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(54) Title: OPPOSED PISTON ENGINE AND LUBRICATION SYSTEM

(57) Abstract: With reference to Figure 1, the invention relates to an op-
posed stepped piston engine having a power piston and an air piston, con-
figured to provide in- cylinder air swirl, in which fuel is sprayed from at
least a first injector towards a power cylinder liner of the power cylinder
in the direction of the air piston, after closure of the air transfer ports but
prior to the one or more fuel ignition injections.

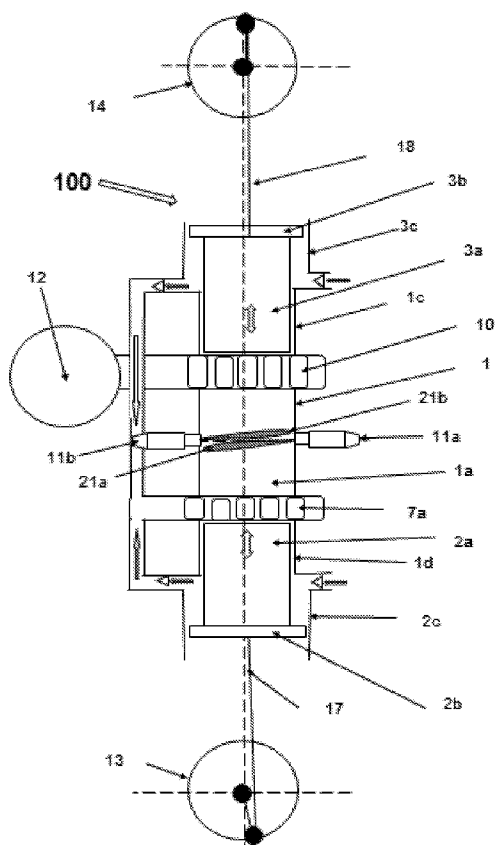


Fig.1



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Title: Opposed piston engine and lubrication system

5 Description of Invention

This invention relates to opposed piston engines, and to a system for lubricating the upper cylinder of opposed stepped piston engines. The invention applies to all opposed piston and opposed stepped piston
10 compression ignition and spark ignition engines that have at least one fluid injector in each cylinder. It also applies to all dual fuelled engines where a first more ignitable fuel is used to ignite a second less ignitable fuel, so as to avoid the need for a spark ignition system. The invention may also be applied to multi-fuelled opposed piston and opposed stepped piston engines with at least
15 two fluid injectors in each cylinder which are arranged for the first fluid injector to provide a more ignitable fuel which is used to ignite a second less ignitable fuel from the second fluid injector.

It is well known that diesel fuel is an excellent lubricant and that most engines
20 with in-cylinder fuel injection may be susceptible to fuel impingement on the cylinder walls under some operating conditions. However, this invention is not solely confined to diesel or compression ignition engines but also applies to all dual fuelled and spark ignition engines as well.

25 In particular, opposed piston engines can generate ordered swirl by virtue of their extensive air ports that can be readily be tuned to provide the desired degree of tangential flow required to achieve the target swirl. In common with other engines having swirl, the mean swirl level in the opposed piston engine cylinder increases as the pistons move towards their inner dead centres.
30 Depending on applications, the centrifugal acceleration from peak air swirl towards inner dead centre typically reaches 1500-2000 m/s², or in other terms

approximately 150-200 times gravitational acceleration of 9.81 metres per second per second.

5 In slowly fuel evaporating situations and below fuel auto-ignition temperatures, fuel injected into the cylinder will diffuse radially outwards and the swirl can deposit the fuel onto the cylinder wall.

10 This situation is usually avoided, as fuel on the cylinder wall is unlikely to combust and is not available to provide useful work, and therefore diminishes the engine fuel efficiency.

This invention makes use of the early injection and deposition of fuel or lubricating oil from in-cylinder injectors onto the power cylinder walls to provide lubrication for the power pistons and their piston rings.

15 This invention takes advantage of a modulated version of fuel impingement on cylinder walls to provide precise and metered lubrication for the power piston rings and power piston skirt of a stepped piston engine, in which the power piston and power piston rings would otherwise run dry.

20 The following descriptions are provided with reference to Figure 1, Figure 2 and Figure 3 to help interpretation of this text. The descriptions are intended to help and are not intended as universal definitions.

25 A piston is the moving part of a cylindrical positive displacement volumetric machine that acts on the fluid to displace, compress or expand the fluid. The piston is usually of a cylindrical male shape which engages in a cylinder of a female shape, the motion of the piston moving the fluid to and from the cylinder.

30

A power piston operates in the combustion cylinder and compresses and expands the gases in the combustion cylinder as part of the combustion process.

- 5 An opposed piston engine or compressor is an engine or compressor in which two power pistons slide in a common cylinder compressing and expanding a common volume of air.

10 An opposed stepped piston engine is an opposed piston engine or compressor that has at least one air transfer piston.

15 A double diameter, also known as stepped, piston is a piston with two diameters, each of which separately engages one of two female cylinders, the diameters of said cylinders lying on a common axis. The two piston diameters are usually rigidly connected, with the smaller diameter piston being the power piston and the larger diameter being the air transfer piston.

20 A stepped cylinder comprises a first cylinder which has a first diameter for a first length and which is joined to a second cylinder which has a second diameter for a second length, the axes of first and second cylinders lying on the same axis.

25 The stepped piston and the stepped cylinder may be part of either a compressor or an engine.

An air transfer piston is a piston used to transfer air from the air intake system to the power piston.

30 The air ports of a 2-stroke engine are those apertures or openings in the cylinder wall of the cylinder of the 2-stroke engine which control the admission of air to the cylinder that will be used for combustion.

The exhaust ports of a 2-stroke engine are those apertures or openings in the cylinder wall of the cylinder of the 2-stroke engine which control the expulsion of exhaust gases from the cylinder after combustion.

5

The “air” piston is the power piston which controls the opening and closing of the air ports of the combustion cylinder.

10 The “exhaust” piston is the power piston which controls the opening and closing of the exhaust ports of the combustion cylinder.

The power cylinder or power cylinder liner of a stepped opposed piston engine is that part of the cylinder or cylinder liner in which the power piston operates, i.e. the “first cylinder” as in the definition of a stepped cylinder.

15

Mid cylinder, or mid cylinder liner, or mid liner is the half-way point between the two open ends of the cylinder, or cylinder liner, or liner.

20 The “phase” of a moving part of an engine relates the relative timing of that moving part to other moving parts. The phase angle is usually defined in terms of crankangle difference between the two moving parts. For example, the exhaust piston of an opposed piston engine usually moves with an advance of 20° crankangle versus the air piston; this means that the exhaust piston will reach its inner dead centre position before the air piston reaches its
25 inner dead centre position, i.e earlier in terms of the engine operating cycle.

“Inner dead centre” (IDC) refers to innermost position of a piston in its travel in the cylinder of an opposed piston engine, i.e. the closest position towards the centre of the cylinder, and usually the closest point to the other piston.

“Outer dead centre” (ODC) refers to outermost position of a piston in its travel in the cylinder of an opposed piston engine, i.e. the furthest position from the centre of the cylinder, and usually the furthest point to the other piston

- 5 With opposed piston engines and opposed stepped piston engines, the air and exhaust pistons approach inner dead centre simultaneously, separated in crankangle only by the phase angle between the air and exhaust pistons.

10 The forward side of an air transfer piston is the side of the larger diameter of the stepped piston which acts in-phase with the air piston or an exhaust piston.

The reverse side of an air transfer piston is the side of the larger diameter of the stepped piston which acts in anti-phase with the air piston or the exhaust piston.

15

“Scavenging” air flow of a 2-stroke engine is the frequently used jargon to describe the air flow that passes into a 2-stroke engine, some of which is retained for combustion. The remainder of the air passes through to the exhaust system, removing or scavenging the burned products of combustion, also known as the exhaust products of combustion, from the cylinder.

25 Ports of 2-stroke engines are the apertures in the cylinder walls that enable the flow of gases from or into the cylinder. For example, reference Figure 1, 10 are the exhaust ports that allow the exhaust to flow from the cylinder, when uncovered by the power piston 3a, to the exhaust pipe 11. Air ports 7a (Figure 1) allow fresh air from the engine scavenge pumps to enter the combustion cylinder volume 1a; the ports are opened and closed by the motion of the power piston 2a.

30 “Side” injection is a spray, usually entirely liquid, from a controlled on-off flow delivery device, commonly known as an injector, which is located in the

cylinder wall or liner of an opposed piston engine or cylinder wall or liner of an opposed stepped piston engine. The spray from the injector is usually directed substantially across the cylinder bore in a divergent plume. Engines with cylinder heads, i.e. engines which are not opposed piston engines, usually
5 have “central” injection in which the injector is located in the cylinder head and the spray(s) from the injector move radially outwards towards the cylinder liner or cylinder wall.

A spray in the context of this disclosure is a moving body of fluid in a gas,
10 normally mainly in a coherent liquid phase at its inception, but becoming a mixed phase of gas and liquid as the fluid moves through the gas, the coherent liquid breaking into multiple droplets that disperse in the gas via their momentum and/or via evaporation.

15 Fuel injected for compression ignition combustion is usually introduced into the cylinder close to the IDC positions of the pistons, i.e. at a point where the compression temperatures are high to ensure fuel evaporation and auto-ignition. Sometimes, earlier injection, or “pilot”, or “pre-injections” are used to assist or control the main combustion phase and reduce emissions and
20 combustion noise. These injections would generally be significantly later than the closing points of the exhaust or air ports.

Where used herein, the term ‘ignition injection’ means the injection of fuel that is to be used in combustion. This includes the ‘main’ injection of fuel, and
25 ‘pilot’ or ‘pre-injections’ that are used to assist or control the main combustion phase as described above. In this way, the cycle of the engine may include one or more fuel ignition injections. This excludes the injection of fuel purely for the purpose of lubricating a part of the engine, such as a power piston. For example, injection of fuel against a wall of the power piston results in that fuel
30 substantially being used for lubricating the piston, and substantially all the injected fuel is used for lubrication rather than fuelling the combustion.

A plume is usually a part of a spray pattern, i.e. an injector may deliver a spray which comprises at least one main body or plume of liquid, or several bodies or plumes of liquid.

5

An aerosol is a mixture of liquid droplets and gas with the liquid droplets being sufficiently small to be transported by any motion of the gas.

10 A dual fuelled engine is one which uses a very small quantity of a first fuel, such as a cetane based fuel, for the ignition process, and a second less ignitable fuel, such as natural gas, as the main fuel for combustion. This avoids the need for a sparking plug and a high tension ignition system.

15 Swirl, also known as in-cylinder swirl, in this context is the ordered bulk movement of air about the main axis of the cylinder of an opposed stepped piston engine. In this invention, bulk air swirl in the cylinder may be generated by arranging either the inlet ports, or the exhaust ports, or both, to have a partly tangential entry angle in to (in the case of the air ports) or from (in the case of the exhaust ports) the main cylinder volume, so that the air entering
20 the cylinder arrives with some tangential motion, or the exhaust leaves the cylinder with some tangential motion, which in turn induces tangential motion in the gas contents of the cylinder.

25 According to an aspect of the invention we provide an opposed stepped piston engine having a power piston and an air piston, configured to provide in-cylinder air swirl, in which fuel is sprayed from at least a first injector towards a power cylinder liner of the power cylinder in the direction of the air piston, after closure of the air transfer ports but prior to the one or more fuel ignition injections.

30

In an embodiment, we provide an opposed stepped piston engine with in-cylinder air swirl in which fuel or lubricating oil is sprayed from at least a first injector towards the power cylinder liner in direction of the air piston after closure of the air transfer ports but prior to the pre or main fuel injections.

5

In another embodiment we provide an opposed stepped piston engine in which fuel or lubricating oil is sprayed from at least a first injector towards the power cylinder liner in direction of the air piston and also in the direction of the exhaust piston. The fuel or oil is sprayed from this at least first injector
10 towards the power cylinder liner prior to the pre or main fuel injections, typically with the injection commencing 100°-60° crankangle before inner dead centre of the leading crankshaft.

Further features of the above aspects of the invention are described in the
15 appended claims.

Embodiments of the invention will now be described, by way of example only, with reference to the following figures, of which:

Figure 1 is a general stick diagram in elevation of a single cylinder opposed
20 piston engine with stepped pistons, also showing typical fuel injector locations.

Figure 2 is a diagram of a plan section diagram through the mid-point of the cylinder of an opposed piston engine with stepped pistons showing a first injector with a single plume.

Figure 3 is a diagram of a plan section diagram through the mid-point of the
25 cylinder of an opposed piston engine with stepped pistons showing a second injector with a single plume.

Figure 4 is a diagram of a plan section diagram through the mid-point of the cylinder of an opposed piston engine with stepped pistons showing a first and second injector, and a third injector with 4 spray plumes.

Figure 5 is a diagram of a plan section diagram through the mid-point of the cylinder of an opposed piston engine with stepped pistons showing a first and second injector, and a fourth injector with 4 spray plumes.

Figure 6 is a diagram of a sectional elevation diagram through the cylinder of an opposed piston engine with stepped pistons showing a first and second injector with at mid cylinder, and a third injector between the mid cylinder and the air ports, with four spray plumes, and a fourth injector between the mid cylinder and the exhaust ports, also with 4 spray plumes.

In all these figures, large, long and voluminous spray plumes are indicated, this being entirely diagrammatic and to ease depiction of the concepts. As will become clear from the following description of the invention, the proposed sprays for lubrication will be very narrow, small and will have truncated plumes which move mainly in a liquid form as the compression temperatures and pressures are relatively low when the fuel or oil is injected for piston, piston ring and liner lubrication.

The invention is particularly suitable for use in engines that are configured to provide swirl. Swirl, also known as in-cylinder swirl, is the ordered bulk movement of air about the main axis of the cylinder of an opposed stepped piston engine – as is well known in the art. For example, bulk air swirl in the cylinder may be generated by arranging one or more air transfer ports (the inlet ports, or the exhaust ports, or both) to have a partially tangential entry angle (i.e. having a tangential component) in to (in the case of the air ports) or from (in the case of the exhaust ports) the main cylinder volume. In this way, the air entering the cylinder arrives with some tangential motion, or the exhaust leaves the cylinder with some tangential motion, which in turn induces tangential motion in the gas contents of the cylinder.

As stated above, the term 'ignition injection' refers to the injection of fuel that is to be used in combustion, including the 'main' injection of fuel, and 'pilot' or

‘pre-injections’ that are used to assist or control the main combustion phase. In this way, the cycle of the engine may include one or more fuel ignition injections. Fuel injected purely for the purpose of lubricating a part of the engine, such as a power piston, is not included in the ‘ignition injection’ stage.

- 5 For example, injection of fuel against a wall of the power piston results in that fuel substantially being used for lubricating the piston, and substantially all the injected fuel is used for lubrication rather than fuelling the combustion.

10 In all embodiments of the invention, the term ‘fuel’ is not confined to diesel, as the engine of the present invention is suitable for use with a wide range of fuels. Furthermore, embodiments are not confined to compression ignition engines but the features described herein are also applicable to all dual fuelled and spark ignition engines as well.

- 15 In embodiments, with reference to Figure 1, lubricating oil from crankshafts 13 and 14 of the opposed stepped piston engine will be flung onto the internal diametral stepped cylinder surfaces 2c and 3c respectively as soon as the crankshafts turn and are supplied with oil. Very little of the oil arriving onto the internal diametral stepped cylinder surfaces 2c and 3c will be transported by
20 the stepped pistons 2b and 3b towards the internal diametral power cylinder surfaces 1c and 1d because of the change in cylinder diameters between cylinders 2c and 1d, and between cylinders 3c and 1c. Any lubricating oil that does pass onto the power pistons 2a and 3a may then be scraped into the ports 7a of the incoming air or out of the exhaust ports 10 into the exhaust
25 gases or scavenge air. Very little oil therefore reaches the power piston cylinder 1a for lubrication of the power pistons 2a and 3a and their piston rings (which are not shown in Figure 1).

- 30 With reference to Figure 1, in embodiments, the opposed stepped piston engine 100 with swirl 22 (Figure 2) has at least a first injector 11a located in the cylinder wall 1. This injector may be the injector that provides fuel for both

combustion and power piston and piston ring lubrication. Alternatively, a further injector, shown later in Figures 4, 5 and 6, is dedicated to injecting fuel or oil for lubricating purposes only. The first injector 11a may have two, three, four, five or six nozzle holes, approximately slightly divergent to the main axis of the first injector 11a, that distribute fuel in two, three, four, five or six spray plumes across the cylinder bore, respectively. In the case of a first injector 11a used to provide the fuel for combustion, the spray plumes are typically configured to traverse the cylinder bore without impingement on cylinder liner 1 when the cylinder pressures are approaching their maximum compression value.

Injection of fuel from first injector 11a for lubrication prior to the ignition injection(s) (i.e. pilot, pre-injection or main injection) for combustion, commences shortly after closure of the air ports, i.e. typically 100° crankangle before IDC and probably no later than 60° crankangle before IDC. The fuel injection pressures are selected to ensure that the fuel plume(s) becomes substantially an aerosol cloud at some small distance from the cylinder liner 1, e.g. at 2-3mm radial distance from the cylinder wall. The injection period is extremely short, for example only 2° crankangle, so that typically only extremely small amounts of fuel are injected per injection; short injection periods are also known to help break-up of the fuel spray. During the remaining approximately 95° of the compression stroke, the injected fuel droplets of this early injection for cylinder liner lubrication are centrifuged through the air in the cylinder onto the cylinder wall 1 in the path of the oncoming power piston 2a. With first injector 11a and its typical two, three, four, five or six nozzles holes, there will be a corresponding number of fuel depositions on the cylinder wall 1 from the plumes, notionally separated by the divergent angles between the nozzle holes.

In a similar fashion, in embodiments, first injector 11a may have nozzle holes that spray a first set of plumes towards the opposite wall of the cylinder or liner

1, biased towards the air piston 2a, and a second set of plumes towards the opposite wall of the cylinder or liner 1, biased towards the exhaust piston 3a. In this case, the injection of fuel from first injector 11a for lubrication prior to the ignition injection(s) for combustion, would commence shortly after closure
5 of the exhaust ports, i.e. typically 90° crankangle before IDC and probably no later than 60° crankangle before IDC .

In embodiments, the fuel for lubrication is injected every 5000 cumulative revolutions of engine operation. For example, typically one injection is made
10 in every five minutes with the engine at 1000rpm, or an injection every one minute with the engine at 5000rpm.

In summary, in embodiments, an opposed stepped piston engine 100 with swirl (i.e. the inlet ports, or the exhaust ports, or both, have a partially
15 tangential entry/exit angle) is provided, in which fuel is sprayed from at least a first injector towards the power cylinder liner 1 in direction of the air piston 2a after closure of the air transfer ports 7a but prior to the ignition injection(s) (pre or main fuel injections), and in which the injection spray from the first injector is timed to begin 100° - 60° crankangle before inner dead centre of the leading
20 crankshaft. In other embodiments, the plumes are directed towards the cylinder liner 1, but biased in the direction of the exhaust piston 3a with the start of injection for lubrication timed to begin 90° - 60° crankangle before inner dead centre of the leading crankshaft.

25 With reference to Figures 1 to 3, in embodiments, opposed piston engines with swirl 22 may use a second injector 11b for supply of the combustion fuel which is generally located on the opposite side of the cylinder bore to first injector 11a, and arranged to spray fuel into the air volume not covered by the spray plumes of first injector 11a. When fitted with two injectors, first injector 11a is
30 orientated to spray towards the first piston 2a, which might be an air piston,

and second injector 11b is orientated to spray towards the second piston 3a which might be an exhaust piston.

The lubrication injection strategy for the second injector 11b is similar to the first injector 11a, but with detail differences for injection quantity, frequency and timing of the start of injection. For example, the fuel for lubrication for the second injector may commence shortly after closure of the exhaust ports 10, i.e typically 90° crankangle before IDC of the exhaust piston 3a and probably no later than 60° crankangle before IDC of the exhaust piston 3a. The fuel injection pressures may be selected to ensure that the fuel plumes 21a and 21b (Figures 1, 2 and 3) become substantially an aerosol cloud at some distance from the cylinder liner, e.g. at 2-3mm radial distance from the cylinder wall. The injection period is extremely short, for example only 2° crankangle, so that typically only extremely small amounts of fuel are injected per injection. During the remaining approximately 85° - 60° of the compression stroke, the injected fuel droplets are centrifuged through the air in the cylinder onto the cylinder wall 23a and 23b in the path of the oncoming pistons 2a and 3a. With second injector 11b and its typical two, three, four, five or six nozzles holes, there will be a corresponding number of fuel deposits on the cylinder wall from the centrifuging of the tips of the spray plumes, the locations of the fuel deposits notionally separated by the divergent angles between the injector nozzle holes; Figures 1,2 and 3 only show for clarity a single fuel spray plume.

In summary, in embodiments, an opposed stepped piston engine 100 is provided in which the fuel is sprayed from a second injector towards the power cylinder liner 1 in direction of the exhaust piston 3a after closure of the exhaust transfer ports 10 but prior to the pre or main fuel injections, with the start of injection for lubrication timed to begin 90° - 60° crankangle before inner dead centre of the leading crankshaft.

With reference to Figures 4 and 5, in embodiments, a third injector 31a is arranged to supply fuel or lubricating oil only for lubrication of the power piston rings and power piston skirt. In such embodiments, the third injector 31a may be located in substantially the same plane as first injector 11a and second
5 injector 11b, and may have at least one nozzle hole, or any practical number of nozzle holes (for example 6). In embodiments, the nozzle holes may be angularly disposed to spray fuel towards the cylinder liner 1 in the direction of the air power piston 2a, i.e. for example sprays 32a, 32b, 32c and 32d (Figure 4) and towards the liner in the direction of the exhaust piston 3a, i.e. for
10 example sprays 34a, 34b, 34c and 34d (Figure 5).

In the case of fuel injection from the third injector 31a, injection commences shortly after closure of the air ports 7a, i.e typically 100° crankangle before IDC. The fuel injection pressures are selected to ensure that the fuel plume(s)
15 32a, 32b, 32c and 32d (Figure 4) becomes substantially an aerosol cloud at some distance from the cylinder liner, e.g. at 2-3mm radial distance from the cylinder wall 1. The injection period is extremely short, for example only 2° crankangle, so that typically only extremely small amounts of fuel would be injected per injection. During the remaining approximately 95° of the
20 compression stroke, the injected fuel droplets from the tips of the spray plumes are centrifuged through the air in the cylinder 1a onto the cylinder wall 1, for example at locations 33a, 33b, 33c and 33d (Figure 4) in the path of the oncoming air power piston 2a, and for example at locations 35a, 35b, 35c and 35d (Figure 5) in the path of the oncoming exhaust power piston 3a.

25

In embodiments, an opposed stepped piston engine 100 is provided in which the third injector 31a and a fourth injector 31b only provide the fuel for the injection periods timed to begin 100°- 60° crankangle before inner dead centre of the leading crankshaft. In this manner, the fuel is injected for lubrication
30 only, and these injections do not form part of the ignition injection. The third injector 31a may be disposed in the cylinder liner or cylinder wall area 1 that

encompasses the clearance volume between the pistons 2a and 2b at their inner dead centre positions, and the fourth injector 31b may be disposed in the cylinder liner or cylinder wall 1 area that encompasses the clearance volume between the pistons 2a and 2b at their inner dead centre positions.

5

With reference to Figure 6, first and second further injectors 40 and 41 are arranged to supply fuel or lubricating oil only for lubrication of the piston rings and piston skirt of the power pistons 2 and 3. In this embodiment, first further injector 40 and second further injector 41 are located in planes which are closer to the air ports 7a and exhaust ports 10 respectively so that lower injection pressures may be used and there is greater precision in targeting early injected fuel to cooler portions of the cylinder liner 1, in comparison to fuel injected from first injector 11a and second injector 11b, or third and fourth injectors 31a and 31b of Figure 4 and Figure 5 respectively.

10

In embodiments, first and second further injectors 40 and 41 may have at least one nozzle hole, or any practical number of nozzle holes, for example 6, which would be angularly disposed to spray fuel towards the liner 1 in the direction of the air power piston 2a, i.e. for example spray plumes 38a, 38b, 38c and 38d, and towards the liner 1 in the direction of the exhaust piston 3a, i.e. for example spray plumes 36a, 36b, 36c and 36d.

15

In the case of oil or fuel injection from second further injector 41, injection commences shortly after closure of the air ports 7a, i.e typically 100° crankangle before IDC.

20

The injection pressures are selected to ensure that the fuel or oil plumes 38a, 38b, 38c and 38d become substantially aerosol clouds at some distance from the cylinder liner, e.g. at 2-3mm radial distance from the cylinder wall. The injection period is extremely short, for example only 2° crankangle, so that typically only extremely small amounts of fuel would be injected per injection.

25

30

During the remaining approximately 95° of the compression stroke, the injected fuel droplets are centrifuged through the air from the plume tips in the cylinder onto the cylinder wall at locations such as 39a, 39b, 39c and 39d in the path of the oncoming air piston 2a.

5

The injection of fuel or lubricating oil for lubrication for the first further injector 40 commences shortly after closure of the exhaust ports 10, i.e typically 90° crankangle before IDC of the exhaust piston. The fuel injection pressures are selected to ensure that the fuel plumes 36a, 36b, 36c and 36d become
10 substantially aerosol clouds at some distance from the cylinder liner 1, e.g. at 2-3mm radial distance from the cylinder wall. The injection period would be extremely short, for example only 2-3° crankangle, so that typically only extremely small amounts of fuel are injected per injection. During the remaining approximately 85° of the compression stroke, the injected fuel
15 droplets are centrifuged through the air 1a in the cylinder onto the cylinder wall 1 at locations such as 37a, 37b, 37c and 37d in the path of the oncoming exhaust piston 3a.

In embodiments of the invention, an opposed stepped piston engine 100 is
20 provided in which a first further injector 40 is disposed in the cylinder liner 1 or cylinder wall area 1 that encompasses the clearance volume between the exhaust piston at its inner dead centre position and the exhaust piston 3a when just covering the exhaust ports 10. The engine further includes a second further injector 41 which is disposed in the cylinder liner 1 or cylinder
25 wall area 1 that encompasses the clearance volume between the air piston 2a at its inner dead centre position and the air piston when just covering the air ports 7a. The first further injector 40 and second further injector 41 are timed to begin injection 90°- 60° crankangle before inner dead centre of the leading crankshaft, i.e. only providing injected fuel for lubrication only.

30

In all previously mentioned embodiments with reference to Figures 1-6, in order to ensure more even distribution of the fuel or oil for lubrication of the cylinder liner, piston and piston rings, several smaller injections on consecutive cycles may be arranged in which there is a lubrication injection timing angle shift between the consecutive sprays.

The third and fourth injectors 31a and 31b (Figure 4 and Figure 5) and the first and second further injectors 40 and 41 (Figure 6) may be used with diesel fuel or lubricating oil with spark ignited combustion engines fuelled by gasoline, or any ignitable volatile liquid fuel, natural gas, or any ignitable and combustible gas.

It should be understood that, unless stated otherwise, when the injection period is described as being extremely short the period may be in the range of 1°-5° crankangle. Preferably, the period is in the range of 1.5°-3° crankangle, and more preferably, is in the region of 2° crankangle.

When used in this specification and claims, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or components.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

CLAIMS

1 An opposed stepped piston engine with in-cylinder air swirl in which fuel
is sprayed from at least a first injector towards the power cylinder liner in
5 direction of the air piston after closure of the air transfer ports but prior to the
one or more fuel ignition injections.

2 An engine according to claim 1, in which the injection spray from the
first injector is timed to begin 100° - 60° crankangle before inner dead centre of
10 the leading crankshaft.

3 An engine according to claim 1 or claim 2, in which fuel is sprayed from
at least a first injector towards the power cylinder liner in direction of the air
piston and in the direction of the exhaust piston.

15

4 An engine according to claim 1 or claim 2, in which fuel is sprayed from
a second injector towards the power cylinder liner in direction of the exhaust
piston after closure of the air transfer ports but prior to the one or more fuel
ignition injections.

20

5 An engine according to claim 4, in which the injection spray from the
second injector is timed to begin 90° - 60° crankangle before inner dead
centre of the leading crankshaft.

25 6 An engine according to any one of claims 1 to 3, in which the first
injector also provides the fuel for combustion with start of injection later than
 100° - 60° crankangle before inner dead centre of the leading crankshaft.

7 An engine according to claims 4 or 5, in which the second injector also
30 provides the fuel for combustion with start of injection later than 90° - 60°
crankangle before inner dead centre of the leading crankshaft.

8 An engine according to any one of claims 1 to 5, in which a third injector and a fourth injector provide fuel only for the injection periods timed to begin 90°- 60° crankangle before inner dead centre of the leading crankshaft, so that
5 substantially all the injected fuel is used for lubrication.

9 An engine according to claim 8, in which the third injector is disposed in the cylinder liner or cylinder wall area that encompasses the clearance volume between the pistons at their inner dead centre positions.

10

10 An engine according to claim 8, in which the fourth injector is disposed in the cylinder liner or cylinder wall area that encompasses the clearance volume between the pistons at their inner dead centre positions.

15 11 An engine according to any one of claims 1 to 7, in which a first further injector is disposed in the cylinder liner or cylinder wall area that encompasses the clearance volume between the exhaust piston at its inner dead centre position and the exhaust piston when just covering the exhaust ports.

20 12 An engine according to any one of claims 1 to 7, or claim 11, in which a second further injector is disposed in the cylinder liner or cylinder wall area that encompasses the clearance volume between the air piston at its inner dead centre position and the air piston when just covering the air ports.

25 13 An engine according to claim 12 where dependent on claim 11, in which the first further injector and second further injector are timed to begin injection 90°- 60° crankangle before inner dead centre of the leading crankshaft, so that substantially all the injected fuel is used for lubrication.

30 14 An engine according to any one of the preceding claims, in which all injectors have at least three nozzle holes.

15 An engine according to claim 8 configured such that multiple small
injections are provided on consecutive cycles by the third and fourth injectors
such that there is a phase angle between the consecutive sprays in order to
5 increase the fuel distribution on the liner.

16. An engine according to claim 14, configured such that multiple small
injections are provided on consecutive cycles by the first further injector and
second further injector such that there is a phase angle between the
10 consecutive sprays in order to increase the fuel distribution on the liner.

17. An engine according to any one of the preceding claims, in which at
least one air transfer port is configured at an angle at least partially tangential
to the cylinder.

15

18. An engine substantially as hereinbefore described with reference to and
as shown in the accompanying drawings.

19. Any novel feature or novel combination of features described herein
20 and/or in the accompanying drawings.

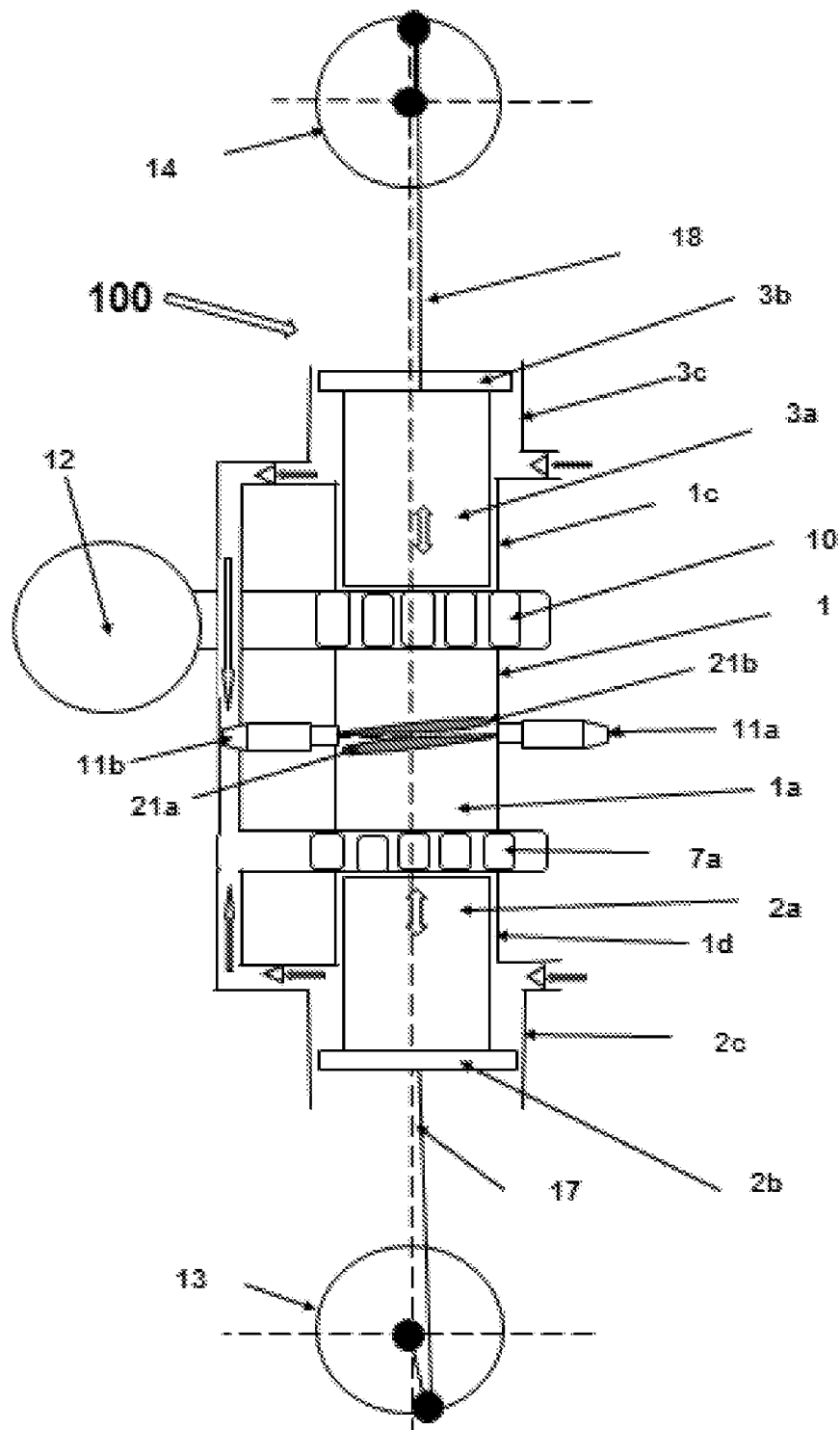


Fig.1

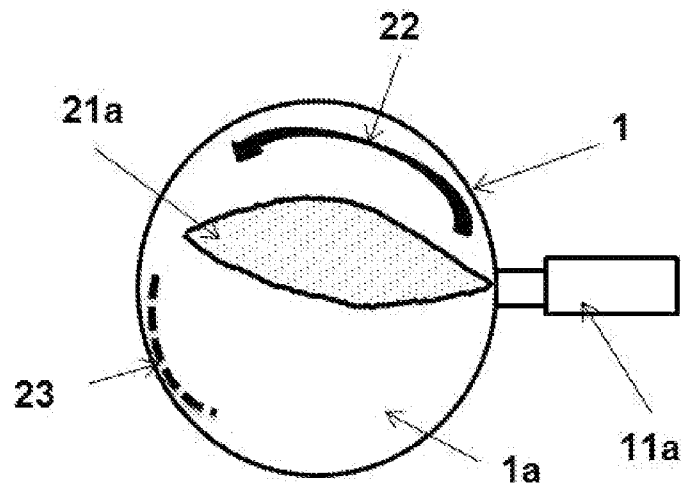


Fig.2

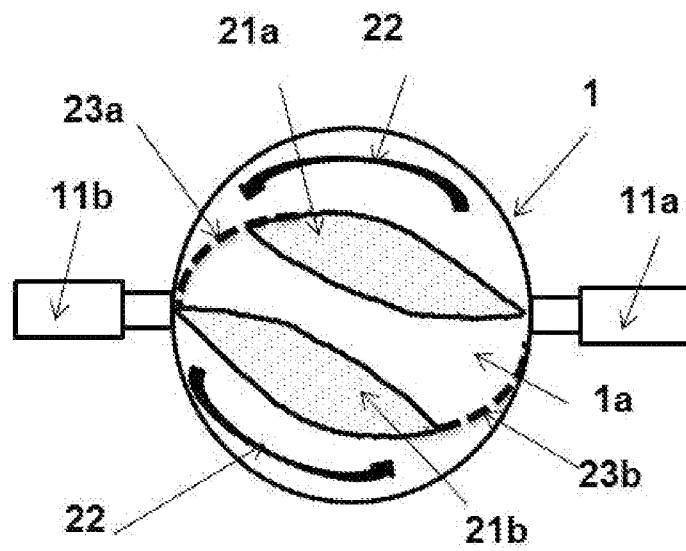


Fig.3

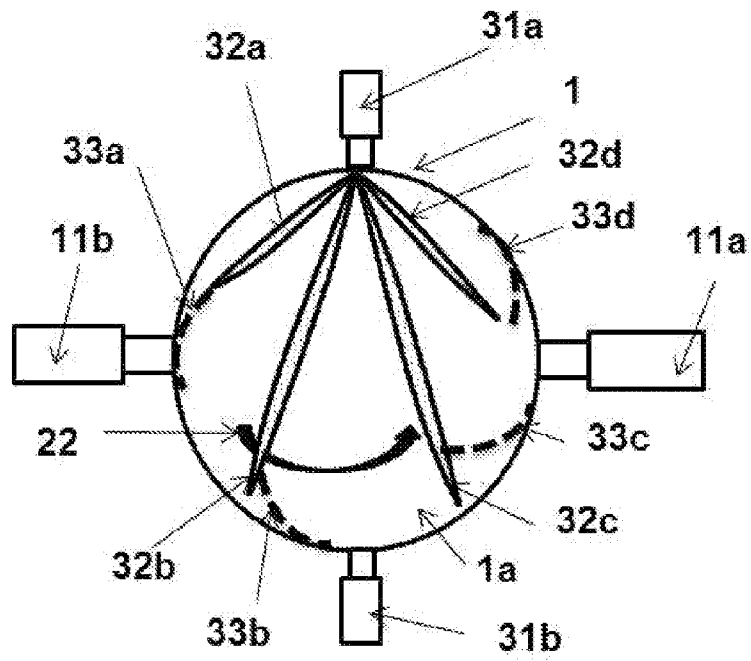


Fig.4

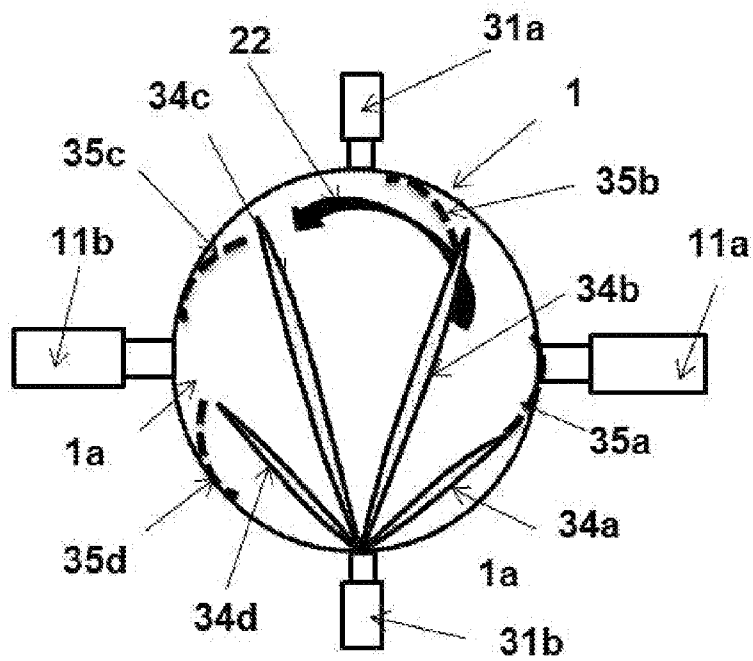


Fig.5

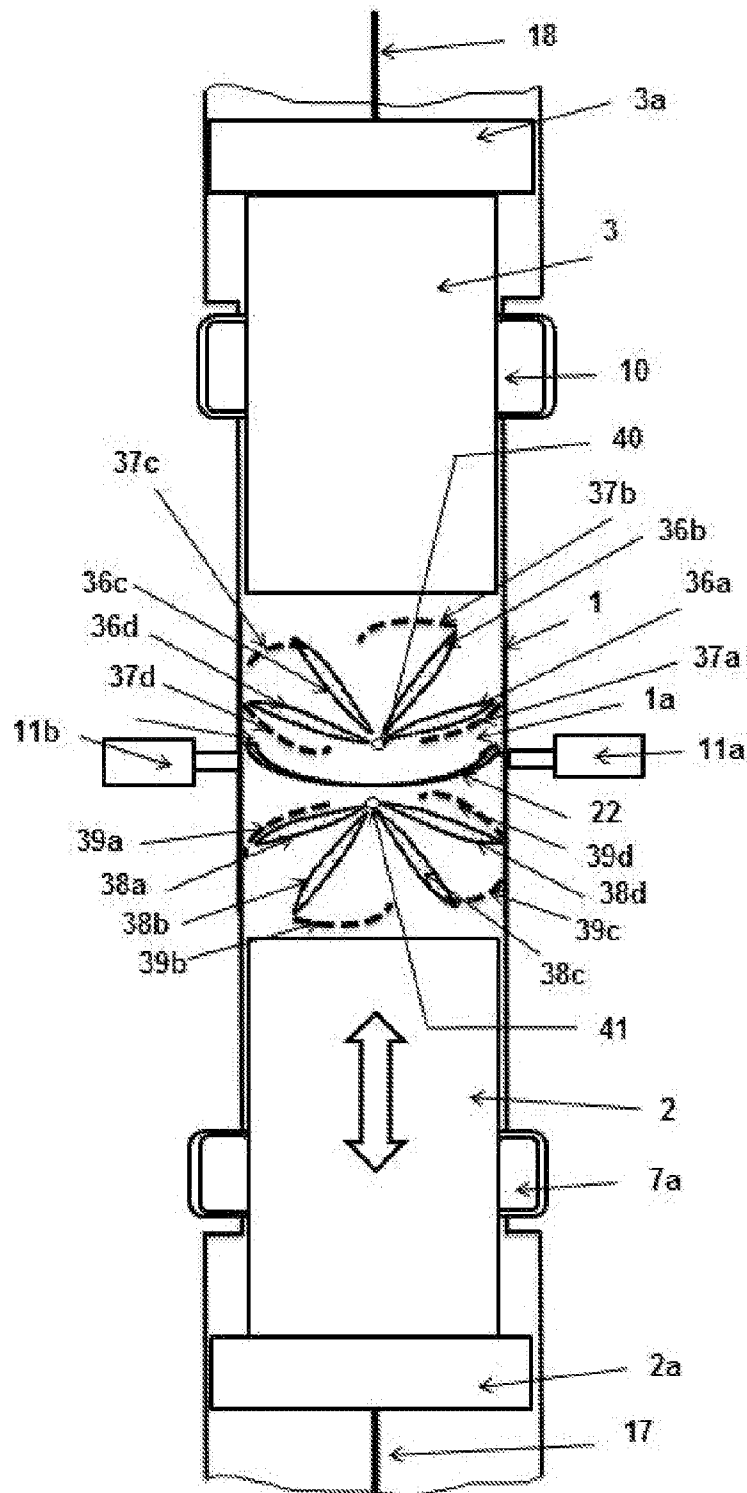


Fig.6

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2014/051051

A. CLASSIFICATION OF SUBJECT MATTER
 ADD. F01M1/08 F01M3/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02B F01B F01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006/219213 A1 (LEMKE JAMES U [US]) 5 October 2006 (2006-10-05) paragraph [0053] - paragraph [0063]; figures 5,6 -----	1-8, 11-14, 17-19
Y	SU 3 092 A1 (BRYLIN P S) 15 September 1924 (1924-09-15) figures 1-3 -----	1-8, 11-14, 17-19
A	US 2006/157003 A1 (LEMKE JAMES U [US] ET AL) 20 July 2006 (2006-07-20) paragraph [0056] -----	8



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search

19 June 2014

Date of mailing of the international search report

25/06/2014

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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