(12) UK Patent Application (19) GB (11) 2508141 (13) A

(43) Date of A Publication 28.05.2014

(21) Application No: 1220888.0

(22) Date of Filing: 21.11.2012

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(51) INT CL:
F01P 1/04 (2006.01) ***F01P 3/12*** (2006.01)
F02B 55/06 (2006.01)

(56) Documents Cited:
GB 2457456 A **GB 2194988 A**
DE 102011014861 A1 **US 5397223 A1**
US 4236496 A1 **US 4102615 A1**
US 3042009 A1

(58) Field of Search:
INT CL **F01C, F01P, F02B**
Other: **EPODOC, WPI**

(54) Title of the Invention: **Cooling systems for rotary engines**
Abstract Title: **Closed-loop cooling system of a rotary engine**

(57) A rotary engine comprises a closed-loop cooling system having a fluid flow path passing through an interior of a rotor 21 of the engine and a heat exchanger (12, figure 1). A fan 27 is mounted on and driven directly by an output shaft 20 of the engine and is arranged to circulate a fluid around the fluid flow path. Ideally, the fan is a centrifugal fan and the fluid a gas mixture of air and oil, whereby the oil is added by an oil injector (14, figure 1) and the fan directs the mixture along an annular path 28 towards an outlet port (29, figure 3) leading to the heat exchanger. Once cooled, the mixture may pass through openings of a first side plate 26, then through at least one opening (22, figure 3) provided in the rotor to cool and lubricate the interior of the rotor. The mixture may then pass through openings 23 of a second side plate 25 that lead back to an inlet of the fan. A pressure relief valve (13, figure 1) may be fluidly coupled to a reservoir of the injector. A rotary engine having a water cooled output shaft is also claimed.

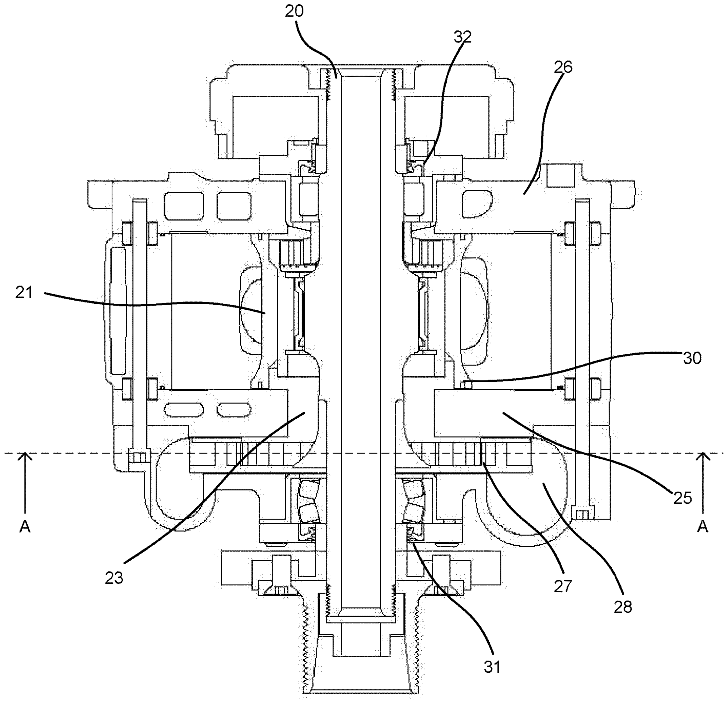

FIG. 2

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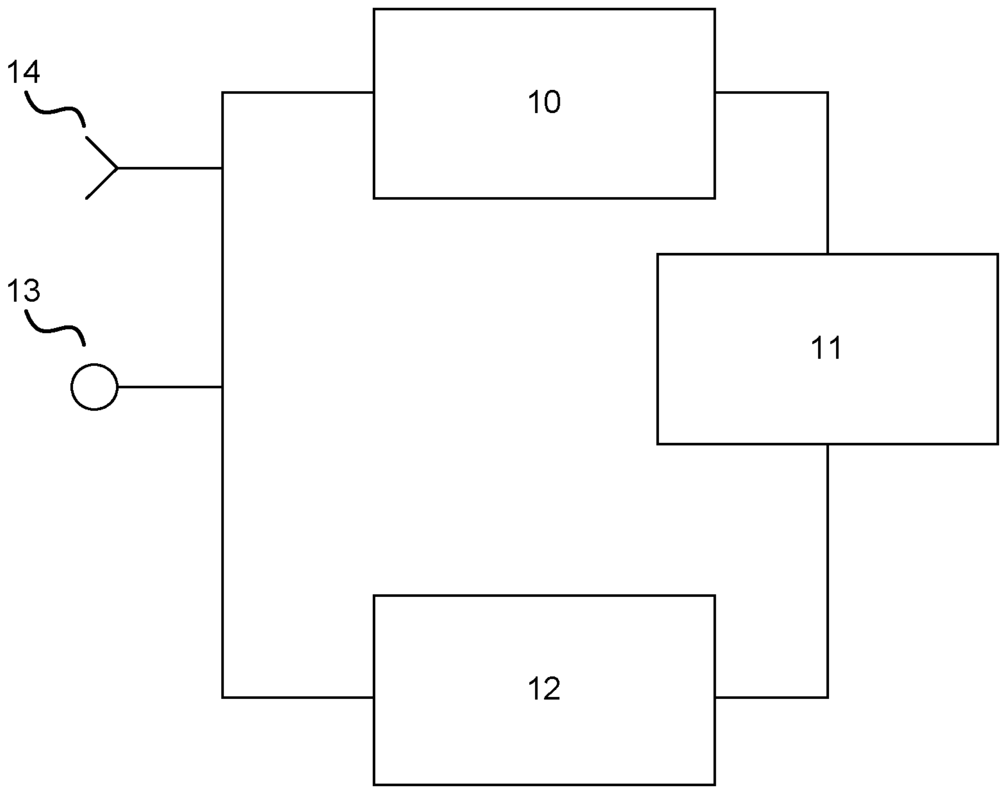

FIG. 1

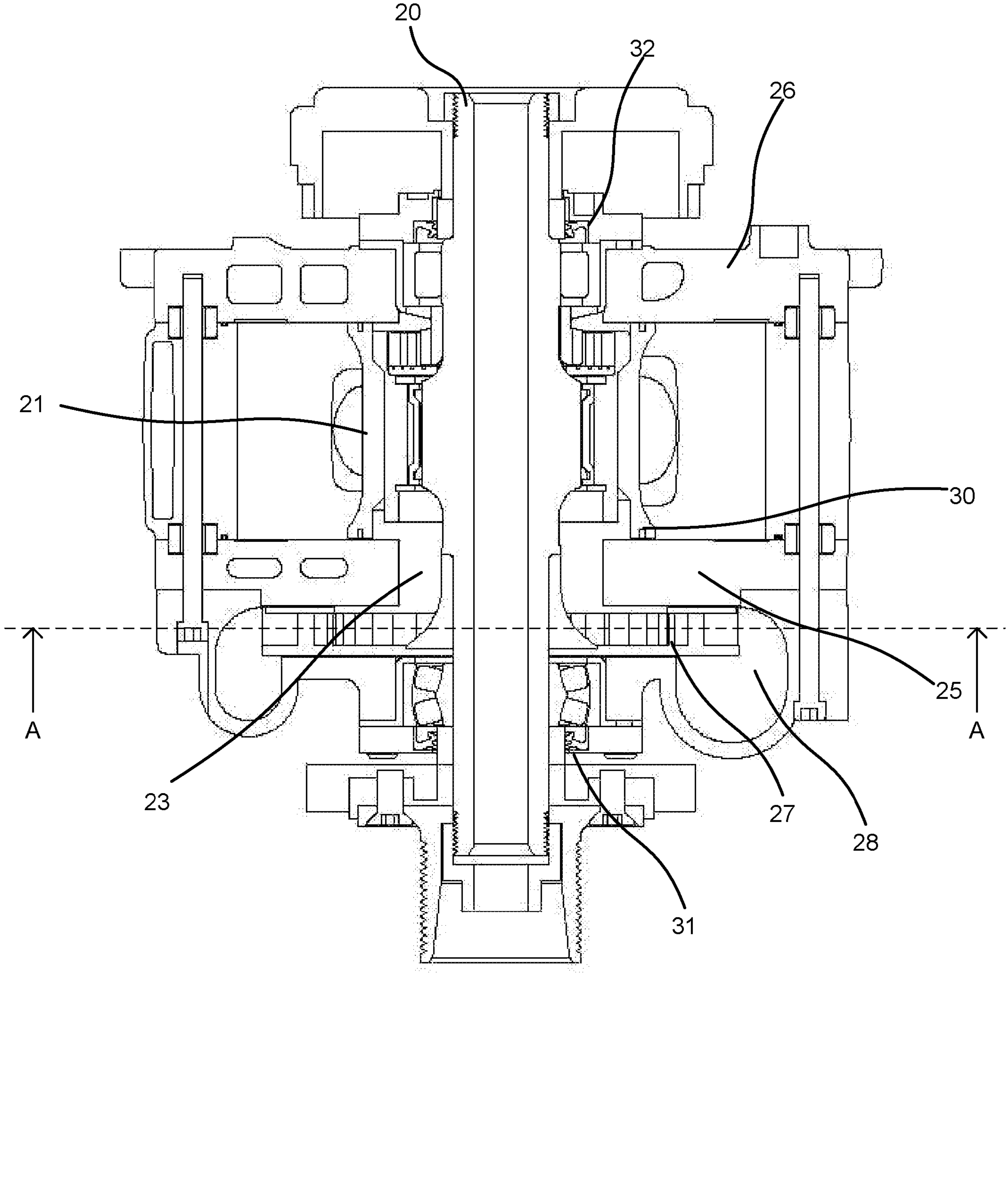

FIG. 2

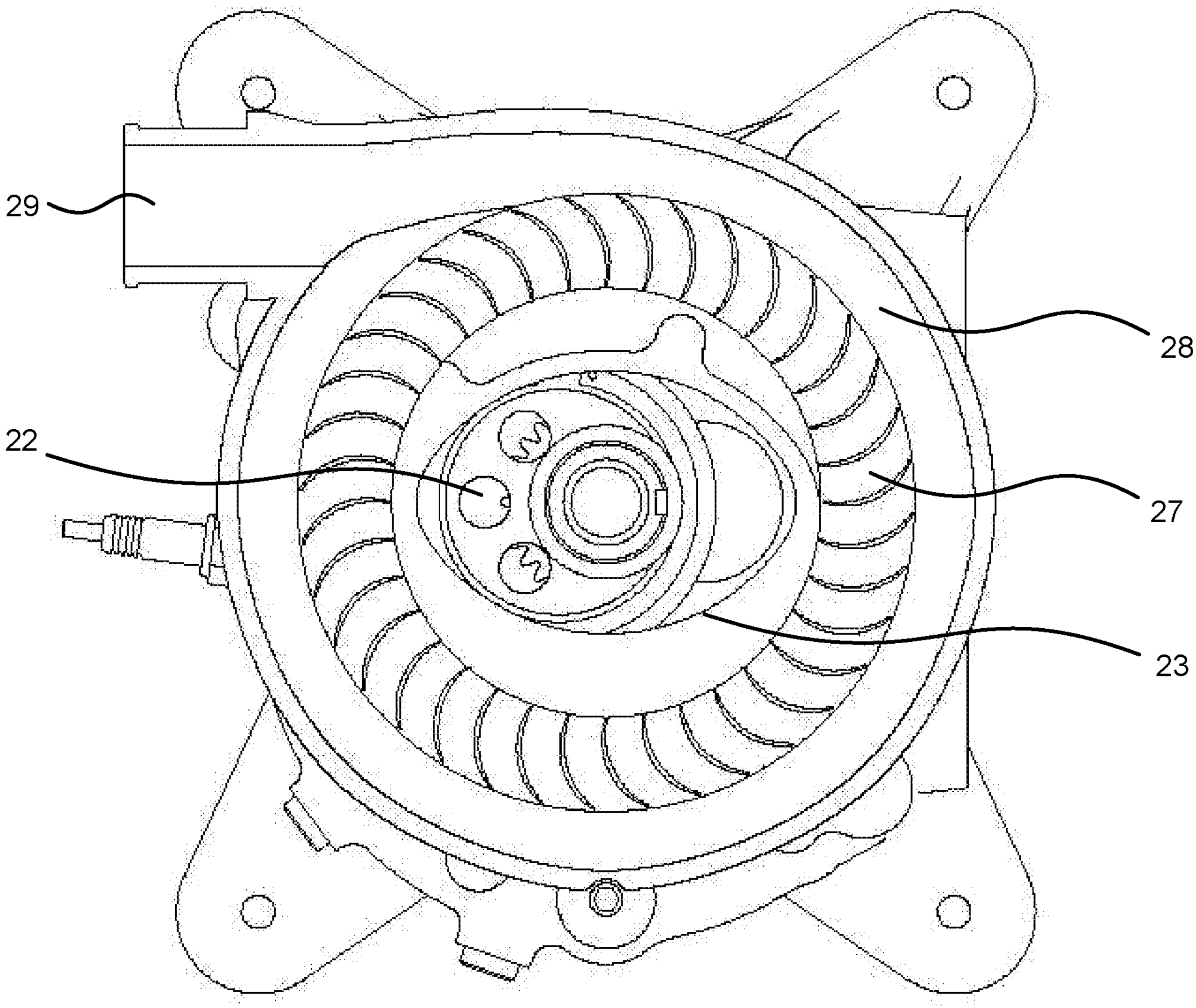

FIG. 3

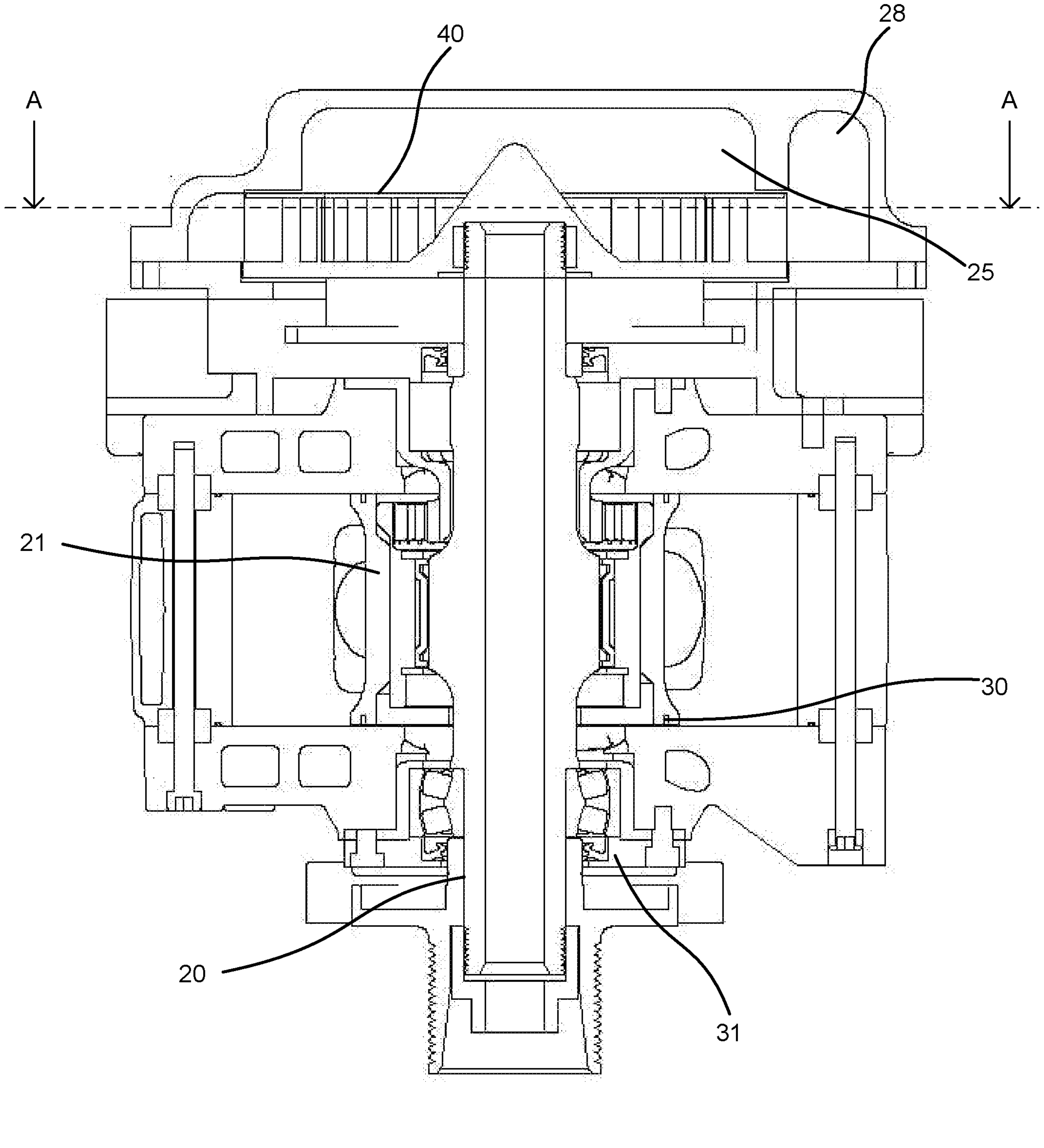

FIG. 4

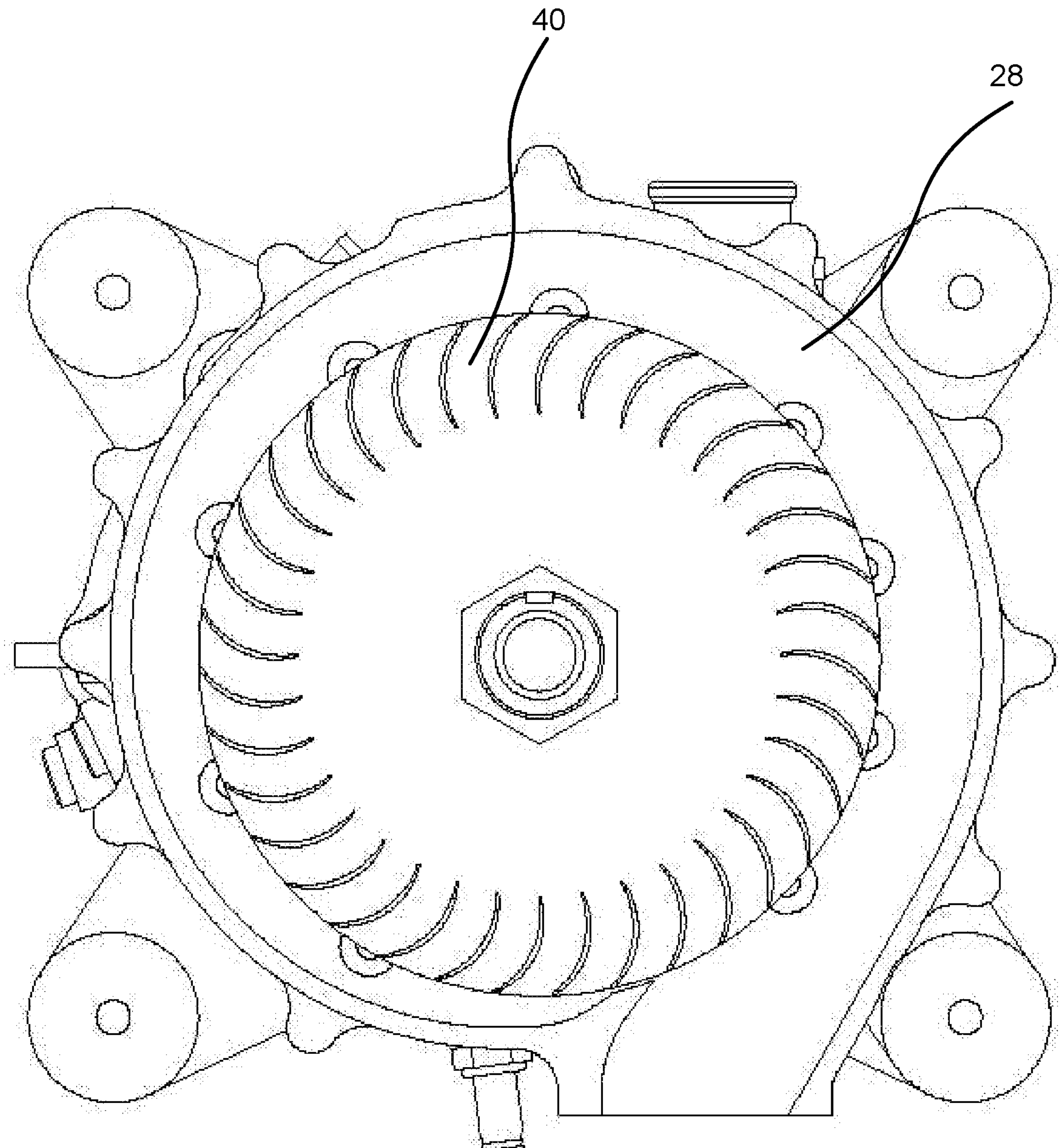

FIG. 5

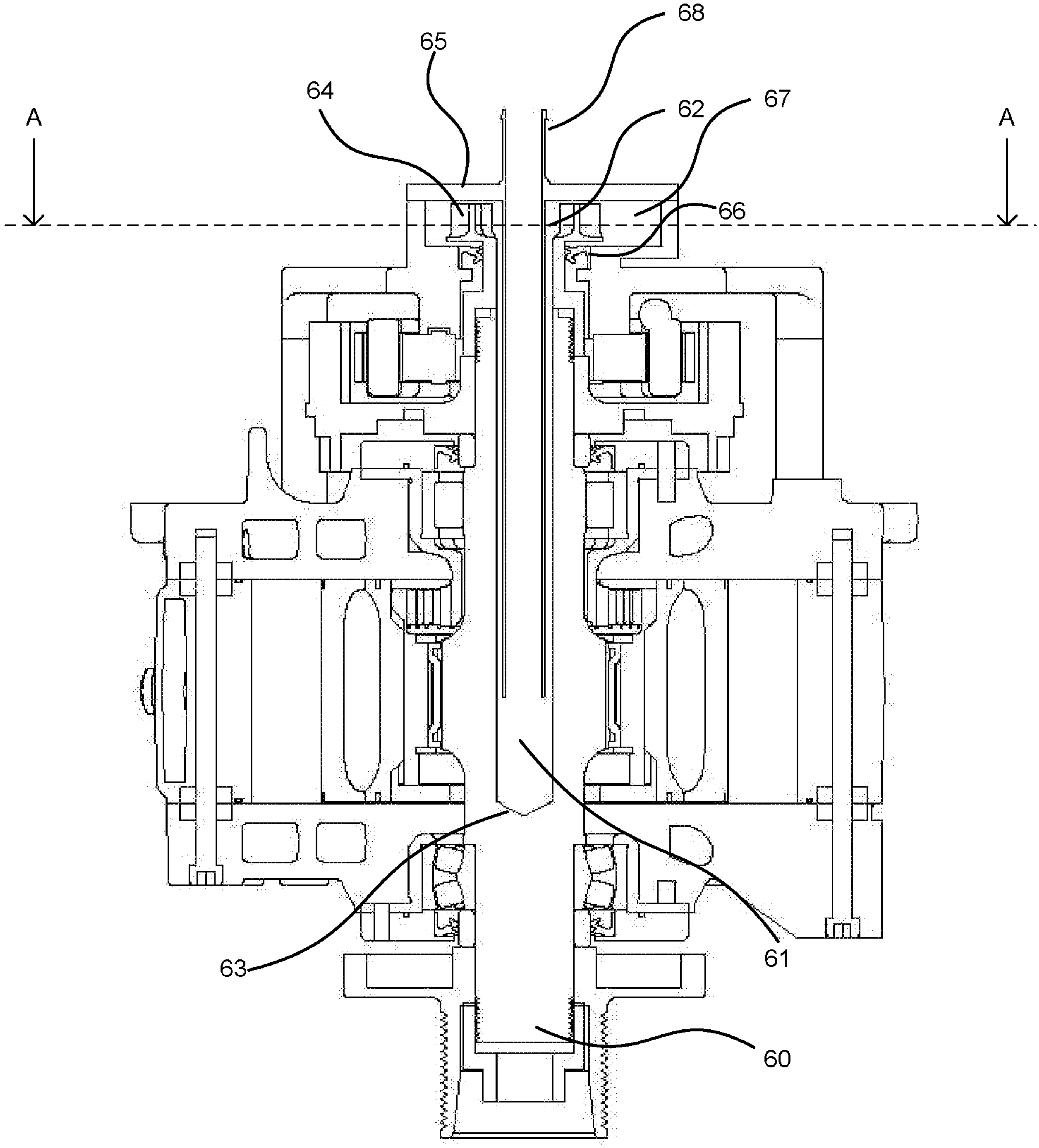

FIG. 6

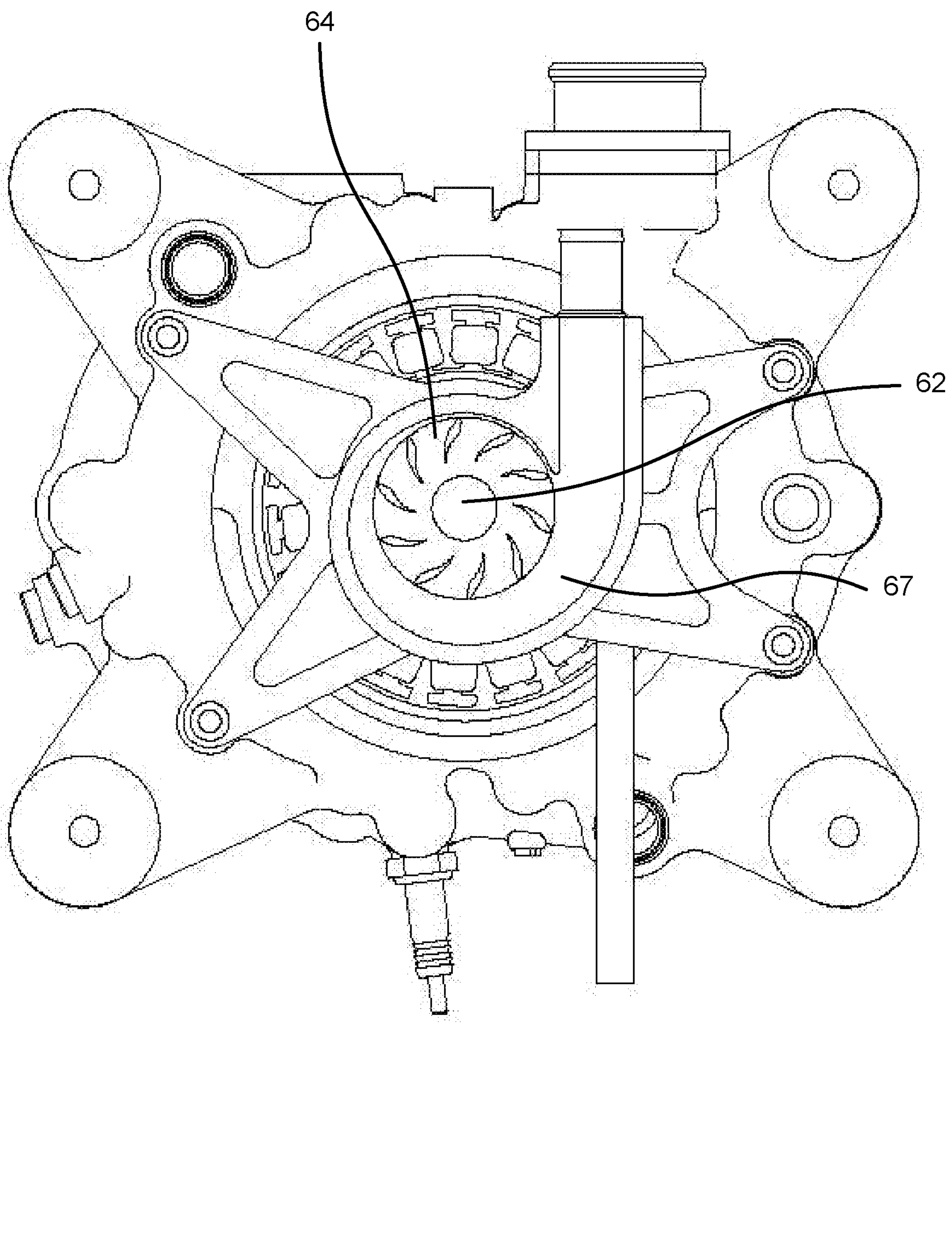

FIG. 7

COOLING SYSTEMS FOR ROTARY ENGINES

Background

In a number of applications rotary internal combustion engines (for example, the Wankel layout) provide an attractive alternative to the more commonly utilised reciprocating piston engine.

In a rotary engine a rotor is mounted eccentrically on an output shaft. The rotor is geared to the shaft such that rotation of the output shaft causes eccentric rotation of the rotor, and vice versa. For example, a Wankel engine uses a three-side (approximately triangular) rotor within an epitrochoidal chamber.

Cooling of a rotary engine can present challenges. Reciprocating piston engines are typically either air cooled through the crankcase, cylinder block and heads, or water cooled by water flow paths in the cylinder block. Oil supplied to the crank shaft also assists with cooling. Although a similar water cooling system can be implemented for a rotary engine, cooling of the output shaft and gearing linking that shaft to the rotor is inefficient as those components are far removed from the cooling medium.

Furthermore, the gears and bearings in the interior of the rotor must be lubricated, which makes circulating cooling media in that area difficult.

There is therefore a requirement for improved cooling systems for rotary engines.

The embodiments described below are not limited to implementations that solve any or all of the disadvantages of known publish/subscribe systems.

Summary

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

There is provided a rotary internal combustion engine, comprising a closed-loop cooling system having a closed-loop fluid flow path through the interior of a rotor of the engine and a heat exchanger, and a fan configured to circulate a fluid around the flow path, wherein the fan is mounted on and driven directly by the engine's output shaft.

The fluid may be a gas.

The gas may be a gas which has blown-past the rotor's side-seals.

The fan may be a centrifugal fan.

The fan may have a diameter of 160mm or greater.

The closed-loop cooling system may comprise a pressure-relief valve configure to limit the maximum pressure in the closed-loop fluid flow path.

The closed-loop cooling system may comprise an oil injector for injecting oil into gas flowing in the closed-loop fluid flow path for lubricating the interior of the rotor.

The closed-loop cooling system may comprise an oil injector for injecting oil into gas flowing in the closed-loop fluid flow path for lubricating the interior of the rotor.

There is also provided a rotary internal combustion engine, comprising an output shaft having an internal cooling chamber with a closed distal end within the output shaft, and an open proximal end at an end of the output shaft; a tube within the cooling chamber spaced from the internal wall of the cooling chamber and from the distal end of the cooling chamber, the tube and cooling chamber forming a cooling flow-path through the centre of the tube, between the end of the tube and the distal end of the cooling chamber, and between the exterior surface of the tube and the interior surface of the cooling chamber; and an impeller for circulating water through the cooling flow-path.

The tube may be stationary with respect to the engine body.

The impeller may be mounted on the open end of the output shaft.

The exterior surface of the tube may be spaced from the interior surface of the cooling chamber by 2 mm or more.

The preferred features may be combined as appropriate, as would be apparent to a skilled person, and may be combined with any of the aspects of the invention.

<u>Brief Description of the Drawings</u>

Embodiments of the invention will be described, by way of example, with reference to the following drawings, in which:

Figure 1 shows a schematic block diagram of a cooling system;

Figures 2 and 3 show cross-sections through a rotary engine comprising an embodiment of a cooling system;

Figures 4 and 5 show cross-sections through a rotary engine comprising an embodiment of a cooling system; and

Figures 6 and 7 show cross-sections through a rotary engine comprising an embodiment of an output shaft cooling system.

Common reference numerals are used throughout the figures to indicate similar features.

<u>Detailed Description</u>

Embodiments of the present invention are described below by way of example only. These examples represent the best ways of putting the invention into practice that are currently known to the Applicant although they are not the only ways in which this could be achieved. The description sets forth the functions of the example and the sequence of steps for constructing and operating the example. However, the same or equivalent functions and sequences may be accomplished by different examples.

Figure 1 shows a schematic diagram of a cooling system for a rotary engine. A closed cooling circuit is provided to circulate cooling fluid through the interior of the rotor 10 to remove heat from the engine. The cooling circuit flows fluid comprises a fan 11 to drive cooling fluid around the circuit. A heat exchanger 12 extracts heat from the cooling fluid, for example by heat exchange to atmospheric air in a gas-gas heat exchanger or to a coolant liquid in a gas-liquid heat exchanger.

The cooling fluid flows from the heat exchanger 12 back to the rotor interior 10 to complete the closed circuit. The cooling circuit may be pressurised by gasses blowing past the rotor side seals and accordingly a pressure relief valve 13 may be provided to limit the pressure within the cooling circuit.

An oil injector 14 is provided to inject oil into the cooling fluid to lubricate the working parts in the interior of the rotor. Since the cooling circuit is a closed loop, the oil circulates continuously and is only lost via leakage at the side seals of the rotor into the combustion chamber. The oil creates a film over the side plates which is then burnt in the combustion process. Previous cooling systems have used a total loss lubrication system which is both expensive to run and environmentally unfriendly. The closed-loop arrangement mitigates these disadvantages. In an embodiment the oil injector is a high-pressure injector capable of injecting oil into the pressurised cooling system without utilising a pressurised reservoir. As explained above, the cooling system may be pressurised to 1 bar. A low-pressure injector could be utilised by also pressurising the reservoir.

Where a non-pressurised oil reservoir is utilised the vent of the pressure release valve may be fluidly connected to the oil reservoir such that air exiting through the pressure release valve passes through the oil reservoir on its path to atmosphere. Oil suspended in the released cooling gasses is collected in the oil reservoir before the gasses are vented to atmosphere. This arrangement allows recycling of the oil, thereby reducing oil use.

Figure 2 shows a cross-section through a rotary engine parallel with, and through, the output shaft 20. Figure 3 shows a cross through A-A in Figure 2. With the exception of the points highlighted below the engine shown in Figures 2 and 3 is conventional and its operation will therefore be apparent to the person skilled in the art. The engine of Figures 2 and 3 comprises a cooling system as described with reference to Figure 1. In an example engine, the combustion chamber volume is 300 cc.

The rotor 21 is provided with at least one opening 22 such that a flow path is open from a first side to a second side of the rotor to allow the flow of fluids through the rotor 21 parallel with the output shaft 20. In an example, the at least one opening 22 may be semi-circular in shape with a 20mm radius. Openings 23 are also defined in the first 25 and second 26 side plates such that fluids can enter the interior of the rotor 21, flow through the at least one opening 22 in the rotor 21, and exit through the other side plate. The side plate openings 23 are positioned within the path traced by the rotor side seals during rotation of the rotor 21 such that they do not disrupt the seal created by those seals. This leads to the ‘lemon’ shape of opening seen in the figures. In a typical example, the opening has dimensions of 95mm and 65mm on the long and short axis.

A centrifugal fan 27 is mounted on the output shaft 20 such that it is driven by and rotates with the output shaft 20. The opening 23 in the first side plate 26 forms a flow path from the rotor interior to the centre, inlet, of the centrifugal fan 27. An annular outlet flow path 28 is defined at the exterior of the fan 27 to collect the output from the fan 27. As will be appreciated, the flow path 28 is shown as a continuous annulus in Figure 3, but alternative shapes may be utilised according to design requirements. The dimensions of the flow path 28 increase in an axial direction around the flow path, but not in a radial direction. This provides an increase in cross-sectional area of the flow path 28, giving improved fan performance, without increasing the diameter of the fan housing.

The direct mounting of the fan 27 on the output shaft 20 removes a requirement for a geared or belt connection to drive the fan 27. This direct connection has improved mechanical efficiency, thereby improving engine power output. Due to the direct mounting of the fan 27 it rotates at the same speed as the output shaft 20 and cannot be geared to provide a higher speed and hence greater output. The limitation in fan speed, and associated reduction in output, has previously been thought to prevent direct mounting of the fan.

A fan capable of providing sufficient output when rotating at typical output shaft speeds has now been designed, thereby allowing this mounting. In an example embodiment, a suitable fan may be centrifugal fan, 160mm in diameter with forwarding curving blades of 10mm height. In further embodiments the fan diameter may be larger than 160mm. In an example, the fan should be capable of providing an airflow with a dynamic pressure of 12" water gauge (48 kPa).

As well as improved mechanical efficiency, the direct mounting of the fan also provides a reduced physical size and simpler construction.

An outlet port 29 in the fan output flow path provides for a fluid connection through a heat exchanger and back to the opening in the second side plate 25, thereby providing a closed flow path as described with reference to Figure 1. The parts of the cooling circuit not shown in Figures 2 and 3 may be provided as exterior parts connected to the engine, or in alternative designs may be provided as part of the engine itself.

As seen in Figure 2 the rotor side seals 30 form part of the wall of the closed cooling circuit. Gasses blowing past those seals 30 pressurise the cooling circuit, thereby providing a pressurised cooling medium. The increase in pressure gives a denser cooling medium with an increased heat capacity, thereby increasing the cooling ability of the circuit. The blow-past gasses are combustion gasses and are hence hot. However, since the system is a closed loop this initially higher temperature is reduced and the gasses then serve as coolant. Once the cooling circuit is pressurised the blow-past is minimal due to the approximately equal pressures either side of the side seals and therefore there is not continuous flow of hot gasses into the cooling circuit.

As noted above, a pressure relief valve is provided in the cooling circuit to prevent the pressure increasing above a predetermined level, for example 1 bar which is bled off back into the oil reservoir and re-cycled into the closed cooling/lubrication circuit. The output shaft main seals 31, 32 also form part of the cooling circuit wall and this pressure limitation protects those seals from damage.

In use, as the engine starts up the output shaft 20 drives the fan 27 which circulates cooling fluid around the closed circuit. Blow past the side seals 30 increases the pressure in the cooling system. As the pressure in the cooling circuit increases blow-past reduces due to the reduced pressure difference between the combustion chambers and the cooling circuit. The fan circulates the gasses around the cooling circuit. The temperature of the gasses reduces from the combustion temperature due to heat transfer through the heat exchanger, and the gasses then transport heat from the rotor interior to the heat exchanger, thereby cooling the engine.

Figures 4 and 5 show an alternative configuration for implementing the cooling system of Figure 1. Functionally the configuration is the same as described hereinbefore, but the fan 40 is mounted in a separate housing to the main engine parts. The fan 40 is mounted on the output shaft 20 as described above. The fan inlet and outlet 28 are connected to the side plate openings by fluid conduits exterior to the engine (not shown).

Figure 6 shows a cross-section parallel with and through the output shaft 60 of a rotary engine comprising a further embodiment of a cooling system. Apart from the features described below, the function and operation of the engine shown in Figure 6 is conventional. Figure 7 shows a cross-section through line A-A in Figure 6.

The output shaft 60 is at least partially hollow comprising a longitudinal cooling chamber 61 extending along the axis of the output shaft 60 from a first end 62 to a second closed end 63.

A water impeller 64 is attached to the open end 62 of the output shaft 60 to turn with that output shaft 60. A water pump housing 65 encloses the water impeller 64 and the open end 62 of the output shaft 60. The output shaft 60 is sealed to the engine body by a seal 66 to create a sealed chamber 67. In an example embodiment the water impeller is 50mm in diameter. As will be appreciated, the diameter of the impeller may be selected according to the required circulation of the cooling system.

A tube 68 extends through the water pump housing 65 and into the cooling chamber 61 within the output shaft 60. The tube 68 is sized such that it is spaced from the interior of wall of the output shaft 60 to allow cooling fluid to flow between the tube 68 and the output shaft 60. That space is in fluid communication with the inlet to the impeller 64. The tube 68 is attached and sealed to the water pump housing 65 and so remains stationary with respect to the engine body, and does not rotate with the output shaft 60.

In an example embodiment the inner diameter of the cooling chamber is 20mm. In further embodiments the diameter may be greater than 20mm. In an example, the inner diameter of the tube 68 is 13mm and the outer diameter is 15mm. These dimensions, when used with a 20mm diameter cooling chamber, provided a flow path around the outside tube having a height of 2.5mm and extending around the circumference of the tube. In alternative embodiments different dimensions may be utilised.

An inlet to the tube 68 is provided for connection to the output of the impeller 64 via a heat exchanger to form a closed cooling path. The closed cooling path is typically filled with water to act as a cooling medium, but as will be appreciated other coolant fluids may be utilised.

In use the impeller 64 is rotated by the output shaft 60 and pumps fluid around the cooling circuit through the heat exchanger, into the centre of the tube 68, and back through the output shaft 60 to the impeller 64 inlet.

The cooling circuit described in relation to Figure 6 achieves direct cooling of the output shaft 60 while only requiring a single additional water seal 66 compared to uncooled systems. The input and output of the water flow path are on a single side of the engine reducing the dimensions required to add the cooling system. The interior of the output shaft 60 is in very close proximity (both physically and thermally) to the output shaft eccentric bearing and rotor gearing thereby providing efficient heat transfer from those components to the cooling fluid.

The cooling chamber is shown extending to approximately the centre of the eccentric bearing, but as will be appreciated the length of the chamber may be selected to provide the required thermodynamic performance.

Two cooling systems have been described hereinbefore for cooling rotary engines. The two systems may be utilised alone or in combination.

Any range or device value given herein may be extended or altered without losing the effect sought, as will be apparent to the skilled person.

It will be understood that the benefits and advantages described above may relate to one embodiment or may relate to several embodiments. The embodiments are not limited to those that solve any or all of the stated problems or those that have any or all of the stated benefits and advantages.

Any reference to 'an' item refers to one or more of those items. The term 'comprising' is used herein to mean including the method blocks or elements identified, but that such blocks or elements do not comprise an exclusive list and a method or apparatus may contain additional blocks or elements.

It will be understood that the above description of a preferred embodiment is given by way of example only and that various modifications may be made by those skilled in the art. Although various embodiments have been described above with a certain degree of particularity, or with reference to one or more individual embodiments, those skilled in the art could make numerous alterations to the disclosed embodiments without departing from the spirit or scope of this invention.

Claims

1. A rotary internal combustion engine, comprising

a closed-loop cooling system having a closed-loop fluid flow path through the interior of a rotor of the engine and a heat exchanger, and

a fan configured to circulate a fluid around the flow path, wherein

the fan is mounted on and driven directly by the engine's output shaft.

2. An engine according to claim 1, wherein the fluid is a gas.

3. An engine according to claim 2, wherein the gas is gas which has blown-past the rotor's side-seals.

4. An engine according to any preceding claim, wherein the fan is a centrifugal fan.

5. An engine according to any preceding claim, wherein the fan has a diameter of 160mm or greater.

6. An engine according to any preceding claim, wherein the closed-loop cooling system comprises a pressure-relief valve configure to limit the maximum pressure in the closed-loop fluid flow path.

7. An engine according to any preceding claim, wherein the closed-loop cooling system comprises an oil injector for injecting oil into gas flowing in the closed-loop fluid flow path for lubricating the interior of the rotor.

8. An engine according to claim 7 when dependent on claim 6, wherein a vent outlet of the pressure-relief valve is fluidly coupled to a reservoir of the oil injector.

9. A rotary internal combustion engine, comprising

an output shaft having an internal cooling chamber with a closed distal end within the output shaft, and an open proximal end at an end of the output shaft;

a tube within the cooling chamber spaced from the internal wall of the cooling chamber and from the distal end of the cooling chamber, the tube and cooling chamber forming a cooling flow-path through the centre of the tube, between the end of the tube and the distal end of the cooling chamber, and between the exterior surface of the tube and the interior surface of the cooling chamber; and

an impeller for circulating water through the cooling flow-path.

10. An engine according to claim 9, wherein the tube is stationary with respect to the engine body.

11. An engine according to claim 9 or 10, wherein the impeller is mounted on the open end of the output shaft.

12. An engine according to any of claims 9 to 11 wherein the exterior surface of the tube is spaced from the interior surface of the cooling chamber by 2 mm or more.

Application No: GB1220888.0 **Examiner:** Colin Whitbread

Claims searched: 1-8 **Date of search:** 14 March 2013

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,Y	X:1-5 Y:6-7	US 4102615 A1 (IRGENS) See lines 65-67 of column 4, lines 18-45 of column 5, lines 10-65 of column 6 and figures 3-4, noting rotary engine 211 having gas recirculation (i.e. closed-loop) system 253 including heat exchanger 220 and centrifugal fan 103 arranged to drive fluid along the gas recirculation system.
Y	6-7	GB 2457456 A (GARSIDE) See whole document noting rotary engine comprising closed circuit (i.e. closed-loop) system including a heat exchanger 24, centrifugal fan 27 configured to circulate an air/oil mixture around the closed circuit, and pressure relief valve 32, the fan being mechanically driven by the engine.
A	-	DE 102011014861 A1 (WOELFLE ET AL) 27.09.12 (See WPI Abstract Accession No. 2012-M51906 [65] and figure 1 noting rotary engine comprising a closed cooling circuit including a cooler 16 {i.e. heat exchanger}, and a fan 11 configured to circulate a fluid around the circuit).

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

F01C; F01P; F02B

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

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
F01P	0001/04	01/01/2006
F01P	0003/12	01/01/2006
F02B	0055/06	01/01/2006

Intellectual Property Office

Application No:	GB1220888.0	**Examiner:**	Colin Whitbread
Claims searched:	9-12	**Date of search:**	18 February 2014

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	9 and 12	US 3042009 A1 (NSU MOTORENWERKE AG AND WANKEL GMBH) See lines 9-17 of column 6 and figure 7 especially, noting shaft 20 of a rotary engine, the shaft having a bore 116 that receives a pipe 114 to provide a cooling liquid flow-path.
X	9 and 12	US 5397223 A1 (AGINFOR AG) See the passages from line 66 of column 3 to line 31 of column 4 and figure 3, noting shaft 24 of a rotary engine, the shaft having a longitudinal bore 53 that receives an oil guide sleeve 39 to provide a cooling oil flow-path.
A	-	US 4236496 A1 (BROWNFIELD) See the passages from line 49 of column 5 to line 44 of column 6 and figure 5, noting shaft of a rotary engine, the shaft having a cylindrical shaped opening that receives a tube 62 to provide a cooling water flow-path.
A	-	GB 2194988 A (WANKEL GMBH) See lines 2-82 of page 2 and figure 1, noting shaft 2 of a rotary engine, the shaft having a concentric bore that receives a tube 11 to provide a coolant flow-path.

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

F01C; F01P; F02B

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

EPODOC, WPI

Intellectual Property Office

International Classification:

Subclass	**Subgroup**	**Valid From**
F01P	0001/04	01/01/2006
F01P	0003/12	01/01/2006
F02B	0055/06	01/01/2006