or in combination form inventive matter. Numerous modifications and adaptations thereof will be readily apparent to those of skill in the art without departing from the scope of the invention claimed or that may in future be claimed based on this disclosure.

Claims

1. An axial turbine comprising a stationary shaft comprising stator blades, and a rotating
5 outer casing comprising rotor blades.
2. An axial turbine comprising a rotating outer casing comprising rotor blades, wherein
the rotating outer casing is cooled externally.
- 10 3. An axial turbine comprising an axially arranged series of rotor sections, wherein each
rotor section comprises an outer ring and rotor blades.
4. The axial turbine of claim 3, additionally comprising an axially arranged series of
stator sections, wherein each stator section comprises an inner hub and stator blades.
15
5. The axial turbine of claim 4, further comprising at least one shroud comprised in an
inner hub.
6. The axial turbine of any of claims 3 to 5, further comprising at least one shroud
20 comprised in an outer ring.
7. The axial turbine of any of claims 3 to 6, wherein at least one rotor section is
comprised of reaction bonded silicon nitride.
- 25 8. The axial turbine of any of claims 3 to 7, wherein at least one rotor section comprises
an external sheath comprised of a material with a higher strength than the material
which the rest of the rotor section is comprised of.
9. The axial turbine of any of claims 3 to 8, wherein the material with a higher strength
30 than the material which the rest of the rotor section is comprised of has thermal and
mechanical characteristics similar to those of the material which the rest of the rotor
section is comprised of.

10. The axial turbine of claim 9, wherein the material which the rest of the rotor section is comprised of is reaction bonded silicon nitride.
- 5 11. The axial turbine of claim 10, wherein the sheath is comprised of silicon nitride 282 or gas-pressure-sintered silicon nitride.
12. The axial turbine of any preceding claim, incorporating the features of any other preceding claim.
- 10 13. An axial turbine substantially as described herein with reference to the accompanying drawings.
14. A combustor for a turbine, comprising a stationary combustor casing at least partially enclosing the turbine to form a combustion chamber in the space between the turbine and the casing, wherein the combustor is adapted to permit rotational motion of the turbine.
- 15 15. A combustor according to claim 14, wherein fuel, air, or fuel/air injection ports are distributed circumferentially around the combustor casing.
- 20 16. A combustor according to any of claims 14 or 15, wherein fuel, air, or fuel/air injection ports are distributed axially along the combustor casing.
17. A system comprising a combustor according to any of claims 14 to 16 and a turbine.
- 25 18. A system according to claim 17, wherein the turbine is enclosed entirely by the stationary combustor casing.
19. A system according to any of claims 17 to 18, wherein the turbine is a turbine according to any of claims 1 to 13.
- 30

Amendments to the Claims have been filed as follows:-

Claims

1. An axial turbine comprising an axially arranged series of rotor sections, wherein each rotor section comprises an outer ring and rotor blades and at least one rotor section is comprised of reaction bonded silicon nitride.
5
2. The axial turbine of claim 1, additionally comprising an axially arranged series of stator sections, wherein each stator section comprises an inner hub and stator blades.
- 10 3. The axial turbine of claim 2, further comprising at least one shroud comprised in an inner hub.
4. The axial turbine of any of claims 1 to 3, further comprising at least one shroud comprised in an outer ring.
15
5. The axial turbine of any of claims 1 to 4, wherein at least one rotor section comprises an external sheath comprised of a material with a higher strength than the material which the rest of the rotor section is comprised of.
- 20 6. The axial turbine of any of claims 1 to 5, wherein the material with a higher strength than the material which the rest of the rotor section is comprised of has thermal and mechanical characteristics similar to those of the material which the rest of the rotor section is comprised of.
- 25 7. The axial turbine of claim 6, wherein the material which the rest of the rotor section is comprised of is reaction bonded silicon nitride.
8. The axial turbine of claim 7, wherein the sheath is comprised of silicon nitride 282 or gas-pressure-sintered silicon nitride.
30
9. The axial turbine of any preceding claim, incorporating the features of any other preceding claim.



Application No: GB1702648.5 **Examiner:** Ms Megan Parker
Claims searched: 1 and 19, when dependent upon claim 1 **Date of search:** 21 March 2017

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 and 19	US 6397577 B1 (SONDERGAARD) Abstract, figure 2, column 3, line 62 - column 4, line 61
X	1 and 19	JP S59120701 A (MITSUBISHI) Abstract, figure 2
X	1 and 19	DE 102011000420 A1 (UNIV DRESDEN TECH) Abstract, figures 3 and 4
X	1 and 19	EP 0462724 A1 (WHITFORD) Abstract, figures 1-3
X	1 and 19	EP 3023617 A1 (GEN ELECTRIC) Abstract, figure 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^X :

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

F01D; F02C

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

WPI and EPODOC

International Classification:

Subclass	Subgroup	Valid From
F01D	0005/03	01/01/2006



Application No: GB1702648.5

Examiner: Ms Megan Parker

Claims searched: 1-9

Date of search: 23 June 2017

Patents Act 1977

Further 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	1-9	DE 3016817 A1 (BOEDDEKER) See abstract and figure 1, noting especially outer ring 1 and rotor blades 2
X	1 and 4-9	GB 2069065 A (ROCKWELL) See abstract, figures 1-3, noting especially outer ring 22 and blades 18

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^X :

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

B22F; C04B; C22C; F01D; F02C

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

WPI, EPODOC, Patent Fulltext

International Classification:

Subclass	Subgroup	Valid From
F01D	0005/03	01/01/2006