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(71) Applicant: **OSP ENGINES LIMITED** [GB/GB]; 8 Laurence Pountney Hill, London EC4R 0BE (GB).

(72) Inventors: **PIRAULT, Jean-Pierre;** 30 Lesser Foxholes, Shoreham-by-Sea, West Sussex BN43 5NT (GB). **VESHAGH, Ali;** 12 Waring Way, Dunchurch, Warwickshire CV22 6PH (GB).

(74) Agent: **FORRESTERS;** Rutland House, 148 Edmund Street, Birmingham B3 2JA (GB).

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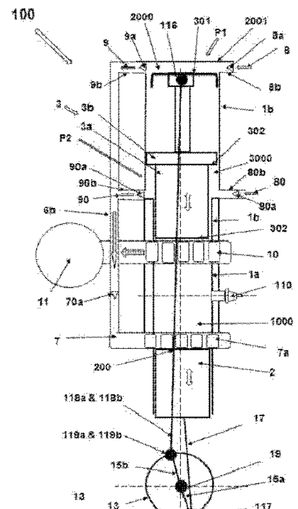

Fig.2

(57) Abstract: With reference to Figure 2, the invention relates to an opposed piston engine comprising a stepped cylinder providing a portion of lesser diameter and a portion of greater diameter, the portion of lesser diameter providing a combustion volume formed between a first and a second power piston operable to expand and compress the combustion volume, and the portion of greater diameter providing a first and a second air transfer volume, the engine comprising an air port for intake of air into the combustion volume from an air delivery passage, and an exhaust port for exhausting gases from the combustion volume, one of the power pistons acting as the air piston controlling opening and closing of the air port and the other power piston acting as the exhaust piston controlling opening and closing of the exhaust port, wherein at least one of the first and second power pistons is a stepped piston providing a double-sided air transfer piston having a forward side and a reverse side, configured such that the forward side compresses and expands the first air transfer volume and the second side compresses and expands the second air transfer volume, wherein each of the first and second air transfer volumes is fluidly connected to the air delivery passage.

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Title: Opposed Stepped Piston Engine

Description of Invention

This invention relates to opposed piston engines that use stepped double sided pistons to provide the air flow used for combustion. The invention applies to two stroke (2-stroke) engines.

The 2-stroke cycle does not, excepting certain examples, have a unique stroke for fresh air induction into the cylinder. The air induction takes places in parallel with the power stroke and exhaust gas exchange.

The proposed invention provides scavenging air for 2-stroke engines without external compressors or scavenge blowers.

The following descriptions are provided with reference to Figure 1, Figure 2 and Figure 3 to help interpretation of this text.

A main journal is a solid of revolution and usually an integral part of the crankshaft and is arranged concentrically on the main axis of a crankshaft and is supported by a bearing in a crankcase.

A crankpin is usually an integral part of a crankshaft which carries and is connected to the connecting rods that are in turn connected to the pistons via a slideable joint called the gudgeon pin. Each engine cylinder usually has a piston, subjected to combustion gas pressure and connected via the gudgeon pin to the "small end" of the connecting rod. The other end of the connecting rod, called the "big-end", connects rotatably with the crankpin.

A crankthrow of a crankshaft is usually an integral part of the crankshaft linking the main journal to the crankpin. There is usually at least one crankthrow connecting with each crankpin.

A crankshaft is usually a single part connecting all crankpins and main journals, the main journals.

A piston is the moving part of a positive displacement volumetric machine that acts on the fluid to displace, compress or expand the fluid. The piston is usually of a male shape which engages in a cylinder of a female shape, the motion of the piston moving the fluid to and from the cylinder. A power piston operates in the combustion cylinder and compresses and expands the gases in the combustion cylinder as part of the combustion process. 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. An opposed stepped piston engine is an opposed piston engine or compressor that has at least one air transfer piston. A double sided piston is a piston having two areas that can be used to displace, compress or expand fluids in engaging cylinders. A double sided stepped piston is a piston having three areas that can be used to displace, compress or expand fluids in engaging cylinders. An air transfer piston is a piston used to transfer air from the air intake system of the power piston.

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.

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

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

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 20º crankangle versus the air piston; this means that the exhaust piston will reach its inner dead centre position before the air piston reaches its inner dead centre position, i.e earlier in terms of the engine operating cycle.

"Inner dead centre" 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. In engines with cylinder heads, this is normally referred to as "top dead centre".

"Outer dead centre" refers to outermost position of a piston in its travel in the cylinder of an opposed piston engine, i.e. the furthest position the centre of the cylinder. In engines with cylinder heads, this is normally referred to as "bottom dead centre".

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

The forward side of an air transfer piston is the side of the larger diameter of the stepped double sided 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 double sided piston which acts in anti-phase with 5 the air piston or an exhaust piston.

An air duct or conduit is a passageway or connecting route which allows air to be transferred from one point to another.

"Scavenging" air flow of a 2-stroke engine is the frequently used terminology 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.

Scavenging efficiency is a measure of the effectiveness of filling the combustion cylinder volume (1000 in Figure 1) with clean air.

A scavenge pump or scavenge blower is a compressor or pump that provides clean air to purge and fill the combustion volume 1000.

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, the exhaust ports 10 that allow the exhaust to flow from the cylinder, when uncovered by the power piston 3, to the exhaust passage 11. Air ports 7a (Figure 1) allow fresh air from the engine scavenge pumps to enter the combustion cylinder volume 1000; the ports are opened and closed by the motion of the power piston 2. The air ports are sometimes referred to as "transfer" ports in that they allow air to be moved from the air transfer pistons to the working cylinder 1000.

A check valve is a flow control mechanism that allows flow in one direction and prevents flow in the reverse direction. The mechanism is usually a simple leaf-spring flap, located in a conduit, that opens in one direction and closes against an abutment in the reverse direction. The opening pressure of a check valve is the flow pressure required to enable flow in one direction.

The compression ratio of a cylinder volume with a piston that moves from an innermost to outer most position within the cylinder volume is the ratio of total cylinder volume with the piston at its outermost position divided by the cylinder volume with the piston at its innermost position.

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.

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

In general terms we provide an opposed piston engine with at least one cylinder in which at least one piston is arranged as a stepped double sided piston in a stepped cylinder to provide some or all of the engine airflow requirements for combustion during both the expansion and compression phases of the power pistons.

According to an aspect of the invention we provide an opposed piston engine comprising a stepped cylinder providing a portion of lesser diameter and a portion of greater diameter, the portion of lesser diameter providing a combustion volume formed between a first and a second power piston operable to expand and compress the combustion volume, and the portion of greater diameter providing a first and a second air transfer volume, the engine comprising an air port for intake of air into the combustion volume from an air delivery passage, and an exhaust port for exhausting gases from the combustion volume, one of the power pistons acting as the air piston controlling opening and closing of the air port and the other power piston acting as the exhaust piston controlling opening and closing of the exhaust port, wherein at least one of the first and second power pistons is a stepped piston providing a double-sided air transfer piston having a forward side and a reverse side, configured such that the forward side compresses and expands the first air transfer volume and the second side compresses and expands the second air transfer volume, wherein each of the first and second air transfer volumes is fluidly connected to the air delivery passage.

Further features of the above aspects of the invention are described in the 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 shows an end view of the general diagrammatic arrangement of a single cylinder opposed piston engine with an external compressor;

Figure 2 shows an end view of the general diagrammatic arrangement of a first embodiment of a single cylinder opposed piston engine 100 with a stepped double sided piston;

Figure 3 shows a side view of the general diagrammatic arrangement of the first embodiment of a single cylinder opposed piston engine 100 with a stepped double sided piston;

Figure 4 is a diagram showing the approximate relative phasings of the volume changes in the air transfer cylinder volumes and in the combustion cylinder volume of the engine depicted in Figure 2 and Figure 3;

Figure 5 is a graph comparing the theoretical gas exchange work for a constant pressure compressor scavenge pump versus the 2-stage stepped double sided piston scavenge system;

Figure 6 shows an end view of the general diagrammatic arrangement of a second embodiment of a single cylinder opposed piston engine 200 with a stepped double sided piston;

Figure 7 shows an end view of the general diagrammatic arrangement of a third embodiment of a single cylinder opposed piston engine 400 with one stepped piston and one stepped double sided piston; and

Figure 8 is a diagram showing the approximate relative phasings of the volume changes in the air transfer cylinder volumes and in the combustion cylinder volume of the engine depicted in Figure 7.

With reference to Figures 2 to 8, we provide an opposed piston engine comprising a stepped cylinder . The stepped cylinder provides a portion of lesser diameter and a portion of greater diameter. The portion of lesser diameter provides a combustion volume formed between a first and a second power piston operable to expand and compress the combustion volume. The engine comprises an air port for intake of air into the combustion volume from an air delivery passage, and an exhaust port for exhausting gases from the combustion volume. One of the power pistons acts as the "air piston" controlling opening and closing of the air port and the other power piston acts as the "exhaust piston" controlling opening and closing of the exhaust port, as the respective pistons move between positions in which the skirts of the pistons block the ports, and positions in which the ports are open.

The portion of the cylinder having a greater diameter provides a first and a second air transfer volume. At least one of the first and second power pistons is a stepped piston providing a double-sided air transfer piston. In embodiments, and as shown in Figure 2, for example, one of the power pistons is a stepped piston, forming an air transfer piston. The air transfer piston has a forward side and a reverse side - in other words, the stepped piston forms a closing diaphragm of wider diameter, operating in the wider diameter portion of the cylinder. That diaphragm provides a forward side, and a reverse side, dividing that portion of the cylinder, and defining the first and second air transfer volumes. The forward side compresses and expands the first air transfer volume and the second side compresses and expands the second air transfer volume. Each of the first and second air transfer volumes is fluidly connected to the air delivery passage, for providing scavenged air to the intake port of the combustion volume.

With reference to Figure 2 and Figure 3, in embodiments of the invention, the outer crankpins 119a and 119b of a crankshaft 13 are rotatably connected respectively to the long connecting rods 118a and 118b which in turn are rotatably connected to a transverse beam 116 of the exhaust piston 3 of the opposed piston engine 100. As shown in Figure 3, the transverse beam 116 may also have a centre pivot bearing 121 which prevents side loading of the piston 3.

The exhaust ports 10 in the cylinder liner 1a are controlled by of the displacement of the exhaust power piston 3, as defined by the crankthrow 15b of the crankshaft 13, such that the exhaust ports are fully open when the piston 3 is at its outer dead centre position, and are fully closed when the piston skirt 3c fully covers the exhaust ports 10.

The air transfer ports 7a in the cylinder liner 1a are controlled by of the displacement of the air power piston 2, as defined by the crankthrow 15a of the crankshaft 13, such that the air transfer ports are fully open when the piston 2 is at its outer dead centre position, and are fully closed when the piston skirt 2a fully covers the air transfer ports 7a.

In embodiments, piston 3 is a stepped double sided piston with a larger diameter 3b that is a first air transfer piston which acts in phase with the smaller diameter exhaust piston 3b. The piston elements 3a and 3b of the piston 3 may be rigidly linked or articulated relative to each other. The skirt of piston 3a slides in the cylinder bore 1a whilst the skirt of piston 3b slides in the cylinder bore 1b. The stepped double sided piston 3b may be either circular, elliptical or rectangular in shape, and cylinder bore 1b would be a corresponding shape.

In embodiments, the air induction streams in to the engine 100 enter via two complementary routes 8 and 80.

Firstly, considering the air stream 8:

The "reverse" or outer side of the stepped double sided piston 3b (hereafter simply referred to as "piston 3b") carries a closing diaphragm 301 so that as piston 3a and 3b move, the volume 2000, enclosed by diaphragm 301, the cylinder walls 1b and the cylinder cap 2001, increases or decreases according to the direction of motion of piston 3b. Whereas the term diaphragm is used to denote the portion of the stepped piston having greater diameter, it is also described herein as providing forward and reverse sides in the same way as a typical double-sided piston. It this manner, the forward surface of the air transfer piston is provided by the forward-facing diaphragm.

Check valve 8a allows air 8 into cylinder 2000 as the piston 3b moves towards inner dead centre, and check valve 9a allows the same air 9 to leave cylinder 2000 in to the air delivery passage 6b as the piston 3b moves towards its outer dead centre position. The check valve 8a ensures that air flow can only enter the cylinder 2000 and cannot leave the cylinder volume 2000, whilst the check valves 9a ensures that air flow can only leave the cylinder volume 2000 and cannot enter the cylinder volume 2000. In this way, the piston 3b, its closing diaphragm 301, the cylinder walls 1b, the cylinder cap 2001 and the check valves 8a and 9a act as a first compressor or air pump P1, transferring air from the surrounding atmosphere or engine air induction system into the compressor volume 2000 and then to the engine combustion cylinder 1000.

The air 9 is displaced along the air delivery passage 6b by a combination of the motion of the piston 3b and the momentum of the air column 9. The air 9 enters the cylinder volume 1000 via the air delivery passage connection 7, joined to air conduit 6b, and then via the air ports 7a. As the diaphragm 301 moves substantially in anti-phase with the air piston 2, the air in the cylinder volume 2000 is transferred into the cylinder volume 1000 during the opening period of the air transfer ports. The engine 100 is therefore supplied firstly with fresh air for combustion from the compressor cylinder volume 2000 to the combustion cylinder volume 1000 during the motion of the pistons 2 and 3 from their inner dead centre positions to their outer dead centre positions.

To re-emphasize, the relative phasing of the volume changes for the cylinder volume 1000 and cylinder volume 2000 are shown in Figure 4, from which it can be seen that volume 2000 moves in anti-phase with volume 1000, and hence volume 2000 is being displaced in to volume 1000 as the pistons 2 and 3 move towards their outer dead centre positions.

Secondly, considering the air stream 80:
The "forward" or "inner " side of the piston 3b has a diaphragm 302 so that as piston 3a and 3b move, the volume 3000, enclosed by diaphragm 302, the cylinder walls 1b and the upper rim of the cylinder liner or wall 1a, increases or decreases according to the direction of motion of piston 3a. Check valve 80a allows air 80 into cylinder 3000 as the piston 3b moves towards outer dead centre, and check valve 90a allows the same air 90 to leave cylinder 3000 in to the air delivery passage 6b from the air passage 90b as the piston 3b moves towards its inner dead centre position. The check valve 80a ensures that air flow can only enter the cylinder 3000 and cannot leave the cylinder volume 3000, whilst the check valves 90a ensures that air flow can only leave the cylinder volume 3000 and cannot enter the cylinder volume 3000. In this way, the piston 3b, its diaphragm 302, the cylinder walls 1b, the upper rim of the cylinder liner 1a and the check valves 80a and 90a act as a second or complementary compressor or air pump P2, transferring air from the surrounding atmosphere or engine air induction system into the compressor volume 3000 and then to the engine combustion cylinder 1000.

The air 90 is displaced along the air delivery passage 90b and thence 6b by a combination of the motion of the piston 3a and the momentum of the air column 90. The air 90 enters the cylinder volume 1000 via the air delivery passage connection 70, joined to air conduit 6b, and then via the air ports 7a. As the diaphragm 302 moves substantially in-phase with the air piston 2, the air in the cylinder volume 3000 is transferred into the cylinder volume 1000 during the closing period of the air transfer ports. The engine 100 is therefore supplied secondly with fresh air for combustion from the compressor cylinder volume 3000 to the combustion cylinder volume 1000 during the motion of the pistons 2 and 3 from their outer dead centre positions to their inner dead centre positions.

With reference to Figure 4, the relative phasing of the volume changes for the cylinder volume 1000, the cylinder volume 2000 and cylinder volume 3000 are shown versus the crankangle position of exhaust piston 3, which is phased notionally 30º crankangle in advance of the air piston 2. The exhaust port open period corresponds to the crankangle between EO-EC, i.e. approximately 160º crankangle duration. The air port open period corresponds to the crankangle between IO-IC, i.e. approximately 100º crankangle duration. The asymmetry of the port timings is an optional beneficial feature of opposed piston engines, and opposed stepped piston engines, and arises from the phasing of the exhaust and air pistons which in this example is notionally 30º crankangle, as previously stated. These curves show volume 2000 moves in anti-phase with volume 1000, and hence volume 2000 is being displaced in to volume 1000 as the pistons 2 and 3 move towards their outer dead centre (ODC in Figure 4) positions. This air transfer from the volume 2000 to the main cylinder 1000 occurs during the expansion stroke of the engine (T1 in Figure 4) as the air ports open (IO in Figure 4) after the opening of the exhaust ports (EO in Figure 4), and continues to outer dead centre of pistons 2 and 3. Figure 4 also shows that volume 3000 moves in-phase with volume 1000, and hence volume 3000 is being displaced in to volume 1000 as the pistons 2 and 3 move towards their inner dead centre positions (T2 in Figure 4). This air transfer provides a continuing scavenging or clearing of the exhaust gases from the cylinder 1000 via the exhaust ports as the pistons 2 and 3 move away from their outer dead centre positions towards their inner dead centre location. In this way, the cylinder 1000 is continuously positively scavenged with fresh air from the opening to closing of the air ports. It should be explained that in Figure 4 the volume displacements 1000, 2000 and 3000 are all shown as having maximums of 96-1 00% notionally for simplicity and clarity.

However, the absolute volumes 1000, 2000 and 3000 can all be different and adjusted as previously mentioned by design of the selected diameters of the pistons 2 and 3, and crankshaft strokes 15a and 15b, and the entry port 8b, 80b and outlet port 9b positions relative to the moving surfaces of the piston 3, and the pressure settings of the check valves 8a, 80a and 9a, 90a.

With reference to Figure 5, the functional advantage of the previously described scavenging system invention ("Staged Scavenging" in Figure 5) versus a constant pressure compressor or scavenge blower system ("Scavenge Blower" in Figure 5) is compared graphically in terms of arbitrary instantaneous power units versus the crankangle position of exhaust piston 3, which is phased notionally 30º crankangle in advance of the air piston 2. The "Scavenge Blower" curve in Figure 5 is the theoretical instantaneous power required to deliver the air from the external scavenge blower which generally produces a constant airflow rate versus the engine crankangle. The work required to drive the external compressor is constant as the air flowrate is constant and backpressure, against the airflow through the cylinder volume 1000 and the exhaust passage and receiver 11, is also constant. The required compressor work is directly proportional to the air flowrate and backpressure acting against the air flowrate; as the air flowrate and the backpressure are constant, the instantaneous work is constant, as depicted by the flat portion of the Scavenge Blower curve during the scavenge period T 1 plus T2 (T1+T2).

The "Staged Scavenging"curve in Figure 5 is the theoretical instantaneous power required to deliver the air from the stepped piston scavenging system which produces a variable airflow rate versus engine crankangle during the scavenge period T 1 plus T2 (T1 +T2), and as a result there is also a proportionally variable backpressure opposing the airflow in the cylinder 1000

and the exhaust passage and receiver 11. At the start of the stepped piston staged scavenging period, i.e. the start of T 1, the scavenge airflow rate from volume 2000 to volume 1000 is designed to be equal to the flowrate from an external compressor and this scavenge air flowrate will have to work against the same backpressure as the externally driven compressor. The power required by the engine to produce the stepped piston scavenging from the air pump P1 is therefore a product of two quantities that vary with engine crankangle, starting with similar values of instantaneous power required during the early phase of air port opening (i.e. IO in Figure 5) for both the compressor and stepped piston staged scavenging system. As the power pistons move towards their outer dead centre positions ("ODC" in Figure 5), the flowrate from the P1 scavenge pump reduces whereas the scavenge blower compressor flowrate remains constant, the same relative differences also applying to the backpressures acting on the the "Staged Scavenging" and "Scavenge Blower" systems. After the power pistons 2 and 3 start returning towards inner dead centre position (IDC in Figure 5), the air pump P2 starts ("e" in Figure 5) to deliver air from the cylinder volume 3000 to the cylinder volume 1000 and continues the scavenging process, again with a variable flowrate and backpressure versus the constant pressure and flowrate of the compressor scavenging system. The flowrate from volume 3000 gradually diminishes as the volume 3000 diminishes, and likewise the instantaneous power reduces towards zero at the point of air port closure (end of period "T2" in Figure 5), whereas the compressor based scavenge system still pushes a substantial air flowrate through the open exhaust ports against a substantial exhaust back pressure until the exhaust ports close ("g" in Figure 5). This last phase of the compressor airflow delivery is particularly wasteful in terms of work and unused air, and does not significantly increase the scavenge efficiency of the engine.

In addition to the lower work required for the airflow delivery with the stepped piston staged scavenging versus compressor scavenging, the mechanical and compression efficiencies of the stepped piston staged scavenging system are significantly higher than those of an externally driven compressor of whatever type, e.g. rotary positive displacement compressor, aerodynamic compressor, and this efficiency advantage further reduces the work requirement of the stepped piston staged scavenging compared to externally driven compressors.

Further advantages of the stepped piston staged scavenging in comparison to other scavenging systems are that it can be well matched to the engine combustion airflow requirements over the engine speed range, and its compactness, simplicity and low cost.

With reference again to Figure 2 and Figure 3, the volumetric displacements 2000 and 3000 of the scavenge air pumps P1 and P2 can be controlled independently of the engine combustion air volumetric displacement 1000 by appropriate sizing of the of the outer piston diaphragm 301 and the inner piston diaphragm 302 of the stepped double sided piston 3b, and also by appropriate sizing of the stroke of exhaust power piston 3, as controlled by the crankthrow 15b.

By appropriate selection of the diameter of the outer piston diaphragm 301 and the inner piston diaphragm 302, and the crankshaft stroke 15b, differing air flowrates can be arranged for the motion of the power pistons 2 and 3 towards outer dead centre and for the motion of the power pistons 2 and 3 towards inner dead centre.

With further reference to Figure 2, Figure 3 and Figure 5, the timing of the start of air delivery from the volume 2000 of scavenge pump P1 is governed primarily by the compression ratio of the compressor P1 and the opening pressure of the check valve 9a; the compression ratio of the compressor P1 and the opening pressure of the check valve 9a are adjusted so that the pressure of the air flowrate 9 is in excess of the pressure in cylinder 1000 as the air ports open ("c" in Figure 5).

The timing of the start of air delivery from the volume 3000 of scavenge pump P2 is governed primarily by the compression ratio of the compressor P2 and the opening pressure of the check valve 90a; the compression ratio of the compressor P2 and the opening pressure of the check valve 90a are adjusted so that the pressure of the air flowrate 90 is in excess of the pressure in cylinder 1000 as the power pistons 2 and 3 are near their outer dead centre positions.

In embodiments, an opposed piston engine 100 has at least one combustion cylinder volume 1000 having one stepped double sided air transfer piston 3a and 3b in a stepped cylinder 1b in which the inner or forward side 302 of the stepped air transfer piston 3b acts in-phase with the corresponding power pistons 3 and 2 and the outer or reverse side 301 of the stepped double sided air transfer piston 3b acts in anti-phase with the power pistons 3 and 2, and in which the inner or forward side 302 and outer or reverse side 301 of the stepped double sided air transfer piston 3b are integral with the exhaust power piston.

In embodiments, the inner or forward side 302 of the stepped double sided air transfer piston 3b discharges air into a first air delivery passage 90b which is in connection with the air ports 7a and the outer or reverse side 301 of the stepped double sided air transfer piston 3b discharges air into a second air delivery passage 9b which is in connection with the air ports 7a. In other embodiments, the inner or forward side 302 of the stepped double sided air transfer piston 3b discharges air via a check valve 90a into a first air delivery passage 90b which is in connection with the air ports 7a and the outer or reverse side 301 of the stepped double sided air transfer piston 3b discharges air via a check valve 9a into a second air delivery passage 9b which is in connection with the air ports 7a. The airflow from the inner or forward side 302 of the stepped double sided air transfer piston 3b and the outer or reverse side 301 of the stepped double sided air transfer piston 3b discharge air into a third passage 7 which is in connection with the transfer ports 7a.

In a variation of the aforementioned flow arrangements, the inner or forward side 302 of the air transfer piston and the outer or reverse side 301 of the stepped double sided air transfer piston discharge 3b air via a check valve 70a into third passage which is in connection with the transfer ports 7a.

In embodiments, the crankshaft of the engine 100 is arranged so that the stepped double sided air transfer piston 3b, which is an integral part of the exhaust power piston 3, is connected via the first connecting rod 118a and third connecting rod 118b to the first crankpin 119a and third crankpin 119b of the a crankshaft 13, and the air power piston 2 is connected via a second connecting rod 17 to a second crankpin 117 of the crankshaft 13. The second crankpin 117 of said crankshaft may be disposed between 150-210^{s} relative to the first crankpin 119a and third crankpin 119b of the crankshaft 13, depending on the direction or rotation and speed of the engine.

With reference to Figure 6, in embodiments, piston 331 is a stepped double sided air power piston controlling air ports 171, and piston 221 is an exhaust power piston controlling the exhaust ports 410. In this arrangement, the air delivery 9 from scavenge pump P1 and the air delivery 90 from scavenge pump P2 would have a shorter routing to the air ports 171 than is shown in Figure 2, as the air ports 171 are located closer to the scavenge pumps P1 and P2. The engine 200 may have some performance advantages over the arrangement in Figure 2 which has longer conduits from the scavenge pumps P1 and P2 to the airports 7a (of Figure 2 and Figure 3). In this embodiment, the stepped double sided air power piston 331 comprises the smaller diameter piston 331b and the larger double diameter piston 331a.

The arrangement of the crankshaft 13 and connecting rods, transverse beam and centre pivot bearing for engine 200 in Figure 6 is the same as described for engine 100 with reference to Figure 2 and Figure 3 with the exceptions that the connecting rod 117 is connected to the exhaust piston 221 and connecting rods 118a and 118b are connected to the stepped double sided air piston 331 via the tranverse beam 116 and the centre pivot bearing 121.

In embodiments, an opposed piston engine 200 is provided with at least one combustion cylinder volume 1000 having one stepped double sided air transfer piston 331a and 331b in a stepped cylinder 331c in which the inner or forward side 302 of the stepped double sided air transfer piston 331 acts in-phase with the corresponding power pistons 331 and 221 and the outer or reverse side 301 of the stepped double sided air transfer piston 331 acts in anti-phase with the power pistons 331 and 221, and in which the inner or forward side 302 and outer or reverse side 301 of the stepped double sided air transfer piston 331a are integral with the air power piston 331.

With reference to Figure 7, this illustrates features of embodiments similar to that shown in Figure 2 with the addition of a third scavenge pump P3 which is formed from the stepped piston 20a attached to the exhaust power piston 20b. Piston 3 and scavenge pumps P1 and P2 of this engine embodiment 400 operate in the same fashion as is described with reference to the scavenge pumps P1 and P2 of engine 100 on Figure 2 and Figure 3.

In the arrangement shown in Figure 7, the "forward" or "inner" side of the piston 20a has a diaphragm 304 so that as piston 20a and 20b move, the volume 4000, enclosed by diaphragm 304, the cylinder walls 20c and the lower rim of the cylinder liner or wall 1d, increases or decreases according to the direction of motion of piston 20a. Check valve 98a allows air 98 into cylinder volume 4000 as the piston 20a moves towards outer dead centre, and check valve 99a allows the same air 99 to leave cylinder 4000 to the air delivery passage 7 from the air passage 99b as the piston 20a moves towards its inner dead centre position. The check valve 98a ensures that air flow can only enter the cylinder 4000 and cannot leave the cylinder volume 4000, whilst the check valves 99a ensures that air flow can only leave the cylinder volume 4000 and cannot enter the cylinder volume 4000. In this way, the piston 20a, its diaphragm 304, the cylinder walls 20c, the lower rim of the cylinder liner 1d and the check valves 98a and 99a act as a third or complementary compressor or air pump P3, transferring air from the surrounding atmosphere or engine air induction system into the compressor volume 4000 and then to the engine combustion cylinder 1000.

The air is displaced along the air delivery passage 99b and thence 70a by a combination of the motion of the piston 20a and the momentum of the air column. The air enters the cylinder volume 1000 via the air delivery passage connection 7, joined to air conduit 6b from the other scavenge pumps P1 and P2, and then via the air ports 7a. As the diaphragm 304 moves in-phase with the air piston 20a, the air in the cylinder volume 4000 is transferred into the cylinder volume 1000 during the closing period of the air ports 7a. The engine 400 is therefore supplied thirdly with fresh air for combustion from the pump cylinder volume 4000 to the combustion cylinder volume 1000 during the motion of the pistons 20 and 3 from their outer dead centre positions to their inner dead centre positions.

With reference to Figure 8, this shows the relative phasing of the volume changes for the cylinder volume 1000, the cylinder volume 2000, the cylinder volume 3000 and the cylinder volume 4000. These curves show that volume 2000 moves in anti-phase with volume 1000, and hence volume 2000 is being displaced in to volume 1000 as the pistons 20 and 3 move towards their outer dead centre positions (ODC in Figure 8). This air transfer to the main cylinder 1000 occurs during the expansion stroke of the engine as the air ports open after the opening of the exhaust ports 10, and continues to outer dead centre of pistons 20 and 3. Figure 8 also shows that volume 3000 and volume 4000 move in-phase with volume 1000, and hence volumes 3000 and 4000 are being displaced in to volume 1000 as the pistons 20 and 3 move towards their inner dead centre positions (IDC in Figure 8). This air transfer provides a continuing scavenging or clearing of the exhaust gases from the cylinder 1000 via the exhaust ports 10 as the pistons 20 and 3 move from their outer dead centre positions towards their inner dead centre location. In this way, the cylinder 1000 is continuously positively scavenged with fresh air from the opening to closing of the air ports 7a.

An advantage of the staged scavenge system of engine 400 (Figure 7) over other systems is that the pistons 20 and 3 may be arranged to have a phase angle between themselves ("Phase Angle" in Figure 8), so that pistons 20 and 3 arrive at their respective inner dead centre positions by a crankangle difference corresponding to the phase angle, and arrive at their outer dead centre positions by a crankangle difference corresponding to the phase angle, as is commonly the case with opposed piston engines, and opposed stepped piston engines. The effect of this phase angle between pistons 20 and 3 is to extend or contract the notional overall 180° crankangle scavenging period of pistons 20 and 3, for example to 210° crankangle or for example to 150° crankangle for a phase angle of 30° crankaigle advance or retard. For example, in Figure 8, the volume 4000 extends the higher scavenge pressure further into the T2 period, or further towards the point of air port (7a) closure (IC in Figure 8), and this will increase the trapped charge density in volume 1000.

A further feature of the three stage scavenge system of engine 400 (Figure 7) is that the diameter of the piston diaphragm 304 can be made different to the diameter of the piston diaphragm 302 so that scavenge pumps P3 can deliver a different quantity of air 4000 to cylinder volume 1000 in comparison to the volumetric delivery 3000 of scavenge pump P2, and phasing of this volumetric delivery 4000 can be different to that of the volumetric delivery 3000, as explained in the preceding paragraph.

In summary, in embodiments, an opposed piston engine 400 is provided with at least one combustion cylinder volume 1000 having a first stepped double sided air transfer piston 3a and 3b in a stepped cylinder 1b and a second air transfer piston 20a and 20b in a stepped cylinder 20c, in which the inner or forward diaphragm 304 of the stepped air transfer piston 20a acts in-phase with the corresponding power pistons 3 and 20, and in which the inner or forward side 304 of the stepped air transfer piston 20a is either integral with the exhaust power piston or integral with the air power piston. Furthermore, in the opposed piston engine 400, the inner or forward diaphragm 304 of the air transfer piston 20a discharges air into a first air delivery passage 99 which is in connection with the air ports 7a. In an alternative arrangement, the inner or forward diaphragm 304 of the air transfer piston 20a discharges air via a check valve 99a into a third air delivery passage 99 which is in connection with the air ports 7a. In both these arrangements, the air delivery passage 99 is in connection with air delivery passage 7 which is in connection with the air ports 7a. The engine embodiment 400 may be arranged either with theair transfer piston 20a as part of an exhaust power piston, or with the air transfer piston 20a as part of an air power piston.

The engine embodiments 100 shown in Figure 2 and Figure 3 may be applied to any number of cylinders to make a multi-cylinder engine. Likewise, the engine embodiments 200 shown in Figure 6 may be applied to any number of cylinders to make a multi-cylinder engine, and the engine embodiments 400 shown in Figure 7 may be applied to any number of cylinders to make a multi-cylinder engine.

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 piston engine comprising a stepped cylinder providing a portion of lesser diameter and a portion of greater diameter, the portion of lesser diameter providing a combustion volume formed between a first and a second power piston operable to expand and compress the combustion volume, and the portion of greater diameter providing a first and a second air transfer volume, the engine comprising an air port for intake of air into the combustion volume from an air delivery passage, and an exhaust port for exhausting gases from the combustion volume, one of the power pistons acting as the air piston controlling opening and closing of the air port and the other power piston acting as the exhaust piston controlling opening and closing of the exhaust port, wherein at least one of the first and second power pistons is a stepped piston providing a double-sided air transfer piston having a forward side and a reverse side, configured such that the forward side compresses and expands the first air transfer volume and the second side compresses and expands the second air transfer volume, wherein each of the first and second air transfer volumes is fluidly connected to the air delivery passage.

2. An engine according to claim 1, in which the forward side of the stepped double sided air transfer piston acts in-phase with the power pistons and the reverse side of the stepped double sided air transfer piston acts in anti-phase with the power pistons.

3. An engine according to claim 1 or claim 2, in which the forward side and reverse side of the stepped double sided air transfer piston are integral with the exhaust power piston.

4. An engine according to claim 1 or claim 2, in which the forward side and reverse side of the stepped double sided air transfer piston are integral with the air power piston.

5. An engine according to any one of claims 1-4, in which the forward side of the stepped double sided air transfer piston discharges air into a first air delivery passage which is in connection with the air port.

6. An engine according to claim 5, in which the forward side of the stepped double sided air transfer piston discharges air via a check valve into the first air delivery passage.

7. An engine according to any one of claims 1-4, in which the reverse side of the stepped double sided air transfer piston discharges air into a second air delivery passage which is in connection with the air port.

8. An engine according to claim 7, in which the reverse side of the stepped double sided air transfer piston discharges air via a check valve into a second air delivery passage which is in connection with the air port.

9. An engine according to any one of claims 1-8, in which the forward side of the stepped double sided air transfer piston and the reverse side of the stepped double sided air transfer piston discharge air into a passage which is in connection with the air ports.

10. An engine according to claim 9 in which the forward side of the stepped double sided air transfer piston and the reverse side of the stepped double sided air transfer piston discharge air via a check valve into the passage.

11. An engine according to claim 3, or to any one of claims 5 to 10 where dependent directly or indirectly on claim 3, in which the stepped double sided air transfer piston is connected via a first connecting rod and third connecting rod to a first crankpin and third crankpin of a crankshaft.

12. An engine according to claim 11, in which the air power piston, is connected via a second connecting rod to a second crankpin of the crankshaft.

13. An engine according to claim 12, in which the second crankpin of the crankshaft is disposed between 150-210^{s} relative to the first crankpin and third crankpin of the crankshaft.

14. An engine according to claim 4, or to any one of claims 5 to 10 where dependent directly or indirectly on claim 4, in which the stepped double sided air transfer piston is connected via a first connecting rod and third connecting rod to a first crankpin and third crankpin of a crankshaft.

15. An engine according to claim 14, in which the exhaust power piston is connected via a second connecting rod to a second crankpin of the crankshaft.

16. An engine as claimed in claim 13, in which the second crankpin of the crankshaft is disposed between 150-210^{s} relative to the first crankpin and third crankpin of the crankshaft.

17. An engine according to any one of the preceding claims, wherein the cylinder defines a second portion of greater diameter providing a third air transfer volume, wherein one of the first and second power pistons is a stepped piston providing a double-sided air transfer piston having a forward side and a reverse side, configured such that the forward side compresses and expands the first air transfer volume and the second side compresses and expands the second air transfer volume, and the other of the power pistons provides a stepped air transfer piston configured to compress and expand the third air transfer volume, wherein each of the first, second and third air transfer volumes is fluidly connected to the air delivery passage.

18. An engine according to claim 17 in which a forward side of the stepped air transfer piston is configured to act in-phase with the power pistons.

19. An engine according to claim 17 or 18, in which the forward side of the stepped air transfer piston is integral with the air power piston.

20. An engine according to claim 17 or 18, in which the forward side of the stepped air transfer piston is integral with the exhaust power piston.

21. An engine according to any one of claims 17 to 20, in which the forward side of the stepped air transfer piston discharges air into a third air delivery passage which is in connection with the air port.

22. An engine according to any one of claims 17 to 21, in which the forward side of the stepped air transfer piston discharges air via a check valve into a third air delivery passage.

23. An engine according to claim 22, in which the third air delivery passage is in fluid connection with the air delivery passage in connection with the air ports.

24. An engine according to any one of claims 17 - 23, in which the air transfer piston is part of a stepped exhaust power piston.

25. An engine according to any one of claims 17 - 23, in which the air transfer piston is part of a stepped air power piston.

26. An engine substantially as hereinbefore described with reference to and as shown in Figures 2 to 8 of the accompanying drawings.

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

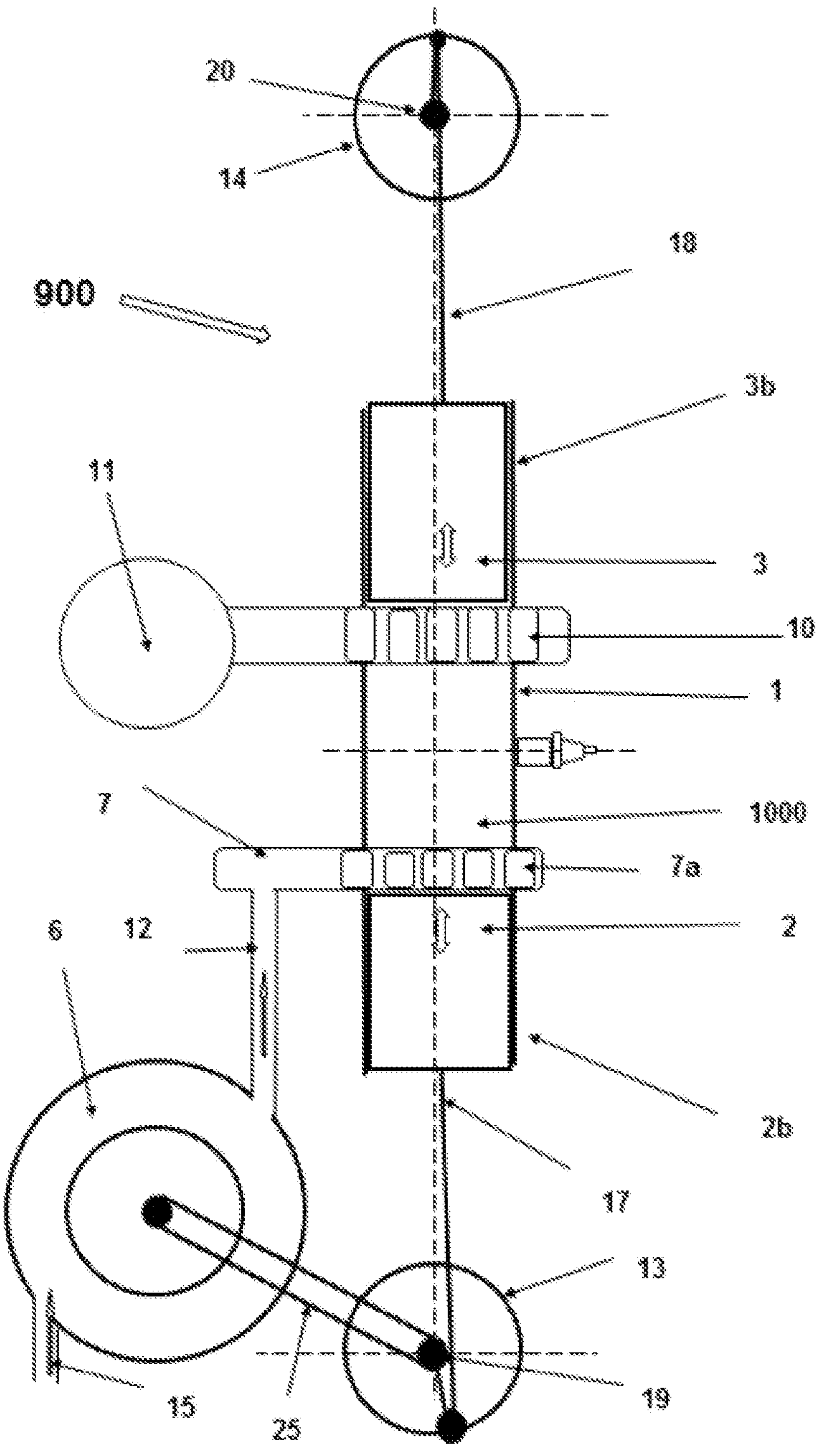
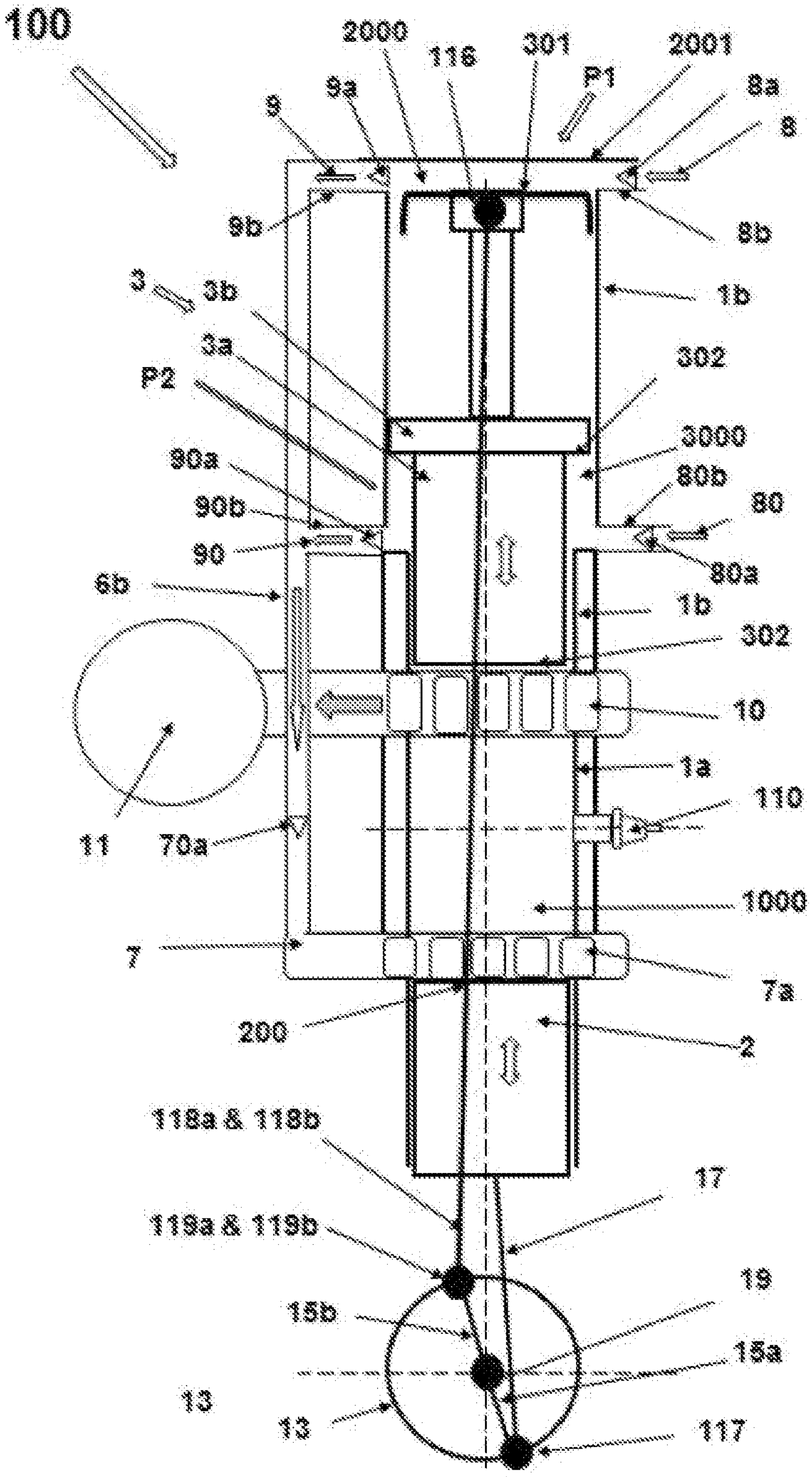


Fig.1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9b
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3b
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90a
80b
90b
80
90
80a
6b
1b
302
10
1a
110
11
70a
1000
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7a
200
2
118a & 118b
17
119a & 119b
19
15b
15a
13
13
117

Fig.2

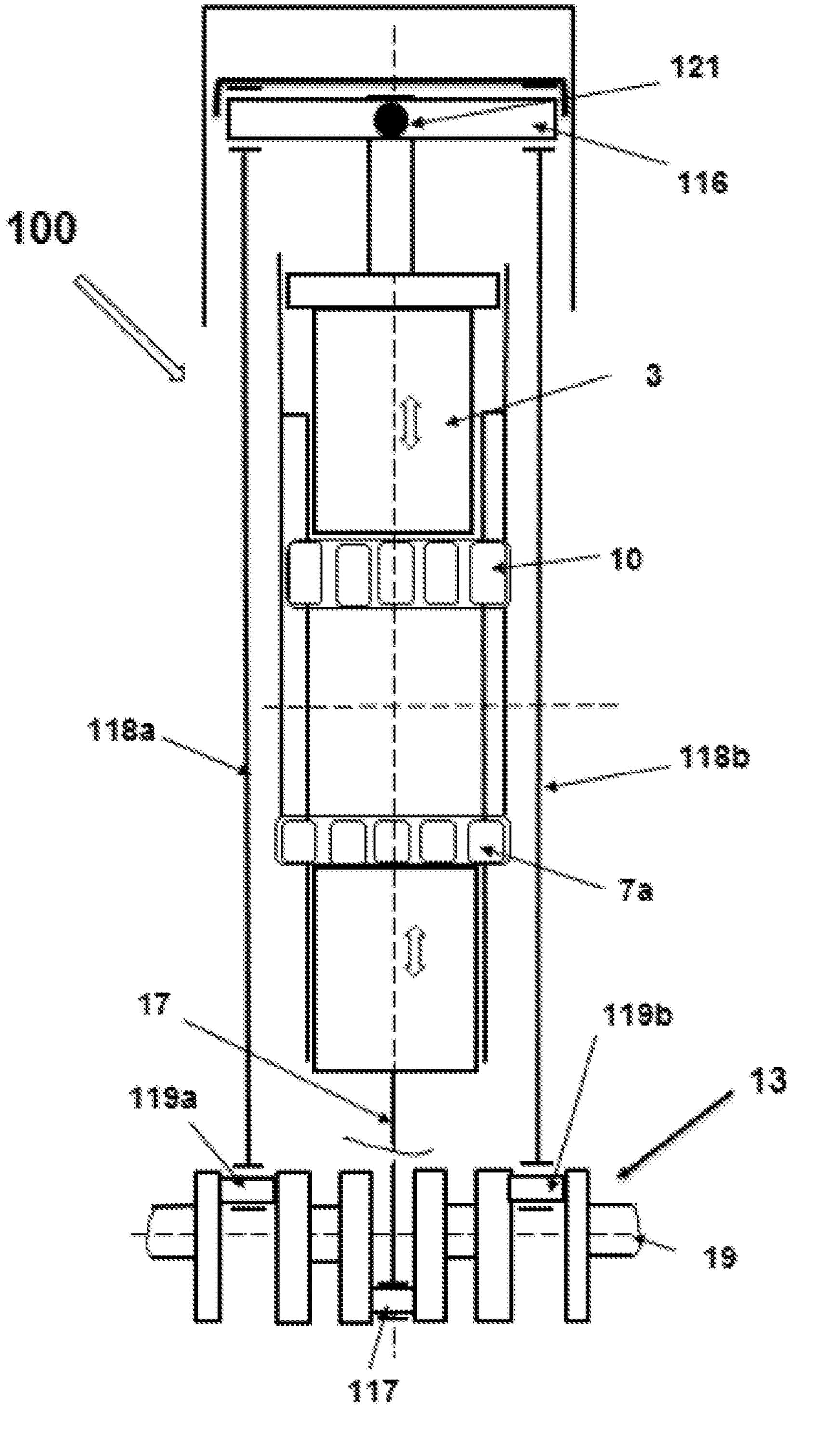
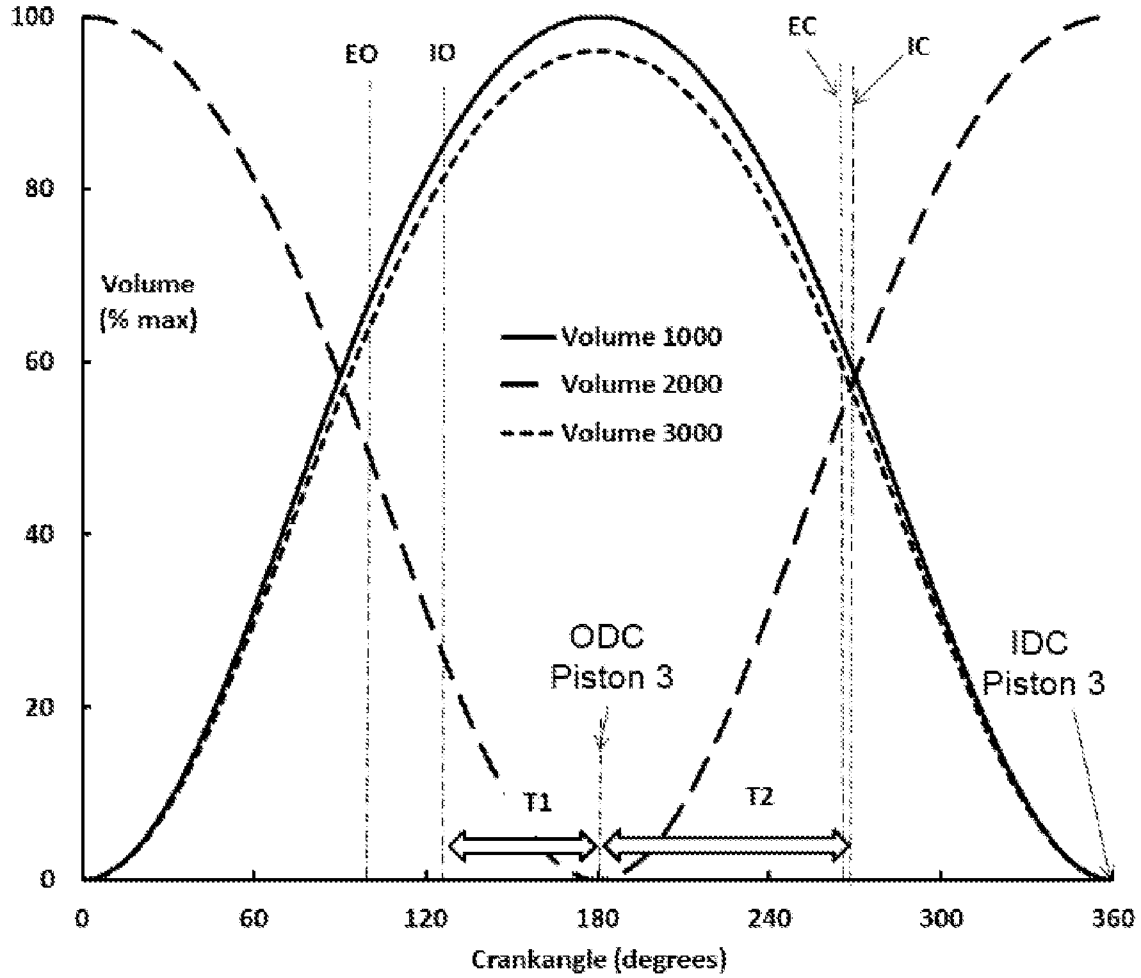


Fig.3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40
20
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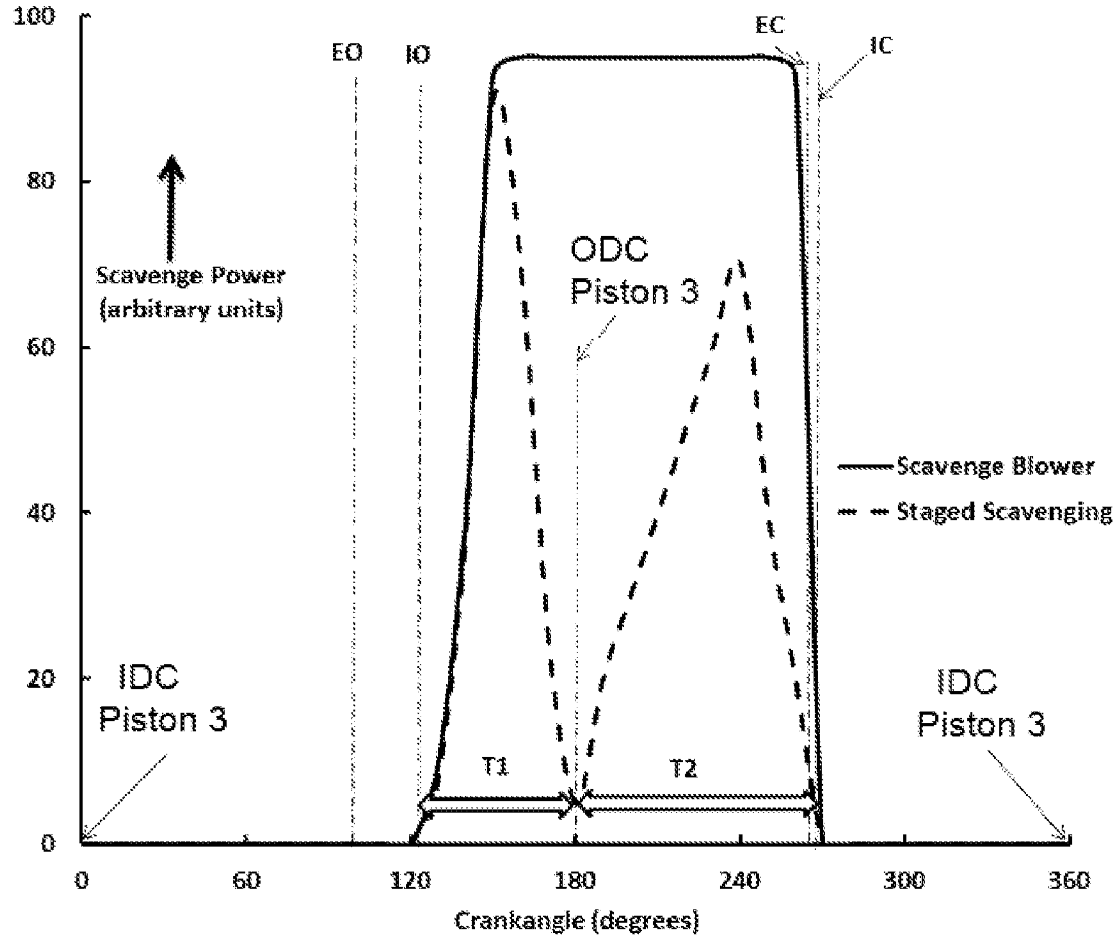
0
60
120
180
240
300
360
Crankangle (degrees)
Volume
(% max)
EO
IO
EC
IC
Volume 1000
Volume 2000
Volume 3000
ODC
Piston 3
IDC
Piston 3
T1
T2

Fig.4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40
20
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EC
IC
Scavenge Power
(arbitrary units)
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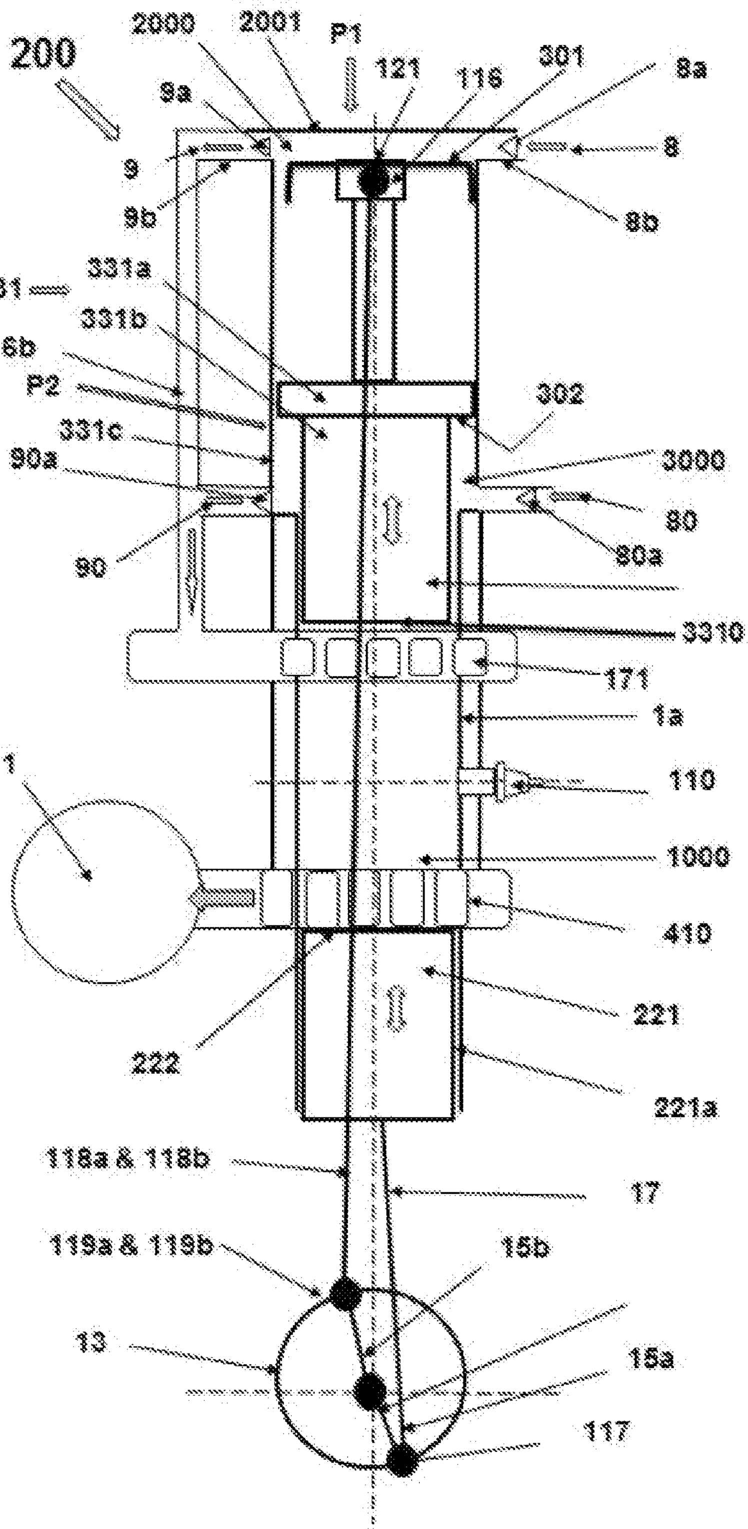
IDC
Piston 3
T1
T2
IDC
Piston 3
Scavenge Blower
Staged Scavenging
0
60
120
180
240
300
360
Crankangle (degrees)

Fig.5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2000
2001
P1
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9b
8b
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331b
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302
331c
3000
90a
80
90
80a
3310
171
1a
11
110
1000
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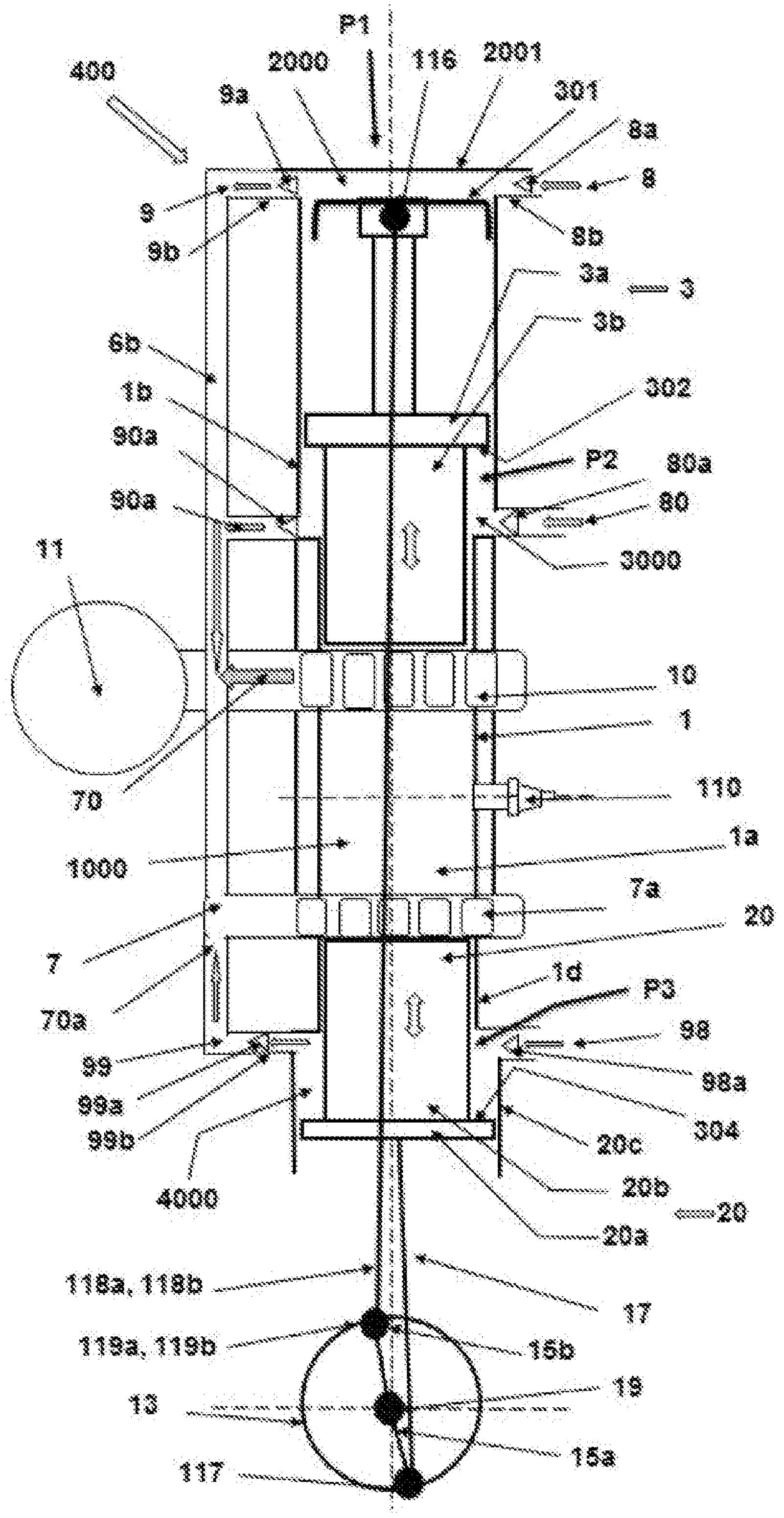
221
222
221a
118a & 118b
17
119a & 119b
15b
13
15a
117

Fig.6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2000
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2001
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9a
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9
8
9b
8b
3a
3
3b
6b
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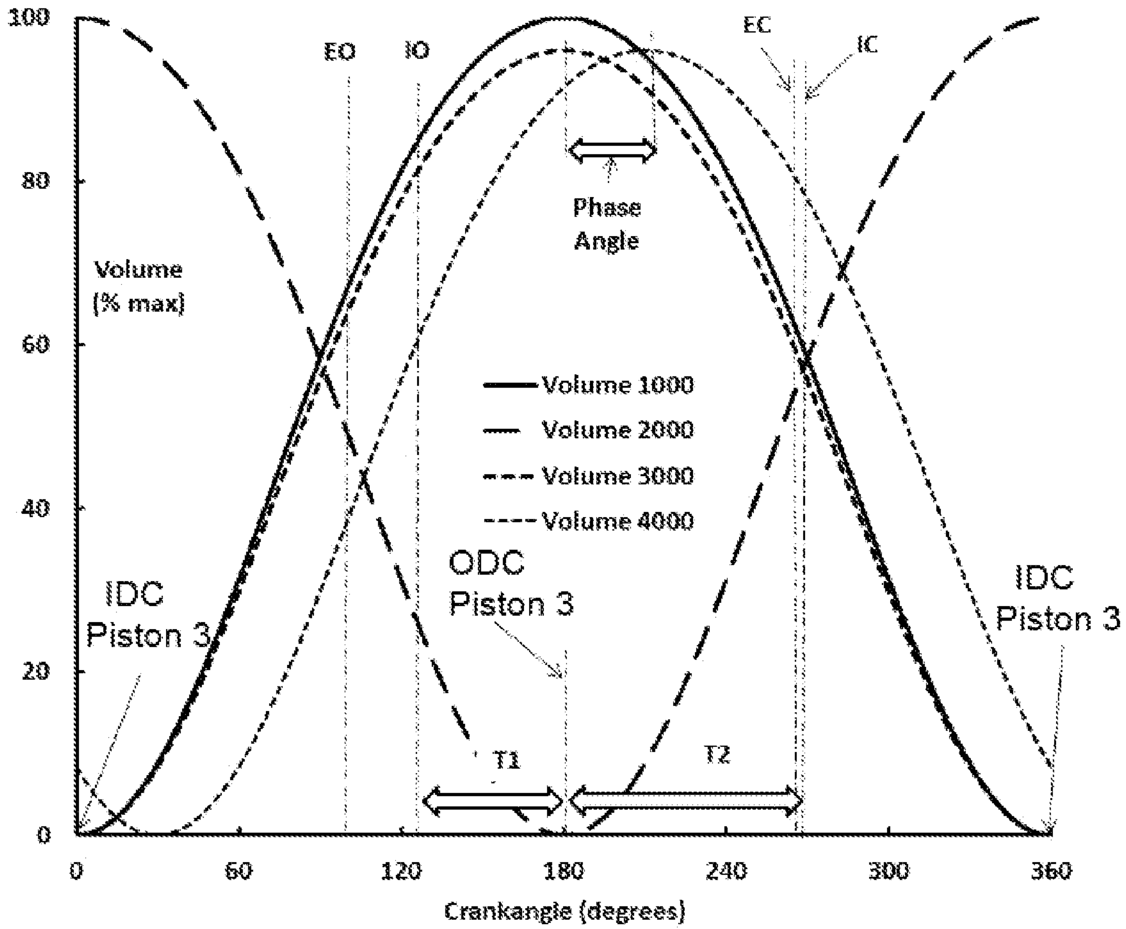
90a
P2
80a
90a
80
3000
11
10
1
70
110
1000
1a
7a
20
7
1d
70a
P3
99
98
98a
99a
304
99b
20c
4000
20b
20
20a
118a, 118b
17
119a, 119b
15b
19
13
15a
117

Fig.7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80
60
40
20
0
Volume
(% max)
EO
IO
EC
IC
Phase
Angle
Volume 1000
Volume 2000
Volume 3000
Volume 4000
IDC
Piston 3
ODC
Piston 3
IDC
Piston 3
T1
T2
0
60
120
180
240
300
360
Crankangle (degrees)

Fig.8

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2014/051049

A. CLASSIFICATION OF SUBJECT MATTER
INV. FO1B7/04 F01B7/18 F02B75/28
ADD.

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)
F01B F02B

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.
X	CH 202 051 A (BUESSING NAG VEREINIGTE NUTZKR [DE]) 31 December 1938 (1938-12-31) the whole document -----	1-25
X	US 2008/271715 Al (DUPONT STEPHEN [US]) 6 November 2008 (2008-11-06) paragraph [0010] - paragraph [0013]; figure 1 -----	1-6, 12, 13, 15-20, 24,25
X	US 2 079 156 A (BRUNO DANCKW0RTT THOMAS) 4 May 1937 (1937-05-04) page 2, column 2, line 42 - line 59; figure 1 -----	1,3,6,7, 12,17, 19,20, 23-25

-/--

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) orwhich is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"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
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 July 2014	23/07/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Tietje, Kai

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2014/051049

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 475 584 A (FREDERIC OSMOND HUNT) 23 November 1937 (1937-11-23) page 2, line 111 - page 4, line 52; figures 1,2 -----	1-6, 11, 12, 14, 15, 17-20, 24,25
A	US 5 213 067 A (KRAMER LOUIS E [US]) 25 May 1993 (1993-05-25) column 3, line 35 - column 4, line 47; figures 3,11,12 -----	1

1

International application No.
PCT/GB2014/051049

INTERNATIONAL SEARCH REPORT

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [X] Claims Nos.: 26, 27
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 26, 27

Claims 26 and 27 contain no technical features but only vague references to the drawings which is not allowed.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2014/05 1049

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
CH 20205 1	A	31-12-1938	NONE	
US 200827 1715	Al	06-11-2008	NONE	
US 2079 156	A	04-05-1937	NONE	
GB 475584	A	23-11-1937	NONE	
US 5213067	A	25-05-1993	NONE	