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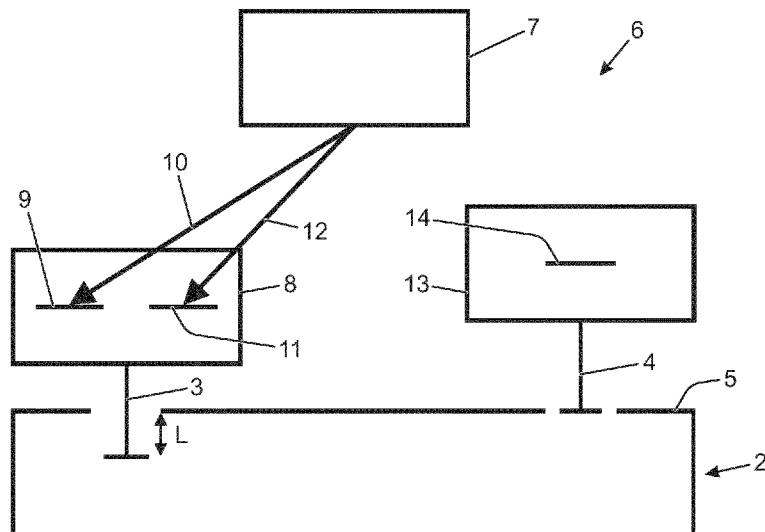


Fig 2a

(57) Abstract: An apparatus 6 for controlling lifting of inlet poppet valves of at least one combustion chamber 5 of an internal combustion engine 2, the apparatus 6 comprising: a first piston 8 arranged to be actuated to control a lift of a first inlet poppet valve 3 of a combustion chamber 5, comprising a first actuation surface 9 and a second different actuation surface 11; a second piston 13 arranged to be actuated to control a lift of a second inlet poppet valve 4 of the combustion chamber 5, comprising a third actuation surface 14; and a hydraulic control system 7 arranged to operate in: a first mode which causes simultaneous actuation of the first actuation surface 9 and the second actuation surface 11 but not the third actuation surface 14; and a second mode which causes simultaneous actuation of the first actuation surface 9 and the third actuation surface 14, but not the second actuation surface 11.

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APPARATUS FOR CONTROLLING VALVES OF AN INTERNAL COMBUSTION ENGINE

TECHNICAL FIELD

5 The present disclosure relates to apparatus for controlling valves of an internal combustion engine. In particular, but not exclusively it relates to apparatus for controlling movement of inlet poppet valves of at least one combustion chamber of an internal combustion engine.

Aspects of the invention relate to an apparatus, an internal combustion engine, and a
10 vehicle.

BACKGROUND

At a predetermined time during a combustion cycle of an internal combustion engine, an inlet
15 poppet valve is lifted away from a valve seat and into a combustion chamber, to open an inlet port and allow the intake of air into the combustion chamber through the inlet port. At a later predetermined time during the combustion cycle, the inlet poppet valve is returned to the valve seat to close the inlet port.

20 It is known for the lifting of an inlet poppet valve to be controlled by apparatus (e.g. a camshaft and valve train). The valve train may comprise a hydraulic control system actuated by the camshaft. The displacement of fluid within the hydraulic control system during actuation by the camshaft moves a small piston within a cylinder. The piston pushes a valve stem of an inlet poppet valve to lift the inlet poppet valve.

25 A combustion chamber may comprise a plurality of inlet ports, each inlet port opened and closed by an inlet poppet valve.

It is an aim of the present invention to address disadvantages of the prior art.

30

SUMMARY OF THE INVENTION

Aspects and embodiments of the invention provide an apparatus, an internal combustion engine, and a vehicle, as claimed in the appended claims. The invention is as set out in the claims.

According to an aspect of the invention there is provided an apparatus for controlling lifting of inlet poppet valves of at least one combustion chamber of an internal combustion engine, the apparatus comprising: a first piston arranged to be actuated to control a lift of a first inlet poppet valve of a combustion chamber, comprising a first actuation surface and a second different actuation surface; a second piston arranged to be actuated to control a lift of a second inlet poppet valve of the combustion chamber, comprising a third actuation surface; and a hydraulic control system arranged to operate in: a first mode which causes simultaneous actuation of the first actuation surface and the second actuation surface but not the third actuation surface; and a second mode which causes simultaneous actuation of the first actuation surface and the third actuation surface, but not the second actuation surface.

This provides the advantage of compensating for the tendency of hydraulic control systems to lift the first inlet poppet valve further in the first mode compared to the second mode. In some examples this allows greater control of intake air velocity.

The second actuation surface and the third actuation surface may have identical areas.

This provides the advantage of eliminating the tendency of hydraulic control systems to lift the first inlet poppet valve further in the first mode compared to the second mode.

The first actuation surface, the second actuation surface and the third actuation surface may have identical areas.

This provides the advantage of eliminating the tendency of hydraulic control systems to lift the first inlet poppet valve further in the first mode than the second inlet poppet valve is capable of lifting.

- 5 The apparatus may be arranged to provide a first restoring force resisting actuation of the first piston and a second restoring force resisting actuation of the second piston, wherein the ratio of a parameter controlling the magnitude of the first restoring force to the area of the first actuation surface combined with/or of the second actuation surface is the same as the ratio of a parameter controlling the magnitude of the second restoring force to the area of the
10 third actuation surface.

This provides the advantage of compensating for the effect of different means, such as return springs, for providing different restoring forces to poppet valves, having different lift-resisting effects, on the lift of inlet poppet valves. Even if the return springs of the first and
15 second inlet poppet valves have different spring constants, the apparatus can still eliminate the tendency of the first inlet poppet valve to lift further in the first mode than the second inlet poppet valve is capable of lifting

The first actuation surface and the second actuation surface may be arranged such that the
20 direction of actuating force acting on the first piston via the first actuation surface and the second actuation surface in the first mode is the same as the direction of actuating force acting on the first piston via the first actuation surface in the second mode.

This provides the advantage of reducing wear of the apparatus as the first piston is actuated
25 axially and without side loading.

At least a portion of the first piston may be T-shaped in cross-section and may comprise the first actuation surface and the second actuation surface.

This provides the advantage of reducing wear of the apparatus as the first piston is capable of being actuated using symmetrical distribution of force, avoiding side loading.

5 The first actuation surface and the second actuation surface may be rotationally symmetrical about a common central axis.

This provides the advantage of reducing wear of the apparatus as the first piston is capable of being actuated using symmetrical distribution of force, avoiding side loading.

10 The first actuation surface and the second actuation surface may be non-coplanar.

The first piston may define a seal between the first actuation surface and the second actuation surface including while the first piston is actuated.

15 This provides the advantage that hydraulic fluid does not easily move between the first actuation surface and the second actuation surface while the first piston is actuated, ensuring reliable operation of the apparatus in the first mode.

20 The hydraulic control system may comprise switching means for switching between the first mode and the second mode.

This provides the advantage that no additional sources of hydraulic fluid are required to enable actuation of both the second actuation and the third actuation surface.

25 The apparatus may be arranged to contain relatively high pressure fluid from a first fluid source for applying actuating force to the first piston and to the second piston, and relatively low pressure fluid from a second different fluid source.

This provides the advantage of an apparatus able to utilize different fluid sources to avoid hydrostatic lock. The apparatus can utilize the low pressure fluid source for avoiding hydrostatic lock.

- 5 The apparatus may comprise a seat for the first piston, the seat and the first piston defining a variable volume cavity therebetween, and may comprise a vent positioned to enable the relatively low pressure fluid to at least enter the variable volume cavity during actuation of the first piston.
- 10 This provides the advantage of a more efficient and reliable apparatus, because the vent prevents hydrostatic locking by fluid trapped in the variable volume cavity. Trapped fluid would resist actuation of the first piston, for example by resisting changes in the volume of the internal volume cavity.
- 15 The seat and the second actuation surface of the first piston may define the variable volume cavity therebetween, and the apparatus may comprise vent switching means for switching whether the variable volume cavity is exposed to the relatively low pressure fluid or to the relatively high pressure fluid during actuation of the first piston.
- 20 This provides the advantage of a more efficient and reliable apparatus, because the vent prevents fluid trapped in the variable volume cavity from resisting actuation of the first piston in the second mode, for example by preventing fluid compression or expansion in the variable volume cavity.
- 25 The vent switching means provides the advantage of an apparatus with fewer components, as the vent can perform two functions, enabling passage of the relatively high pressure fluid and the relatively low pressure fluid.

The vent switching means may be operable such that in the first mode the variable volume cavity is exposed to the relatively high pressure fluid and in the second mode the variable volume cavity is exposed to the relatively low pressure fluid.

- 5 This provides the advantage of conserving relatively high pressure fluid by enabling it to be pushed out of the variable volume cavity in the first mode while remaining in the hydraulic control system for later use.

10 The apparatus may comprise a fluid routing switch comprising: a first inlet for the relatively high pressure fluid; a second separate inlet for the relatively low pressure fluid; a first outlet for the second actuation surface; and a second separate outlet for the third actuation surface, wherein the fluid routing switch may be arranged such that: in the first mode the first inlet is exposed to the first outlet but not the second outlet and the second inlet is not exposed to the first outlet or the second outlet; and in the second mode the first inlet is exposed to the second outlet but not the first outlet, and the second inlet is exposed to the first outlet but not the second outlet.

20 This provides the advantage of a more reliable and simple construction having fewer moving parts, in which a single fluid routing switch provides the function of the switching means and the vent switching means.

The relatively low pressure fluid may comprise liquid phase fluid.

25 According to another aspect of the invention there is provided an internal combustion engine comprising the apparatus as described herein.

According to a further aspect of the invention there is provided a vehicle comprising the apparatus or the internal combustion engine as described herein.

According to a further aspect of the invention there is provided an apparatus comprising: first means for controlling a lift of a first valve of a combustion chamber, comprising a first actuation surface and a second different actuation surface; second means for controlling a lift of a second valve of the combustion chamber, comprising a third actuation surface; and
5 control means arranged to operate in: a first mode which causes simultaneous actuation of the first actuation surface and the second actuation surface but not the third actuation surface; and a second mode which causes simultaneous actuation of the first actuation surface and the third actuation surface, but not the second actuation surface.

10 In some examples, the first means is a first piston. In some examples, the second means is a second piston. In some examples, the control means is a hydraulic control system.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims
15 and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim
20 to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

25 One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig 1 illustrates an example of a vehicle 1;

Fig 2A illustrates an example of an apparatus 6 actuating a single inlet poppet valve 3;

30 Fig 2B illustrates an example of an apparatus 6 actuating two inlet poppet valves 3, 4;

Fig 3A illustrates another example of an apparatus 6 actuating a single inlet poppet valve 3; and

Fig 3B illustrates another example of an apparatus 6 actuating two inlet poppet valves 3, 4.

5 DETAILED DESCRIPTION

The figures illustrate an apparatus 6 for controlling lifting of inlet poppet valves of at least one combustion chamber 5 of an internal combustion engine 2, the apparatus 6 comprising: a first piston 8 arranged to be actuated to control a lift of a first inlet poppet valve 3 of a combustion chamber 5, comprising a first actuation surface 9 and a second different
10 actuation surface 11; a second piston 13 arranged to be actuated to control a lift of a second inlet poppet valve 4 of the combustion chamber 5, comprising a third actuation surface 14; and a hydraulic control system 7 arranged to operate in: a first mode which causes simultaneous actuation of the first actuation surface 9 and the second actuation surface 11
15 but not the third actuation surface 14; and a second mode which causes simultaneous actuation of the first actuation surface 9 and the third actuation surface 14, but not the second actuation surface 11.

Fig 1 illustrates a vehicle 1. The vehicle 1 is a land based vehicle, in this example a
20 passenger car. Embodiments of the invention could be incorporated within a vehicle such as the vehicle 1 of Fig 1.

Figs 2A and 2B schematically illustrate an example of the apparatus 6 in use. Fig 2A shows the apparatus 6 in a first mode of operation and Fig 2B shows the apparatus 6 in a second
25 mode of operation.

Figs 2A and 2B illustrate the apparatus 6 and a combustion chamber 5 of an internal combustion engine 2. In some examples the internal combustion engine 2 comprises a plurality of combustion chambers 5.
30

In Fig 2A, the apparatus 6 comprises a first piston 8, a second piston 13, and a hydraulic control system 7.

5 The apparatus 6 comprises a first inlet poppet valve 3 and a second inlet poppet valve 4. In other examples the first inlet poppet valve 3 and second inlet poppet valve 4 are separate components from the apparatus 6 and can be supplied separately from the apparatus 6.

10 The apparatus 6 is proximal to the combustion chamber 5 of the internal combustion engine 2, such that in use the first inlet poppet valve 3 is positioned between the first piston 8 and the combustion chamber 5 and the second inlet poppet valve 4 is positioned between the second piston 13 and the combustion chamber 5.

15 The first inlet poppet valve 3 is arranged to be moved by actuation of the first piston 8 and the second inlet poppet valve 4 is arranged to be moved by actuation of the second piston 13. The first piston 8 and second piston 13 are movable when actuated.

In some examples the first inlet poppet valve 3 is in contact with a portion of the first piston 8 and the second inlet poppet valve 4 is in contact with a portion of the second piston 13.

20 The hydraulic control system 7 comprises a hydraulic circuit providing a first source of hydraulic fluid and is arranged to displace hydraulic fluid in use. The hydraulic control system 7 is arranged such that displacement of the hydraulic fluid within the hydraulic circuit causes actuation of at least the first piston 8; and the second piston 13.

25 The first piston 8 comprises a first actuation surface 9 and a second actuation surface 11. The second piston 13 comprises a third actuation surface 14.

An actuation surface such as the first actuation surface 9, second actuation surface 11 and third actuation surface 14, is defined by a surface area on a piston such as the first piston 8

or the second piston 13. The surface area may extend over at least an entire face of the piston.

The surface area can be arranged such that displacement of hydraulic fluid adjacent to the surface area in a direction at least partially orthogonal to the plane of the surface area imparts a distributed load over the surface area. The surface area is arranged to cause actuation of the piston when an actuating force acts over the surface area. The actuating force is an unbalanced force on the piston caused at least in part by the distributed load, which causes the piston to move in the direction of displacement of the hydraulic fluid.

The first actuation surface 9 extends over a first surface area of the first piston 8. In Fig 2A a first arrow 10 is shown which extends from the hydraulic control system 7 to the first actuation surface 9. The first arrow 10 is not part of the apparatus 6, and is merely illustrative of a direction in which displaced hydraulic fluid is directed. The first arrow 10 points towards the first actuation surface 9, therefore displaced hydraulic fluid is directed towards the first actuation surface 9, actuating the first actuation surface 9.

The second actuation surface 11 extends over a second surface area of the first piston 8. The second surface area does not overlap the first surface area. As shown in Fig 2A, the first actuation surface 9 and the second actuation surface 11 are separated from each other by a discontinuity. The discontinuity is not capable of being acted upon by an actuating force caused by displacement of hydraulic fluid.

In Fig 2A, a second arrow 12 is shown which extends from the hydraulic control system 7 to the second actuation surface 11. The second arrow 12 is not part of the apparatus 6, and is merely illustrative of a direction in which displaced hydraulic fluid is directed. The second arrow 12 points towards the second actuation surface 11, therefore displaced hydraulic fluid is directed towards the second actuation surface 11, actuating the second actuation surface 11.

In the first mode of operation shown in Fig 2A, the total actuating force which moves the first piston 8 is the sum of the actuating force acting on the first actuation surface 9 and the actuating force acting on the second actuation surface 11. The resulting movement of the first piston 8 pushes the first inlet poppet valve 3, moving the first inlet poppet valve 3 away from its valve seat by a lift distance L. Movement of a poppet valve away from its valve seat is referred to herein as lifting of the poppet valve.

The third actuation surface 14 extends over a surface area of the second piston 13. The third actuation surface is for causing the second piston 13 to be moved by actuating force acting on the third actuation surface 14. Although not shown in Fig 2A, movement of the second piston 13 pushes the second inlet poppet valve 4 out of its valve seat, allowing air to enter the combustion chamber 5.

In the first mode of operation shown in Fig 2A displaced hydraulic fluid is not directed to the third actuation surface 14. Therefore in Fig 2A the hydraulic control system 7 causes actuation of the first actuation surface 9 and the second actuation surface 11 but not the third actuation surface 14. The third actuation surface 14 receives zero actuating force, or at least insufficient force to cause movement of the second piston 13.

Fig 2A as described above illustrates the apparatus 6 in the first mode of operation. The first mode of operation is a single valve lift mode which causes simultaneous actuation of the first actuation surface 9 and the second actuation surface 11 but not the third actuation surface 14, causing only the first inlet poppet valve 3 to lift.

Fig 2B illustrates the apparatus 6 of Fig 2A and corresponding reference numerals refer to corresponding features. Fig 2B shows the apparatus 6 in the second mode of operation.

The difference between Fig 2B and Fig 2A is that the second arrow 12 is omitted and instead a third arrow 15 is shown extending from the hydraulic control system 7 towards the third actuation surface 14 of the second piston 13.

In Fig 2B, the third arrow 15 extends from the hydraulic control system 7 to the third actuation surface 14. The third arrow 15 is not part of the apparatus 6, and is merely illustrative of a direction in which displaced hydraulic fluid is directed. The third arrow 15 points towards the third actuation surface 14, therefore displaced hydraulic fluid is directed towards the third actuation surface 14, actuating the third actuation surface 14.

In Fig 2B, the hydraulic control system 7 causes actuation of the first actuation surface 9 and the third actuation surface 14 but not the second actuation surface 11. As a result, the hydraulic fluid moves the first piston 8 and the second piston 13. This results in lifting of both the first inlet poppet valve 3 and the second inlet poppet valve 4 simultaneously. The second actuation surface 11 receives zero actuating force, or at least insufficient force to itself cause movement of the first piston 8.

In Fig 2B the lifting of both the first inlet poppet valve 3 and the second inlet poppet valve 4 is simultaneous, meaning the opening time of the first inlet poppet valve 3 occurs before the closing time of the second inlet poppet valve 4 and the opening time of the second inlet poppet valve 4 occurs before the closing time of the first inlet poppet valve 3.

Fig 2B as described above illustrates the apparatus 6 in the second mode of operation. The second mode is a dual valve lift mode as shown in Fig 2B which causes simultaneous actuation of the first actuation surface 9 and the third actuation surface 14, but not the second actuation surface 11, causing both inlet poppet valves 3, 4 to lift.

Referring to Figs 2A and 2B, by actuating the second actuation surface 11 in only the single valve lift mode, the apparatus 6 compensates for the tendency of the hydraulic control system 7 to lift the first inlet poppet valve 3 further in the single valve lift mode compared to the dual valve lift mode.

The apparatus 6 can be further adapted to eliminate this tendency by suitable control of surface areas of the actuation surfaces. Examples are described below.

In one example, the surface area of the second actuation surface 11 is identical to the surface area of the third actuation surface 14. As a result, the first inlet poppet valve 3 will lift by distance L in both the single valve lift mode and the dual valve lift mode.

The person of ordinary skill in the art would understand the term 'identical' to mean identical within a certain engineering tolerance, such as a tolerance based on linear dimensions in the order of: 10^{-6}m ; 10^{-5}m ; 10^{-4}m ; or 10^{-3}m .

In some but not necessarily all examples, the first actuation surface 9, the second actuation surface 11 and the third actuation surface 14 have identical surface areas. As a result, the first inlet poppet valve 3 will lift by distance L in both the single valve lift mode and the dual valve lift mode and the second inlet poppet valve 4 will lift by the distance L in the dual valve lift mode.

Figs 3A and 3B schematically illustrate another example of an apparatus 6 comprising all of the features of the apparatus 6 described in relation to Figs. 2A and 2B, as well as several other new features which are described herein. Corresponding reference numerals refer to corresponding features. Fig 3A shows the apparatus 6 in the first mode of operation corresponding to the single valve lift mode and Fig 3B shows the apparatus 6 in the second mode of operation corresponding to the dual valve lift mode.

In Fig 3A, the hydraulic control system 7 comprises a master piston 36 within a cylinder 34. At least a portion of the surface of the master piston 36 forms part of an exterior surface of the apparatus 6 and is not exposed to the internal hydraulic fluid within the apparatus 6, and at least a different opposing portion of the surface of the master piston 36 is exposed to the internal hydraulic fluid within the apparatus 6.

The master piston 36 is arranged to be actuated by a camshaft lobe 35. More specifically, the camshaft lobe 35 moves the master piston 36 within the cylinder 34. The movement of the master piston 36 by the camshaft lobe 35 displaces the hydraulic fluid within the apparatus 6.

5

In Fig 3A the hydraulic control system 7 comprises a hydraulic accumulator 30 and a blocking switch 32. When the blocking switch 32 is closed, to block flow therethrough, the hydraulic accumulator 30 is not exposed to displaced hydraulic fluid. When the blocking switch 32 is open, to enable flow therethrough, the hydraulic accumulator 30 is exposed to displaced hydraulic fluid. The blocking switch 32 may be moved between open and closed positions using any suitable means such as a solenoid.

10

If the blocking switch 32 is open, the displaced hydraulic fluid fills the hydraulic accumulator 30 without imparting sufficient actuating force to lift the first inlet poppet valve 3 or the second inlet poppet valve 4. In the example of Fig 3A the blocking switch 32 is blocked.

15

The hydraulic control system 7 comprises a first passage 38 for displaced hydraulic fluid extending from the cylinder 34 towards the first piston 8 and the second piston 13. In the example of Fig 3A the first passage 38 leads to the first actuation surface 9.

20

In Fig 3A, hydraulic fluid displaced by the master piston imparts actuating force on the first actuation surface 9 as denoted by arrow 10.

The hydraulic control system 7 comprises a second passage 40 meeting the first passage 38 at a junction, and extending to switching means 41, 42 in the form of a fluid routing switch 41 having a first inlet 42 for fluid from the second passage 40. The fluid routing switch 41 is a type of directional control valve for routing the displaced hydraulic fluid.

25

The second passage 40 extends from the junction to a first inlet 42 of the fluid routing switch 41.

30

The hydraulic control system 7 comprises a third passage 50 extending from a first outlet 46 of the fluid routing switch 41 to the second actuation surface 11 of the first piston 8.

5 In Fig 3A, the fluid routing switch 41 is arranged such that the first inlet 42 of the fluid routing switch 41 is exposed to the first outlet 46 of the fluid routing switch 41. Therefore hydraulic fluid displaced by the master piston passes through the third passage 50 to actuate the second actuation surface 11, as denoted by arrow 12.

10 The hydraulic control system 7 comprises a fourth passage 52 extending from a second outlet 48 of the fluid routing switch 41 to the third actuation surface 14 of the second piston 13.

In Fig 3A, the first inlet 42 of the fluid routing switch 41 is not exposed to the second outlet 15 48 of the fluid routing switch 41. Therefore hydraulic fluid displaced by the master piston does not cause the second piston 13 to move. Therefore the hydraulic control system 7 of Fig 3A is operating in the single valve lift mode, in which only the first inlet poppet valve 3 lifts by distance L.

20 The fluid routing switch 41 of Fig 3A also comprises a second separate inlet 44. The second separate inlet is exposed to separate fluid from a separate fluid source 66.

In some examples the separate fluid is liquid phase fluid. In some examples the separate fluid is engine oil and the separate fluid source 66 is an engine oil gallery.

25

In the single valve lift mode as illustrated in Fig 3A the second inlet 44 is not exposed to the first outlet 46 or to the second outlet 48, therefore the second inlet 44 does not perform any function in Fig 3A. The second inlet 44 is described later in relation to Fig 3B.

The fluid routing switch 41 of Fig 3A is movable between two positions to control whether the second actuation surface 11 or the third actuation surface 14 is caused to be actuated in dependence on application of fluid displacement. In other examples the fluid routing switch 41 is movable between more than two positions.

5

Any suitable actuator can be used for controlling the position of the fluid routing switch 41, such as a solenoid, or a fluid actuator as shown in Fig 3A. In Fig 3A the fluid routing switch 41 is a two-inlet, two-outlet switch. In other examples any suitable number of inlets and outlets can be provided.

10

The fluid actuator of Fig 3A comprises a source 68 of pressurized fluid, a switch 56, and a fifth passage 54. The switch 56 can control the direction in which fluid travels through the fifth passage 54, thereby controlling operation of the fluid routing switch 41. The switch 56 could be operated using any suitable actuator controlled by any suitable controller such as an engine control unit.

15

In Fig 3A, a first piston 8 and second piston 13 is included as described in relation to Figs 2A and 2B. However in Fig 3A the shape of the first piston 8 differs from the shape of the second piston 13.

20

In Fig 3A the first piston 8 is T-shaped in cross-section whereas the second piston 13 is a cylinder and may be a uniform cylinder. In the illustration of Fig 3A the T-shaped first piston 8 is inverted.

25

The T-shaped cross-section is symmetrical about an axis of symmetry. The axis of symmetry passes through the centroid of the T-shaped cross-section. The first actuation surface 9 and the second actuation surface 11 are rotationally symmetrical about a common central axis and the common central axis is co-axial with the axis of symmetry.

The maximum diameter of the second actuation surface 11 is a predetermined multiple of the maximum diameter of the first actuation surface 9. The multiple is, for example, equal to the square root of two.

5 In some examples the T-shaped first piston 8 is formed of a continuous piece of material and has a flange and a leg. The flange extends perpendicularly to the leg while the leg extends parallel to the axis of symmetry. The flange and leg are also rotationally symmetrical about the axis of symmetry.

10 The flange defines opposing planar continuous surfaces, a first of which defines the second actuation surface 11 and a second of which comprises the portion in contact with the first inlet poppet valve 3.

The second actuation surface 11 forms an annular ring, the centre of the ring defining the
15 base of the leg.

The first actuation surface 9 is defined by an end surface of the leg, and is therefore non-coplanar with the second actuation surface 11.

20 A sidewall of the leg extending between the base of the leg and the end of the leg defines the discontinuity between the first actuation surface 9 and the second actuation surface 11.

In other examples other shapes are possible, for example any shape which, like the above shape, enables the first actuation surface 9 and the second actuation surface 11 to be
25 arranged for zero side loading.

Zero side loading means that the direction of total actuating force acting on the first piston 8 in the single valve lift mode is the same as the direction of total actuating force acting on the first piston 8 in the dual valve lift mode. The function of zero side loading is to prevent wear

caused by unbalanced lateral forces on the first piston 8 orthogonal to the direction in which the first piston 8 is constrained to move.

Suitable shapes for the first piston 8 include shapes having at least one axis of symmetry
5 and shapes which are rotationally symmetrical about at least one plane.

The first piston 8 of Fig 3A is arranged proximal to a seat 58.

10 The seat 58 defines a T-shaped cavity having a leg cavity for the leg of the first piston 8 and a flange cavity for the flange of the first piston 8. The cavity provides a close fit to resist hydraulic fluid leakage between the first actuation surface 9 and the second actuation surface 11.

15 In some examples the first piston 8 is biased against the seat 58 while the first piston 8 is not actuated, for example via a first restoring force 62 such as a return spring force.

At least a portion of the leg of the first piston 8 protrudes into the leg cavity of the seat 58 even while the first piston 8 is actuated fully to lift the first inlet poppet valve 3 to distance L. Therefore the sidewall of the leg acts as a continual seal 16 between the first actuation
20 surface 9 and the second actuation surface 11. In some examples the sidewall of the leg can support a sealing o-ring, for providing additional sealing.

A variable volume cavity 60 is defined between the second actuation surface 11 of the first piston 8 and the flange cavity of the seat 58 such that when the first piston 8 is lifted away
25 from the seat 58 the internal volume of the variable volume cavity 60 increases.

During actuation of the second actuation surface 11 hydraulic fluid is displaced into the variable volume cavity via an aperture 18 in the seat 58 for the third passage 50.

When actuation of the first piston 8 ceases by virtue of the master piston reaching maximum displacement, the first restoring force 62 moves the first piston 8 back towards the seat 58, causing the first piston 8 to push hydraulic fluid out of the internal volume within the seat 58 and back towards the first passage 38. The hydraulic fluid in the variable volume cavity 60 is
5 pushed out of the variable volume cavity 60 and into the third passage 50, via the aperture 18.

In some examples the first piston 8 is provided with a first restoring force 62 and the second piston 13 is provided with a second restoring force 64. For example each piston may be
10 provided with a return spring for moving the pistons into their respective seats when actuation ceases. In other examples the first restoring force 62 and second restoring force 64 can be provided by other mechanical, hydraulic, electrical or pneumatic means.

The restoring forces 62, 64 can resist actuation of the respective pistons 8, 13 but are not
15 sufficiently high to prevent any actuation of the respective pistons 8, 13.

If a parameter of the first restoring force 62 and the second restoring force 64 differs, for example if the respective return springs have different spring constants, then the surface areas of the respective actuation surfaces 9, 11, 14 need not all be identical to provide the
20 advantages described herein. For example, the ratio of spring constant for the first restoring force 62 to the surface area of the first actuation surface 9 and/or of the second actuation surface 11 is the same as the ratio of spring constant for the second restoring force 64 to the surface area of the third actuation surface 14.

In examples where the restoring forces are provided by means other than return springs, suitable parameters may include any constant of proportionality between displacement and restoring force, such as magnetic reluctance of a magnetic material.
25

Fig 3B illustrates the apparatus 6 of Fig 3A in which the hydraulic control system 7 is in the second mode of operation corresponding to the dual valve lift mode. Corresponding reference numerals refer to corresponding features.

- 5 The blocking switch 32 to the hydraulic accumulator 30 remains closed. Therefore the apparatus 6 as shown in Fig 3B is lifting the first inlet poppet valve 3 by distance L and the second inlet poppet valve 4 by distance L, in a similar manner to the apparatus 6 of Fig 2B.

10 In Fig 3B the apparatus 6 has switched from the single valve lift mode to the dual valve lift mode by switching the fluid routing switch 41 to a different position in which the first inlet 42 is exposed to the second outlet 48 but not the first outlet 46.

Switching is achieved by repositioning the fluid routing switch 41 between the positions of Fig 3A and Fig 3B, using the fluid actuator for example.

15

As a result of the switching, displaced hydraulic fluid actuates the third actuation surface 14, as shown by arrow 15, but does not actuate the second actuation surface 11.

20 As in Fig 3A, displaced hydraulic fluid from passage 38 actuates the first actuation surface 9, as shown by arrow 10.

Consequently both the first piston 8 and the second piston 13 move, in the manner described in relation to Fig 2B.

- 25 Further as a result of the switching, the fluid routing switch 41 is now arranged to expose the second inlet 44 to the first outlet 46 but not the second outlet 48.

The first piston 8 is able to draw the relatively low pressure fluid from the separate fluid source 66 into the variable volume cavity 60 via the second inlet 44, first outlet 46, third

passage 50 and aperture 18, while the first piston 8 is actuated by the relatively high pressure fluid acting on the first actuation surface 9.

5 The pressure of the relatively low pressure fluid from the separate fluid source 66 is relatively lower than the pressure of the hydraulic fluid in the hydraulic control system 7, to ensure that the relatively low pressure fluid does not actuate the second actuation surface 11.

10 The first piston 8 is then able to draw the relatively low pressure fluid into the variable volume cavity 60 while the first piston 8 is actuated and lifted away from its seat 58, and to vent the relatively low pressure fluid in the variable volume cavity 60 back into the separate fluid source 66 via the aperture 18, third passage 50, first outlet 46 and second inlet 44, when the first piston 8 is no longer actuated and is returning to its seat 58. Consequently hydrostatic locking does not occur in the variable volume cavity 60.

15 The fluid routing switch 41 described above serves two simultaneous functions: switching means 41, 42 for switching between the single valve lift mode and the dual valve lift mode; and vent switching means 41, 44 for switching whether the variable volume cavity 60 is exposed to the relatively low pressure fluid or to the relatively high pressure fluid during
20 actuation of the first piston 8. In other examples these functions are provided by separate components.

The hydraulic control system 7 as described in relation to Figs. 3A and 3B is arranged to operate in: a single valve lift mode as shown in Fig 3A which causes simultaneous actuation
25 of the first actuation surface 9 and the second actuation surface 11 but not the third actuation surface 14; and a dual valve lift mode as shown in Fig 3B which causes simultaneous actuation of the first actuation surface 9 and the third actuation surface 14, but not the second actuation surface 11.

In some, but not necessarily all examples, the apparatus 6 is arranged to switch between the single valve lift mode and the dual valve lift mode only while the master piston is not being moved, for instance by the camshaft lobe 35. This has the benefit of predictable valve lifting behavior and avoiding mixing of the hydraulic fluid and the separate fluid from the separate fluid source 66.

Although embodiments of the present invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications to the examples given can be made without departing from the scope of the invention as claimed. For example instead of poppet valves, butterfly valves or any other suitable type of valve could be used for controlling intake air into the combustion chamber. In another example the apparatus 6 could be used for controlling lifting of exhaust poppet valves, or for controlling lifting of both inlet and exhaust poppet valves.

Further, the apparatus 6 is scalable for use with any number of combustion chambers by repeating the structure shown in Figs 2A to 3B. The apparatus 6 is scalable for use with any number of inlet poppet valves per combustion chamber. In some examples the second mode may be an all valve lift mode in which all inlet poppet valves of a combustion chamber are lifted.

In another variation, each of the first inlet poppet valve 3 and second inlet poppet valve 4 is actuated by a different hydraulic circuit, enabling the opening time and/or closing time of the first inlet poppet valve 3 to be different from the opening time or the closing time of the second inlet poppet valve 4.

Features described in the preceding description may be used in combinations other than the combinations explicitly described.

Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not.

Although features have been described with reference to certain embodiments, those features may also be present in other embodiments whether described or not.

- 5 Whilst the terms 'inlet' and 'outlet' have been used in relation to hydraulic ports, this language is not intended to suggest that fluid can only travel in one direction through the port.

- 10 Whilst the term 'piston' has been used, it would be appreciated that the term is intended to cover any element, at least a portion of which moves in dependence upon a pressure difference, and which is capable of causing, at least indirectly, movement of an inlet poppet valve.

- 15 Whilst endeavoring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

CLAIMS

1. An apparatus for controlling lifting of inlet poppet valves of at least one combustion chamber of an internal combustion engine, the apparatus comprising:

5 a first piston arranged to be actuated to control a lift of a first inlet poppet valve of a combustion chamber, comprising a first actuation surface and a second different actuation surface;

a second piston arranged to be actuated to control a lift of a second inlet poppet valve of the combustion chamber, comprising a third actuation surface; and

10 a hydraulic control system arranged to operate in:

a first mode which causes simultaneous actuation of the first actuation surface and the second actuation surface but not the third actuation surface; and

a second mode which causes simultaneous actuation of the first actuation surface and the third actuation surface, but not the second actuation surface.

15 2. An apparatus as claimed in any preceding claim, wherein the second actuation surface and the third actuation surface have identical areas.

20 3. An apparatus as claimed in any preceding claim, wherein the first actuation surface, the second actuation surface and the third actuation surface have identical areas.

4. An apparatus as claimed in any preceding claim, arranged to provide a first restoring force resisting actuation of the first piston and a second restoring force resisting actuation of the second piston, wherein the ratio of a parameter controlling the magnitude of the first
25 restoring force to the area of the first actuation surface and/or of the second actuation surface is the same as the ratio of a parameter controlling the magnitude of the second restoring force to the area of the third actuation surface.

5. An apparatus as claimed in any preceding claim, wherein the first actuation surface and
30 the second actuation surface are arranged such that the direction of total actuating force

acting on the first piston via the first actuation surface and the second actuation surface in the first mode is the same as the direction of total actuating force acting on the first piston via the first actuation surface in the second mode.

5 6. An apparatus as claimed in any preceding claim, wherein at least a portion of the first piston is T-shaped in cross-section and comprises the first actuation surface and the second actuation surface.

7. An apparatus as claimed in any preceding claim, wherein the first actuation surface and
10 the second actuation surface are rotationally symmetrical about a common central axis.

8. An apparatus as claimed in any preceding claim, wherein the first actuation surface and the second actuation surface are non-coplanar.

15 9. An apparatus as claimed in any preceding claim, wherein the first piston defines a seal between the first actuation surface and the second actuation surface including while the first piston is actuated.

10. An apparatus as claimed in any preceding claim, wherein the hydraulic control system
20 comprises switching means for switching between the first mode and the second mode.

11. An apparatus as claimed in any preceding claim, wherein the apparatus is arranged to contain relatively high pressure fluid from a first fluid source for applying actuating force to the first piston and to the second piston, and relatively low pressure fluid from a second
25 different fluid source.

12. An apparatus as claimed in claim 11 comprising a seat for the first piston, the seat and the first piston defining a variable volume cavity therebetween, and comprising a vent positioned to enable the relatively low pressure fluid to at least enter the variable volume
30 cavity during actuation of the first piston.

13. An apparatus as claimed in claim 12, wherein the seat and the second actuation surface of the first piston define the variable volume cavity therebetween, and wherein the apparatus comprises vent switching means for switching whether the variable volume cavity is exposed to the relatively low pressure fluid or to the relatively high pressure fluid during actuation of the first piston.

14. An apparatus as claimed in claim 13, wherein the vent switching means is operable such that in the first mode the variable volume cavity is exposed to the relatively high pressure fluid and in the second mode the variable volume cavity is exposed to the relatively low pressure fluid.

15. An apparatus as claimed in any one of claims 11 to 14, comprising a fluid routing switch comprising:

a first inlet for the relatively high pressure fluid;
a second separate inlet for the relatively low pressure fluid;
a first outlet for the second actuation surface; and
a second separate outlet for the third actuation surface,
wherein the fluid routing switch is arranged such that:

in the first mode the first inlet is exposed to the first outlet but not the second outlet and the second inlet is not exposed to the first outlet or the second outlet; and
in the second mode the first inlet is exposed to the second outlet but not the first outlet, and the second inlet is exposed to the first outlet but not the second outlet.

16. An apparatus as claimed in any one of claims 11 to 15, wherein the relatively low pressure fluid comprises liquid phase fluid.

17. An internal combustion engine comprising the apparatus of any preceding claim.

18. A vehicle comprising the apparatus of any one of claims 1 to 16 or the internal combustion engine of claim 17.

19. An apparatus and/or an internal combustion engine and/or a vehicle as hereinbefore
5 described with reference to the accompanying drawings.

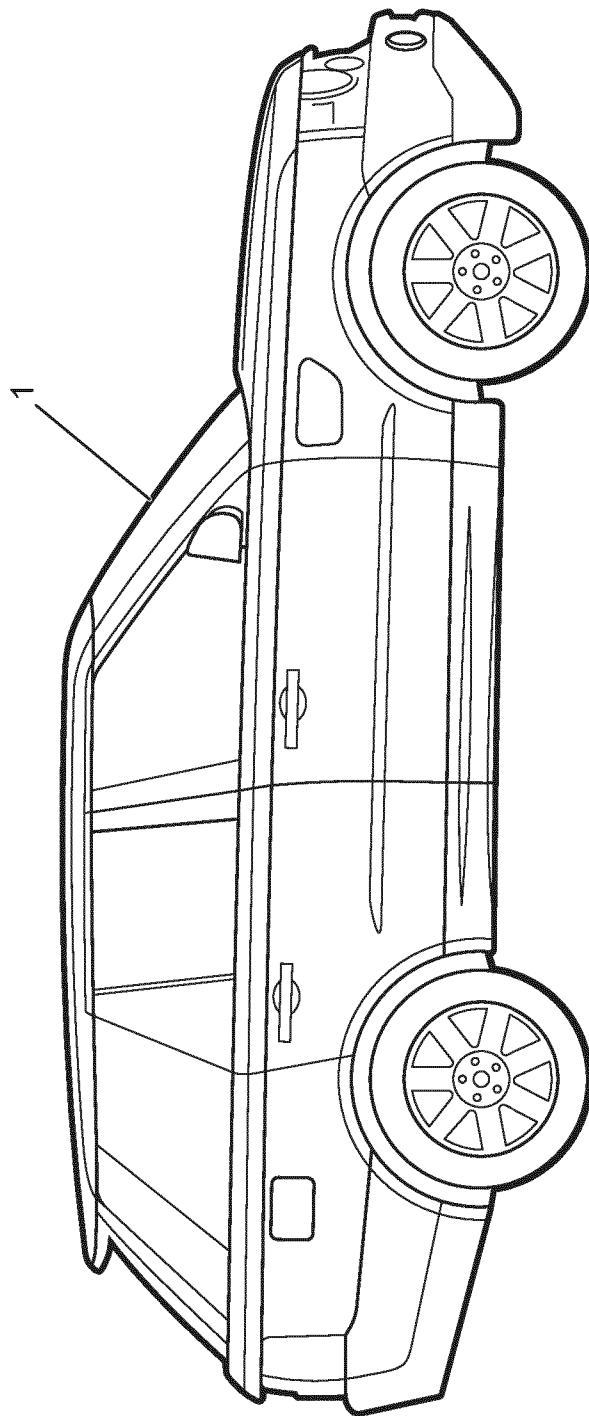


Fig. 1

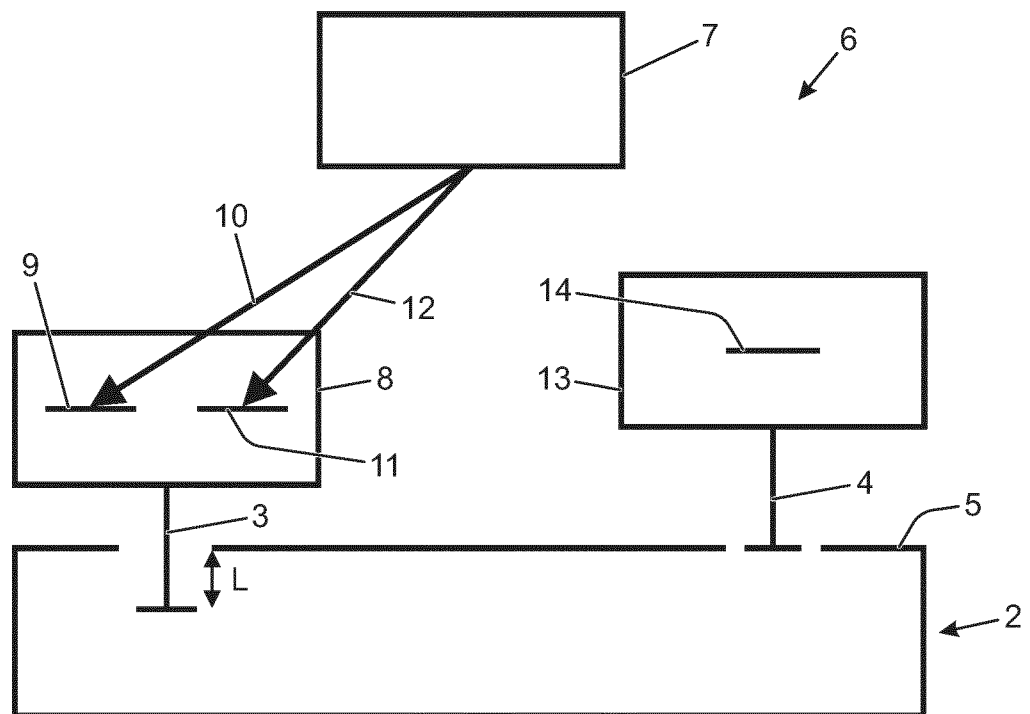


Fig 2a

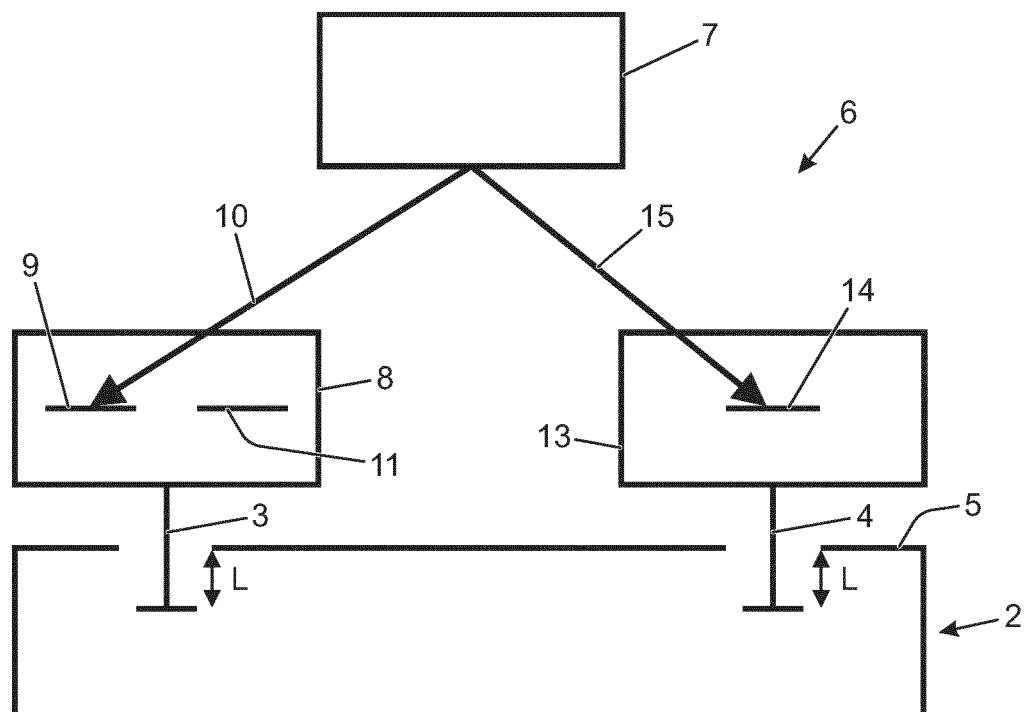


Fig 2b

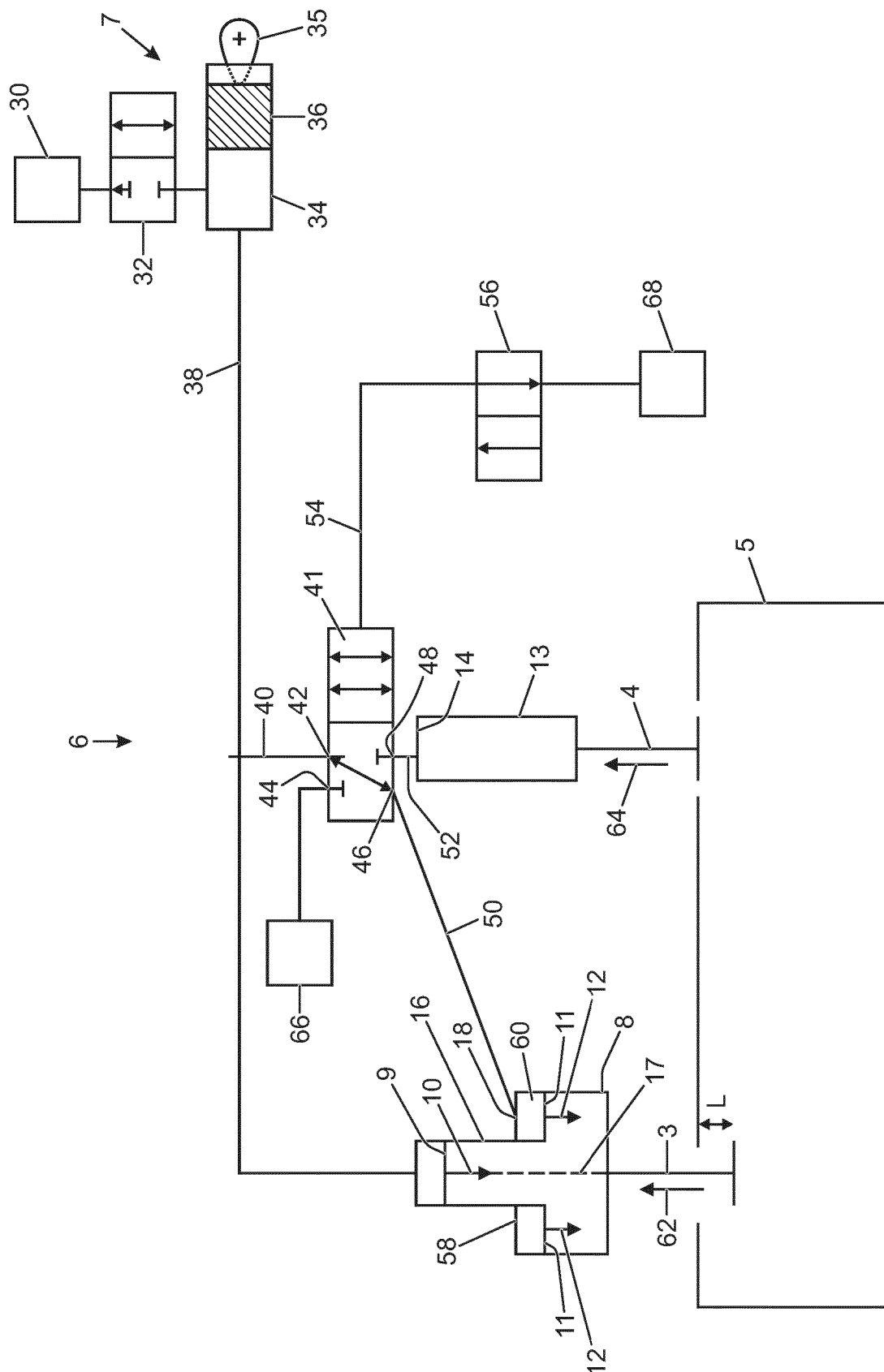


Fig. 3a

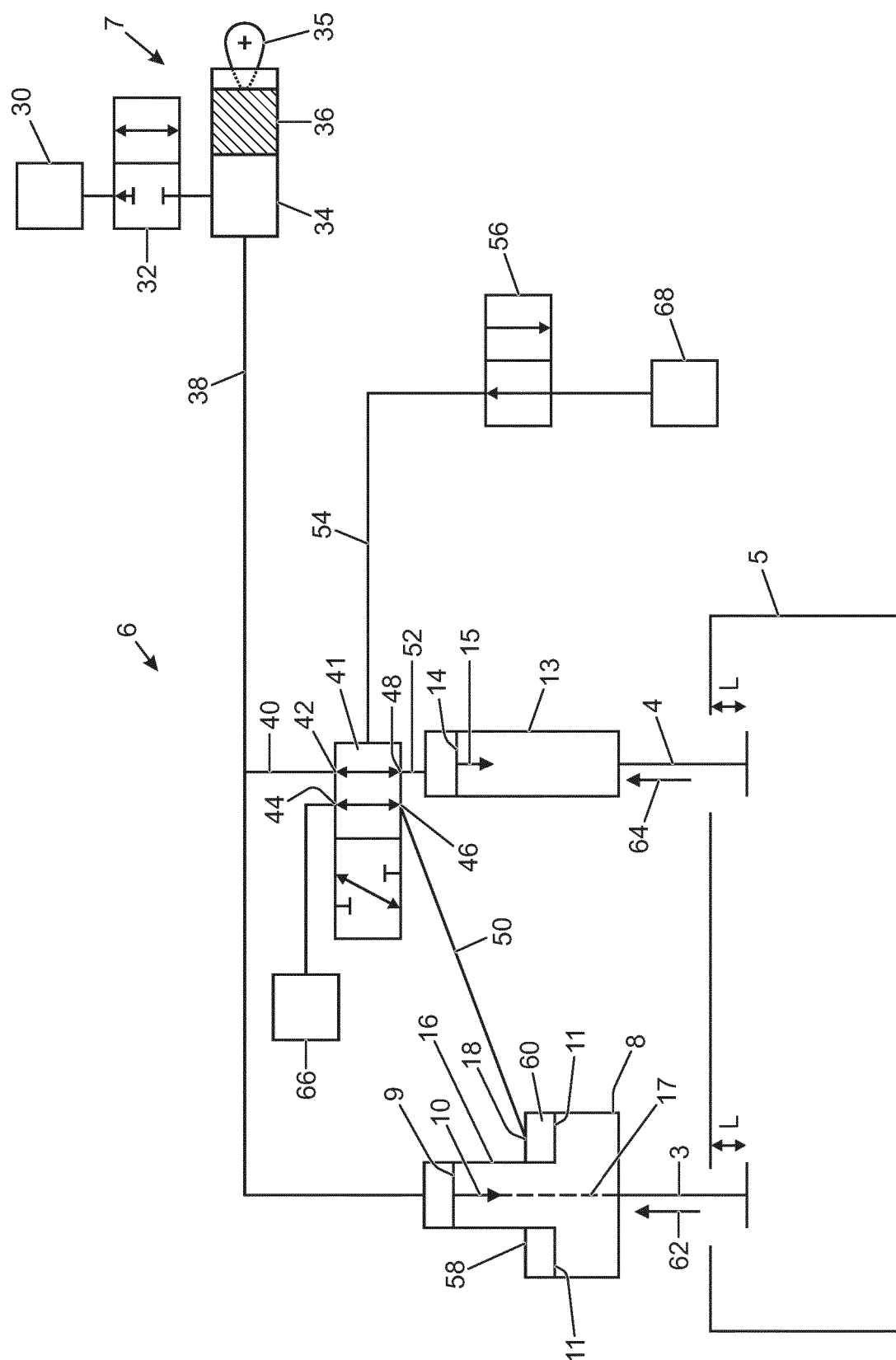


Fig 3b

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/064032

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01L1/26 F01L9/02
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)
F01L

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.
A	DE 42 02 542 A1 (VOLKSWAGEN AG [DE]) 13 August 1992 (1992-08-13) the whole document -----	1
A	EP 0 767 295 A1 (NEW SULZER DIESEL AG [CH]) 9 April 1997 (1997-04-09) the whole document -----	1
A	EP 2 693 007 A1 (FIAT RICERCHE [IT]) 5 February 2014 (2014-02-05) the whole document -----	1



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"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

6 September 2017

Date of mailing of the international search report

14/09/2017

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/064032

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