(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 March 2020 (26.03.2020)

WIPO | PCT

(10) International Publication Number
WO 2020/058413 A1

(51) International Patent Classification:
F02D 13/04 (2006.01) *F01L 13/06* (2006.01)

(21) International Application Number:
PCT/EP2019/075192

(22) International Filing Date:
19 September 2019 (19.09.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1815268.6 19 September 2018 (19.09.2018) GB

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: VALVE TRAIN ASSEMBLY

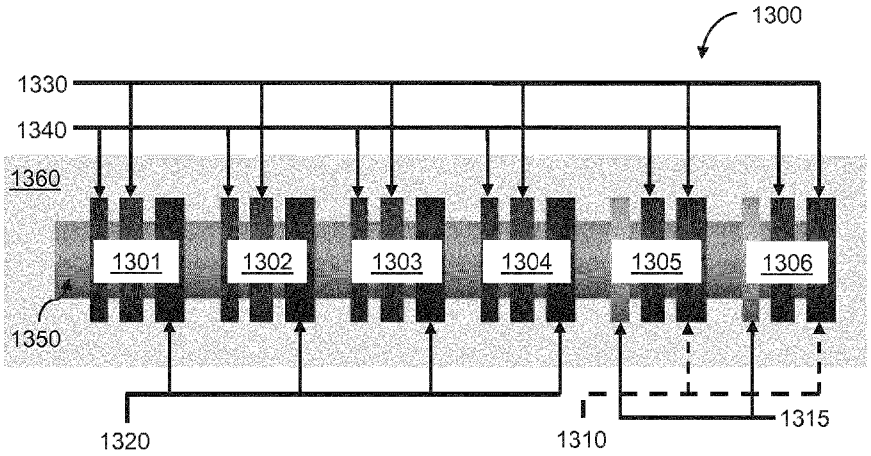


FIG. 25

(57) Abstract: An engine braking system for an internal combustion engine comprising a plurality of engine cylinders, the engine braking system comprising a single-stroke engine brake arrangement configured to provide single stroke engine braking on at least one cylinder of the plurality of cylinders and a two-stroke engine brake arrangement configured to provide two-stroke engine braking on at least one other cylinder of the plurality of cylinders.

WO 2020/058413 A1

VALVE TRAIN ASSEMBLY

Technical Field

The present invention relates to valve train assemblies of internal combustion engines, specifically to variable valve train components of a valve train assembly.

Background

Internal combustion engines, such as four-stroke diesel engines, may comprise variable valve train components. Valve train assemblies may include a camshaft that rotates with engine speed to sequentially move a push rod, rocker arm and valve. An eccentric cam lobe determines the movement of the push rod for each revolution of the camshaft. For example, valve train assemblies may comprise a variable valve lift to provide for control of an opening of a valve (for example, control of an opening of an intake valve and/or exhaust valve) by alternating between at least two or more modes of operation (e.g. valve-lift modes). The timing and/or duration of the valve lift may be controlled by the valve train assembly. Optimising valve operations helps to reduce fuel consumption, particularly when the engine speed and/or engine load is varied.

Summary

Aspects of the present invention are listed in the accompanying claims.

Features of the present invention will now be described, by way of example only, with reference to the accompanying drawings, of which:

List of Figures

Figure 1 illustrates schematically a cam phasing mechanism for a cam assembly of an internal combustion engine according to an example;

Figure 2 illustrates schematically a cross-sectional side view of a cam phasing mechanism according to an example;

Figure 3a illustrates schematically a cross-sectional side view of a cam assembly according to an example;

Figure 3b illustrates schematically an enlarged cross-sectional side view of a force transfer member shown in Figure 3a;

Figure 4 illustrates schematically a part cross-sectional side view of a valve train assembly according to an example;

Figure 5 illustrates schematically a reference timing diagram according to an example;

Figure 6 illustrates schematically a timing diagram showing an example of a late exhaust valve closing (LEVC) scenario according to an example;

Figure 7 illustrates schematically a part cross-sectional side view of a valve train assembly according to another example;

Figure 8 illustrates schematically a part cross-sectional side view of an actuation assembly of the valve train assembly shown in Figure 7;

Figure 9 illustrates schematically an arrangement of an hydraulic circuit of the actuation assembly shown in Figure 7;

Figure 10 illustrates schematically a cross-sectional side view of the actuation assembly shown in Figure 7;

Figure 11 illustrates schematically a cross-sectional side view of an actuation mechanism of the actuation assembly shown in Figure 10;

Figures 12a to 12d illustrate schematically cross-sectional side views of different positions of the actuation mechanism shown in Figure 11;

Figures 12B and 12B illustrate schematically cross-sectional side views of different positions of the actuation assembly shown in Figure 10;

Figures 13 and 14 illustrate schematically the timing diagram shown in Figure 6 and the points on the timing diagram corresponding to the different positions of Figures 12a to 12d;

Figure 15 illustrates schematically a cross-sectional side view of a motion controller shown in Figure 10;

Figure 16 illustrates schematically a side view of a camshaft arrangement according to an example;

Figure 17 illustrates schematically a cross-sectional side view of a position of the actuation mechanism shown in Figure 10;

Figure 18 illustrates schematically a timing diagram showing an example of a late intake valve closing (LIVC) scenario according to an example;

Figures 19a and 19b illustrate schematically cross-sectional side views of different states of the motion controller shown in Figure 15;

Figure 20 illustrates schematically a timing diagram showing an example of a combined late intake valve opening (EIVO) and early intake valve closing (EIVC) scenario according to an example;

Figures 21a to 21f illustrate schematically cross-sectional side views of different arrangements of the motion controller shown in Figure 15;

Figures 22 to 24 illustrate schematically the locations on a timing diagram corresponding to the different arrangements of Figures 21a to 21f;

Figure 25 illustrates schematically a camshaft arrangement for a six cylinder internal combustion engine according to an example;

Figure 26 illustrates schematically a timing diagram of a two-stroke engine brake system according to an example;

Figure 27 illustrates schematically a top view of a valve assembly according to an example;

Figure 28a illustrates schematically an engine brake rocker arm assembly according to an example;

Figure 28b illustrates schematically an engine brake control capsule of the engine brake rocker arm assembly of Figure 28a;

Figure 28c illustrates schematically an actuator of the engine brake rocker arm assembly of Figure 28a; and

Figure 29 illustrates schematically a rocker arm arrangement according to an example.

Throughout, like reference signs denote like features.

Description

Referring to Figure 1 an example of a cam phasing mechanism 1 for a cam assembly 100 according to an example is shown. The cam phasing mechanism 1 is suitable for a valve train assembly 1000 of an internal combustion engine (not shown), as shown in Figure 4. The internal combustion engine may comprise six cylinders (not shown) and may be a compression ignition (CI) engine suitable for diesel fuel

combustion. Preferably, the internal combustion engine is a four-stroke combustion engine.

The cam assembly 100 shown in Figure 1 comprises a camshaft 120 and an actuator 130 having an axis for opening a valve 505 at a reference position of rotation of the camshaft 120. The camshaft 120 is rotatable about an axis (not shown). The reference position is a position of angular rotation of the camshaft 120 about the axis of the camshaft at which point the valve 505 is caused to open and move away from a valve seat of a cylinder head. The cam phasing mechanism 1 comprises a force transfer member 2a and an adjuster 2b. The force transfer member 2a is to be interposed between the camshaft 120 and the actuator 130 of the cam assembly 100 so that force is transferable between the camshaft 120 and the actuator 130. The adjuster 2b is to selectively move the force transfer member 2a to bring about an adjustment of the reference position of rotation of the camshaft 120.

Figure 2 shows the cam phasing mechanism 1 in more detail. The adjuster 2b comprises a first member 4, a second member 5 and a third member 3. The third member 3 is described in more detail below. The first member 4 is moveable relative to the second member 5 so that the force transfer member 2a is selectively moved relative to the second member 5. This allows the reference position of rotation of the camshaft 120 to be adjusted. The first member 4 is shown to be moveable through a centre of the second member 5. That is, the second member 5 surrounds the first member 4 an at least partially enclose the first member 4. While the second member 5 is configured to rotate about an axis, the first member 4 is configured to move linearly along an axis. Each axis may be the same. The first member 4 and second member 5 may be concentric.

In the example shown, the first member 4 is continuously moveable relative to the second member 5 for continuously adjusting the reference position of rotation of the camshaft 120 within a predetermined range. The predetermined range may be 50 degrees of rotation of the camshaft, corresponding to 100 crank angle degrees (100CAD). That is, the reference position of rotation of the camshaft 120 at which the

valve 505 is caused to open or close can be shifted, *i.e.* phased, by 50 angular degrees of rotation of the camshaft 120.

In the example provided, the first member 4 of the adjuster 2b is a threaded bushing and the second member 5 is a wheel gear. That is, the first member 4 and second member 5 are engageable by respective threaded portions. The respective threaded portions mesh together to provide the required movement of the first member 4 relative to the second member 5 to allow a translational position of the force transfer member 2a to be changed. As the second member 5 is rotated about an axis, the first member 4 is moved along the second member 5 to a translated location of the first member 4'. This movement is shown as translational motion of the first member 4 about a translation axis L in a first direction B. The axis of rotation of the second member 5 may be coexist on translation axis L. The first member 4 is configured to move up and down the translation axis L. Movement of the first member 4 in the first direction B may, for example, cause advance timing of the valve 505. That is, the valve 505 may open sooner in an engine cycle.

As shown in Figure 2, the force transfer member 2a is spaced from the first member 4 by the third member 3. The third member 3 comprises a lever arm 31 which is pivotable relative the first member 4 and the second member 5. The pivot in this example is a bearing 6. The lever arm 31 extends between a proximal portion 32 and a distal portion 33 of the third member 3. The proximal portion 32 is shown to be moveable within the second member 5 and the proximal portion 32 moves with the first member 4. The third member 3 may be generally Y-shaped such that the distal portion 33 is a bifurcated portion. In this example, the bifurcated portion extends around axial ends of the force transfer member 2a to enclose the force transfer member 2a between branches of the bifurcated portion. When the third member 3 is generally Y-shaped, the lever arm 31 comprises a stem portion from which the branches of the bifurcated portion extend.

As discussed, the pivotable motion of the lever arm 31 is achieved by the bearing 6. The bearing 6 comprises a portion that is coupled to the first member 4. The

bearing 6 is therefore configured to experience the same translational motion of the first member 4 with respect to the second member 5, which is represented by a translated location of the bearing 6' in Figure 2. The bearing 6 allows the force transfer member 2a to freely pivot about the first member 4. A first portion of the first member 4 comprises an abutment to contact the lever arm 31 of the third member 3 and prevent pivoting motion in one rotational direction. Equally, a second potion of the first member 4 comprises an abutment to contact the lever arm 31 of the third member 3 and prevent pivoting motion in another rotational direction. Each abutment may be opposite each other and may be on an internal surface of the first member 4. Each abutment may be diametrically opposed.

The cam phasing mechanism 1 of Figure 2 comprises a driving member 10 for driving the second member 5 of the adjuster 2b. The driving member 10 may be electromechanically controlled and driven by an electrical signal. An axis of rotation of the driving member 10 for driving the driving member 10 in rotation direction R2 is perpendicular to an axis of rotation of the second member 5. The driving member 10 may be a worm gear. The driving member 10 comprises a first threaded portion 11 which engages with a second threaded portion 52 of the second member 5. The second member 5 comprises two threaded portions. The threaded portions are shown on opposite sides of the second member 5. In the example of Figure 2, the second threaded portion 52 is located on an external side of the second member 5. An additional third threaded portion 53 is located on an internal side of the second member 5. The third threaded portion 53 is configured to mesh with a fourth threaded portion 41 of the first member 4. The engagement of the first to fourth threaded portions 11, 52, 53, 41, movement of which is driven by the driving member 10, causes the force transfer member 2a to move and affect the valve timing. The relative movement of the first member 4 and second member 5 is prevented when the driving member 10 is rotationally fixed. However, the third member 3, and thus the force transfer member 2a, can still freely pivot to allow the transfer of force between the camshaft 120 and actuator 130.

In the example shown in Figure 2, the force transfer member 2b is moveable about three axes. A first axis of movement of the force transfer member 2b is the axis about which the force transfer member 2b moves translationally. This is caused by the relative movement of the first member 4 and second member 5. A second axis of movement of the force transfer member 2b is the axis about which the force transfer member 2b pivots. The pivoting motion causes the force transfer member 2b to move relative to the first member 4 and the second member 5. The second axis of movement is caused by the transfer of force between the camshaft 120 and the actuator 130. A third axis of movement of the force transfer member 2b is the axis about which a roller assembly rotates. The third axis of movement may be parallel to the first axis of moment. Either or both of the first and third axes of movement may be perpendicular to the secocnd axis of movement. The roller assembly is shown in Figure 3b and is described in more detailed below. The roller assembly reduces the friction between the engaging parts of the camshaft 120 and the actuator 130 with the force transfer member 2b so that the transfer of energy is more efficient. The roller assembly also helps to reduce wear and noise of the respective engaging parts.

The cam phasing mechanism 1 of Figure 2 comprises a housing 7 to enclose the moving parts of the cam phasing mechanism 1. The housing 7 may be part of a case 8 which encloses the camshaft, such as a cam cover or crankcase. In Figure 2, the housing 7 and the case 8 are separate and may be interposed by a gasket to prevent lubricant oil leakage from the cam phasing mechanism 1. The housing 7 and the case 8 may therefore be coupled together by at least one fastener, such as a bolt. The housing 7 is shown with a locating member 71 which helps to control an axial position of the second member 5. The locating member 71 defines a recess into which the second threaded portion 52 is located. The case 8 is also shown with a locating member 81 which interacts with the locating member 71 of the housing 7 to accommodate the first member 5 of the adjuster 2b. The first member 5 of the adjuster 2b is shown with a locating member 51 which is a protrusion to fit inside a recess of the locating member 81.

Turning to Figure 3a, a schematic illustration of a cross-sectional side view of a cam assembly 100 according to an example is shown. The cam assembly 100 comprises the cam phasing mechanism 1 shown in Figure 2. The cam phasing mechanism 1 engages with the camshaft 120 and actuator 130 to open and close a valve 505. The actuator 130 in this example is a curved mushroom type lifter that is configured to act on a push rod which then acts on a rocker assembly to open the valve 505. This operation is discussed in relation to Figure 4. The actuator 130 moves in a second direction D, which is shown to be perpendicular to the first direction B.

The camshaft 120 shown in Figure 3a, for example, comprises at least one cam 121 accommodated within a housing 124. Each cam 121 has a base surface 123a and a raised profile 123b of a cam lobe 122. When the cam 120 is orientated such that the base surface 123a is engaged with the force transfer member 2a, no actuation force is transmitted to the actuator 130, via the force transfer member 2a, for opening the valve 505. The camshaft 120 is configured to rotate about a camshaft axis 125 in direction R1. As the camshaft 120 rotates, the raised profile 123b engages with the force transfer member 2a and the raised profile 123b applies a force, via the force transfer member 2a, to the actuator 130. The actuator 130 subsequently moves in the second direction D to act on a rocker arm assembly and open the valve 505. The force transfer member 2a thereby acts as an intermediate member to transmit an actuation force from the camshaft 120 to the actuator 130 in order to open the valve 505.

As is best shown in Figure 3a, the force transfer member 2a is selectively moveable either side S1, S2 of a reference plane P between an axis 115 of the camshaft 120 and an axis 135 of the actuator 130. The axis 135 of the actuator 130 is a pivot of a push rod and lifter, whereby the push rod pivots about the axis 135 as the lifter moves along a predefined path. The force transfer member 2a is shown on a first side S1 when the adjuster 2b is at one limit of movement. At another limit of movement of the adjuster 2b the force transfer member 2a can move through the reference plane and to a second side S2. This movement is possible while the camshaft 120 rotates and the force transfer member 2a pivots.

An enlarged view of a roller assembly region A of the force transfer member 2a is shown in Figure 3b. Here, the force transfer member 2a comprises a first roller 21 for engagement with the camshaft 120 of the cam assembly 100 and a second roller 22 for engagement with the actuator 130 of the cam assembly 100. The first roller 21 and the second roller 22 are each independently rotatable about a third roller 23. In the example shown, the first roller 21 and the second roller 22 are coaxial. The actuator 130 comprises a first surface 131 and a second surface 132. The second surface 132 of the actuator 130 engages with the second roller 22 of the force transfer member 2a, whereas the first surface 131 of the actuator 130 avoids contact with the force transfer member 2a. The first surface 131 is shown as a groove in the actuator 130. In the example shown, the first surface 131 of the actuator 130 is spaced away from both the first roller 21 and the second roller 22 so that only the second surface 132 of the actuator engages with the respective portion of the force transfer member 2a, i.e. the second roller 22. In the example shown, the first roller 21 is arranged centrally, whereas the second roller 22 is exposed at either side. The central location may refer to a location along a shared axis of rotation of the first roller 21 and second roller 22. That is, the first roller 21 and the second roller 22 are rotatable about a common axis and the first roller 21 is restricted to a central location along the common axis. The first roller 21 is shown with a greater diameter than the second roller 22. The second roller 22 may comprise two rollers, wherein each of the two rollers are arranged either side of the first roller 21. That is, one of the two rollers is arranged on one side of the first roller 21 and the other of the two rollers is arranged on another side of the first roller 21. The first surface 131 and the second surface 132 of the actuator 130 are concave and may complement the curvature of the base surface 123a of the cam 121.

Figure 4 shows a valve train assembly 1000 according to an example. The valve train assembly 1000 is suitable for an internal combustion engine (not shown). The valve train assembly 1000 comprises a valve assembly 500 which may be a pair of exhaust valves including the valve 505 and the cam assembly 100 as previously described for actuating the valve 505 of the valve assembly 500. As the camshaft 120 rotates, force is transmitted to the force transfer member 2a of the cam assembly 100 when the raised profile 123b of the cam 121 engages with the force transfer member

2a. Subsequently, the actuator 130 moves a push rod 200 to cause a rocker arm of a rocker arm assembly 300 to pivot and press a valve bridge assembly 400 to open the valve 505 by pressing a valve stem 501 and moving a valve head 502. The valve 505 may be an exhaust valve that opens an exhaust port (not shown) to allow exhaust gas to leave a combination chamber of an internal combustion engine.

Figure 5 illustrates schematically a reference timing 1100 diagram according to an example. The reference timing 1100 diagram shows the amount of lift of an intake and exhaust valve. That is, the degree of movement of the intake valve and exhaust valves. The reference timing of the exhaust valve 1120 and the reference timing of the intake valve 1110 is shown together. In the scenario show, a region of overlap E1 is present. This is when both the intake and exhaust valves are simultaneously open, which, in the example shown. occurs a few degrees either side of top dead centre (TDC) of the piston stroke. The exhaust valve opens at a valve opening 1121 timing, reaches a maximum lift 1123 and then closes at a valve closing 1122 timing. Equally, the intake valve opens at a valve opening 1111 timing, reaches a maximum lift 1113 and then closes at a valve closing 1112 timing.

The cam phasing mechanism 1 is configured to change the timing at which a valve, such as the exhaust valve opens. In the example, shown, a valve phasing range F represents the degree to which the reference timing of the exhaust valve 1120 can be changed to advance or retard the opening timing of the exhaust valve. For example, the early phasing 1101 of the valve opening, e.g. early exhaust valve opening (EEVO) may be up to 100 crank angle degrees, corresponding to 50 camshaft angle degrees from the reference timing of the exhaust valve 1120. Movement of the timing of the exhaust valve opening towards the reference timing of the exhaust valve 1120 may be considered to be late phasing 1102 in this example. The EEVO scenarios moves the timing of the maximum lift of the exhaust valve towards bottom dead centre (BDC) timing of a piston of the internal combustion engine.

Figure 6 shows a schematic example timing diagram of an exhaust valve event The timing diagram is an example of an elongated timing 1200 to increase the valve lift

duration. The intake valve timing 1110 in Figure 6 is the same as the reference intake valve timing shown in Figure 5 and there is no change to the timing in this specific example. However, the reference timing of the exhaust valve 1120 shown in Figure 5 has been advanced and elongated to create a different region of overlap E2. A lost motion region K is shown on a closing side of the exhaust valve. The lost motion region K maintains the exhaust valve in a lift position such that the exhaust port remains open. In this instance, the camshaft is disengaged with the valve while the valve is kept open. This process will be described in further detail below. Although a fixed lift position of the exhaust valve is shown in Figure 6, the lost motion does not have to result in a fixed position and may be represented by reduced motion of the exhaust valve closing event.

Figure 7 shows a schematic illustration of a part cross-sectional side view of a valve train assembly 2000 according to an example. Here, a set of components for an intake side and an exhaust side are shown. For example, an intake cam 111 causes an intake push rod 210 to exert a force to control the actuation of a pair of intake valves including an intake valve 515 by sequentially transferring force to an intake rocker arm assembly 310 and an intake valve bridge assembly 410. The intake valve bridge assembly 410 exerts a force on the intake valve stem 511 of an intake valve assembly 510 which causes the intake valve head 512 to move about an intake valve seat of the cylinder head. Equally, an exhaust cam 121 causes an exhaust push rod 220 to exert a force to control the actuation of a pair of exhaust valves including an exhaust valve 525 by sequentially transferring force to an exhaust rocker arm assembly 320 and an exhaust valve bridge assembly 420. The exhaust valve bridge assembly 420 also exerts a force on the exhaust valve stem 521 which causes the exhaust valve head 522 to move about an exhaust valve seat of the cylinder head. As shown in the example of Figure 7, the intake cam 111 and exhaust cam 121 are part of the same camshaft, which rotates about a single, common axis. Also shown in Figure 7 is an actuation assembly 600 which is interposed between the push rods 210, 220 and respective rocker arm assemblies 310, 320.

As shown in Figure 8, the actuation assembly 600 comprises an actuation mechanism 700 and a motion controller 800. The actuation mechanism 700 may be

considered a first actuation arrangement and the motion controller 800 may be considered a second actuation arrangement. In the example shown, the actuation mechanism 700 and motion controller 800 are in communication with each other, whereby, in one example, the motion controller 800 is configured to influence an operation of the actuation mechanism 700.

In the example shown in Figure 9, the actuation assembly 600 is hydraulically controlled and is shown with a hydraulic circuit. Therefore, operation of the actuation assembly 600 may be affected by a working fluid, such as oil which is moved around the hydraulic circuit by a pump (not shown). When the working fluid is pressurised, respective parts of the actuation assembly 600 can be moved to bring about a change in valve timing. The hydraulic circuit comprises a pressurising device which is shown as an accumulator 601. The accumulator 601 comprises a moveable member, such as a piston 605, that is moveable with respect to a housing 604 back and forth along a reciprocation path C. The accumulator piston 605 is biased towards a first position by a resilient device such as a spring S. The spring S acts on the piston 605 to pressurise the working fluid. One function of the accumulator 601 is to accommodate changes in the volume of working fluid passing into and out of the actuation assembly 600. The working fluid is moved away from the accumulator 601 by a pump. The working fluid is then supplied, by a first supply line 602 of the hydraulic circuit, to the motion controller 800 and, by a second supply line 603 of the hydraulic circuit, to the actuation mechanism 700. Respective return lines 606, 607 are then used to transport the working fluid away from the actuation mechanism 700 and the motion controller 800. The hydraulic circuit is provided as a closed system.

In Figure 10, the actuation mechanism 700 and the motion controller 800 of the actuation assembly 600 are shown in more detail. The actuation mechanism 700 and the motion controller 800 comprise a network of passageways that form part of the hydraulic circuit. In the example shown, a common passageway 608 is shown to interconnect the respective passageways of the actuation mechanism 700 and the motion controller 800. The actuation assembly 600 is shown with two force transmitters 610, 620. A first force transmitter 610 predominantly for controlling

actuation of an intake valve 515 and a second force transmitter 620 is predominantly for controlling actuation of an exhaust valve 525. Each force transmitter 610, 620 engages with the respective push rod 210, 220 and camshaft 111, 121 and rocker arm assembly 310, 320. The actuation mechanism 700 and the motion controller 800 are explained in further detail below.

Figure 11 shows a schematic cross-sectional side view of the actuation mechanism 700 of the actuation assembly 600 shown in Figure 10. The force transmitter 610 of the actuation assembly 600 comprises a first actuator 710 and a second actuator 720. The second actuator 720 may be a hydraulic lock piston such that a resistance to movement of the second actuator 720 is achieved by hydraulic force. The first actuator 710 and the second actuator 720 are moveable relative each other. The relative movement may be along a common axis of motion M1. The first actuator 710 is engageable with the exhaust push rod 220 and the exhaust rocker arm assembly 320. However, the second actuator 720 is not engageable with the exhaust push rod 220 but is engageable with the exhaust rocker arm assembly 320. Each of the first actuator 710 and the second actuator 720 comprise a respective engagement face to directly abut an engagement face 323a of a joint 321 of the exhaust rocker arm assembly 320. The engagement face 721 of the second actuator 720 is spaced from the joint 321 because in the orientation shown in Figure 11, the first actuator 710 is directly engaging with the joint 321 without engagement of the second actuator 720. As the joint 321 is pressed by an engagement face of the first actuator 710 a ball 322 moves within a socket 323 of the exhaust rocker arm assembly 320.

The first actuator 710 comprises a slave part 710a and a master part 710b that are separable from each other. Each of the slave part 710a and the master part 710b is shown as a rod that are moveable with respect to each other. The slave part 710a is a first rod that is moveable within a hole provided in the second actuator 720. The master part 710b is a second rod that is moveable within a hole provided in a housing 770 of the actuation mechanism 700. In the orientation shown in Figure 11, the slave part 710a and the master part 710b are engaged with each other in an engagement area 704 in an engagement position.

The actuation mechanism 700 comprises a controller that allows a working fluid to enter the housing 770 via a fluid inlet 730. The controller in this example is a spool valve 750. The spool valve 750 comprises a rotating member 751 such as a cam and a sliding member 752 which acts as a valve. As the rotating member 751 rotates about a motion axis M2 in direction R3, a raised profile of the rotating member 751 causes the sliding member 752 to move and allow the working fluid to communicate between the fluid inlet 730 and an intermediate passageway 731. The intermediate passageway 731 contains a non-return valve 760. The non-return valve 760 comprises a moveable part 761 such as a ball and a resilient member such as a spring S. The moveable part 761 is moveable relative to a base 762 to open the non-return valve 760 by moving the moveable part 761 along a motion axis M3 and allow the working fluid to flow to a working zone 733. The working zone 733 is a reservoir for causing hydraulic lock of the second actuator 720 and varies in volume. The working zone 733 comprises a reserve passageway 734 which allows a volume of working fluid to remain in the working zone 733 when the second actuator 720 is moved fully down by the exhaust rocker arm assembly 320 when the exhaust valve 525 is closed. Finally, working fluid is removed from the working zone 733 through a fluid outlet 735.

Figures 12a to 12d schematically show cross-sectional side views of the actuation mechanism 700 at different stages of operation of the actuation mechanism 700 to highlight the different positions of the various components. The positions shown in Figures 12a to 12d are performed when the exhaust valve 525 is moving away from the position of maximum lift and is therefore closing the exhaust port.

Figure 12a shows the actuation mechanism 700 arranged in a first position 700-1. In the first position 700-1, the first actuator 710 is configured to control actuation of the exhaust valve 525. The engagement area 740 is therefore defined by the first actuator 710 only and not the second actuator 720. In the first position 700-1, the socket 323 of the rocker exhaust arm assembly 320 engages with the slave part 710a of the first actuator 710 which is engaged with the master part 710b and exhaust push rod 220. The location of the exhaust valve at the first position 700-1 of the actuation mechanism

700 is shown in Figure 13. When the engagement area 740 is defined by the engagement of the slave part 710a with the socket 323 the exhaust valve closes according to the shape of the curve shown in the reference timing of Figure 5. Rotation of the raised profile 123b of the exhaust camshaft 121 causes the slave part 710a and master part 710b of the first actuator 710 to move in contact with each other at the same rate. This is a movement in a valve closing direction H, which may correspond to a downward direction. In the first position 700-1, the spool valve 750 is open such that the working fluid could be pumped into the working zone 733. However. to prevent movement of the second actuator 720 in the valve closing direction H, the fluid outlet 735 is closed. Therefore, even though the working fluid may be pumped, the first position 700-1 represents a no flow condition of the working fluid inside the actuation mechanism 700. This helps to hydraulically lock the second actuator 720 in position so that no movement of the second actuator 720 is possible.

In order to position the second actuator 720 in the correct location in the housing 770 when in the first position 700-1, the working fluid forces the second actuator 720 to an extent of the housing 770, which may correspond to an upward direction. The second actuator 720 therefore comprises an abutment which engages with a corresponding abutment of the housing 770 as shown in abutment area N. The second actuator 720 is held in abutment with the housing 770 by a pressure of the working fluid as well as the action of the non-return valve 760 which prevents working fluid from escaping the working zone 733.

Each rocker arm assembly 310, 320 is biased to close the valve as a default configuration. Therefore, the exhaust rocker arm assembly 320 exerts a force against the first actuator 710. As the exhaust camshaft 121 is rotated, the socket 323 is brought towards the second actuator 720. During this event, the exhaust valve 525 continues to close, as shown by the downward arrow in Figure 13.

Figure 12b shows the actuation mechanism 700 when arranged in a second position 700-2. Here, actuation of the exhaust valve 525 is controlled by the second actuator 720 rather than the first actuator 710. In this position, the movement of the

exhaust valve 525 is brought to a gradual stop, as shown by the corresponding location of the second position 700-2 in Figure 13. The exhaust valve 525 remains open at a certain lift, for example 3mm for a predetermined crank angle degrees. When lifting the exhaust valve 525 the exhaust valve 525 is raised away from an exhaust valve seat. The second actuator 720 now acts as a hydraulic lock piston to prevent any movement of the exhaust rocker arm assembly 320 in the valve closing direction H. Given that the fluid outlet 735 and the non-return valve 760 are closed, the working fluid cannot leave the working zone 733 and the second actuator 720 is held in position relative to the housing 770. In the second position 700-2, the engagement area 740 comprises respective engagement portions of the first actuator 710 and second actuator 720. This engagement area 740 in the second position 700-2 is therefore greater than the engagement area 740 in the first position 700-1. Nevertheless, in some examples, the engagement area 740 in the second position 700-2 may only comprise the second actuator 720 and not the first actuator 710.

As discussed above, the movement of the first actuator 710 is governed by a first driver and the movement of the second actuator 720 is governed by a second driver that is different to the first driver. In the example provided, the first driver comprises a mechanical force and the second driver comprises a hydraulic force.

In Figure 12c, the actuation mechanism 700 is arranged in a third position 700-3. At this point, the fluid outlet 735 is open and working fluid can flow through the working zone 733. A controller may control release of working fluid from the fluid outlet 733 to reduce the volume of working fluid within the working zone 733. The controller may hydraulically control movement of the second actuator 720. This reduces the pressure inside the working zone 733 and a volume of working fluid in the working zone 733 starts to decrease. Between the second position 700-2 and the third position 700-3, the master part 710b moves away from the slave part 710a as the raised profile 123b continues to rotate to create a gap G that is greatest just before the exhaust valve 525 resumes a closing action. In the third position 700-3, the resilience of the rocker arm assembly 320 and valve assembly 520 forces the second actuator 720 to move downward towards a lower part of the housing 770. The location of the third

position 700-3 in the valve timing diagram is shown in Figure 14 using the corresponding reference value 700-3.

The period between the second position 700-2 and the third position 700-3 may be changed by changing the timing of opening the exhaust valve 525. That is, the motion of the second actuator 720 towards the lower part of the housing 770 is independent of rotation of the exhaust camshaft 121. In this instance, the period at which the exhaust valve 525 is constantly kept open is variable. Specifically, the motion of the second actuator 720 is independent of rotation of the exhaust camshaft 121 when the raised profile 123b of the exhaust camshaft 121 no longer raises the exhaust valve 525. That is the exhaust valve closing (EVC) event is always substantially at the same point and is independent of the timing of the exhaust valve opening (EVO). Selecting the timing of the opening of the exhaust valve 525 to begin earlier than that of a standard exhaust valve lift event (e.g. that shown un the reference timing diagram of Figure 5) is referred to herein as Early Exhaust Valve Opening (EEVO).

In some instances, for example in the example provided, the first force transmitter 610 controls the opening of the fluid outlet 735 and acts as a controller. The first force transmitter 610 may comprise a channel which allows the fluid outlet 735 to communicate with the return line 606 of the hydraulic circuit. This may occur when the intake valve 515 is lifted to around 0.5 to 0.7mm of lift since the first force transmitter 610 governs the lifting operation of the valve to raise the intake valve 515 from the intake valve seat (not shown). In this instance, the timing location of the third position 700-3 is determined by the intake valve operation. The exhaust valve 525 operation and the intake valve operation 515 are therefore directly linked by the actuation assembly 600.

Figure 12d shows a fourth position 700-4 of the actuation mechanism 700. The location of the fourth position 700-4 on the valve lift diagram is shown in Figure 14 with corresponding notation 700-4. Between the third position 700-3 and the fourth position 700-4, the second actuator 720 continues to be moved downward by the

resilience of the exhaust rocker arm assembly 320 and exhaust valve assembly 520. The second actuator 720 comprises a damper 705 that is used to decelerate the bringing together of the second actuator 720 to the housing (valve closed position) 770. The damper 705 shown is an arcuate portion. The arcuate portion may be convex. Additionally, the arcuate portion may be conical in shape. A damper with a conical shape allows a discharge area to gradually vary in order to provide a gradual closure of the exhaust valve 525. Due to the conical shape, the discharge area decreases at a lower rate with constant movement of the second actuator 720 to allow working fluid to more gradually flow out of the working zone 733 through the fluid outlet 735. The working zone 733 comprise a reserve passageway 734 which comprises working fluid in the fourth position 700-4. The reserve passageway 734 is formed from a space between the slave part 710a and the second actuator 720. In the region of the reserve passageway 734 the second actuator 720is sized to accommodate a portion of the master part 710b but does not come into contact with the master part 710b since the master part 710b engages with the slave part 710a.

The operation of the actuation mechanism 700 sequentially between the first to fourth positions 700-1 to 700-4 elongates the period during which the exhaust valve is open compared to the period shown in the reference timing diagram of Figure 5. When the actuation mechanism 700 is used in combination with the cam phasing mechanism 1 as previously described a size of the elongation is variable. When the actuation mechanism 700 is further combined with the motion controller 800 as shown in Figure 10, the exhaust valve closing (EVC) timing is determined by a pressure release portion 802. The pressure release portion 802 allows the working fluid to discharge out of the working zone 733 and through the fluid outlet 735. When combining the actuation mechanism 700 with the motion controller 800, the fluid outlet 735 acts as one part of the common passageway 608. Given that the pressure release portion 802 of the motion controller 800 may be controlled by an intake camshaft 111, the actuation mechanism 700 may move to the third position 700-3 by movement of the intake camshaft 111 rather than the exhaust camshaft 121. This scenario is shown in Figures 12B and 12C whereby a direction of movement of a motion controller 800 and corresponding pressure release portion 802 is shown by arrow J. Figure 12B corresponds to the timing

location of the second position 700-2, as described in Figure 12b. Figure 12C corresponds to the timing location of the third position 700-3, as described in Figure 12c.

Figure 15 shows a schematic illustration of a cross-sectional side view of the motion controller 800 shown in Figure 10. The force transmitter 620 of the actuation assembly 600 comprises a first part 810 and a second part 820. The first part 810 and the second part 820 may operate as a hydraulic lock piston such that a resistance to movement of both the first part 810 and the second part 820 is achieved by hydraulic force. The first part 810 and the second part 820 are moveable relative each other. The relative movement may be along a common axis of motion M1. The second part 820 is engageable with the intake push rod 210 but is not engageable with the intake exhaust rocker arm assembly 310. The first part 810 is not engageable with the intake push rod 210 but is engageable with the intake rocker arm assembly 310. Each of the first part 810 and the second part 820 comprise a respective engagement face to directly abut the other part. The first part 810 comprises a further engagement face to abut a joint 311 of the intake rocker arm assembly 310. In Figure 15, the first part 810 is directly engaging with the joint 311 without respective engagement faces of the first part 810 and second part 820 engaging with each other. A resilient member such as a spring S, is used to separate the first part 810 and second part 820. The joint 311 therefore presses against an engagement face of the first part 810 at engagement area 840 and a ball 312 of the joint 311 moves within a socket 313 of the joint 311.

The first part 810 and the second part 820 are separable from each other. Each of the first part 810 and the second part 820 are shown as a cylinder that each have a cavity 811, 821 for being filled by the working fluid. Together the cavities 811, 821 form a reservoir. As the first part 810 and the second part 820 move with respect to each other, the size of the reservoir changes even though the size of the cavities 811, 821 remain fixed. In the orientation shown in Figure 15, the motion controller 800 is in an unlocked state such that the second part 820 is moveable towards the first part 810 by the camshaft 111 without imparting a lifting force to the intake valve 515. The motion controller 800 may be moved to a locked state before the intake valve 515 is

opened whereby the first part 810 and second part 820 are brought together and engage. The spring S resists relative movement between the first part 810 and the second pat 820 in the unlocked state.

The motion controller 800 comprises a controller that allows a working fluid to enter the housing 870 via a fluid inlet 831. The controller in this example is a non-return valve 860. The non-return valve 860 comprises a moveable part 861 such as a ball, a resilient member such as a spring S and a switch 862 for opening and closing the non-return valve 860. The moveable part 861 is moveable relative to the switch 862 to open the non-return valve 860 by moving the moveable part 861 along a motion axis M3 and allow the working fluid to flow to a working zone 833. The working zone 833 is the reservoir for causing hydraulic lock of the first part 810 and second part 820 and varies in volume. The working zone 833 comprises a port 832 which allows a volume of working fluid to fill or be released in the working zone 833 when the second part 820 is moved away from the first part 810 to allow the fluid inlet 831 to communicate with the cavities 811, 821 of the respective first part 811 and second part 821. The working fluid can be removed from the working zone 833 through the fluid inlet 831 when the motion controller 800 is move to a locked state and the switch 862 is open in the position shown in Figure 15. In this position, the moveable member 861 no longer acts as a one-way valve and working fluid may flow in either direction through the non-return valve 860.

Also shown in Figure 15 is a further controller that allows a working fluid to leave the housing 870 via a fluid outlet 835c. The controller in this example is a spool valve 850. The spool valve 850 comprises a rotating member 851 such as a cam and a sliding member 852 which acts as a valve. As the rotating member 851 rotates about a motion axis M2 in direction R3, a raised profile of the rotating member 851 causes the sliding member 852 to move and allow the working fluid to communicate between a fluid inlet 835b and a fluid outlet 835c.

A further fluid inlet 830 is shown that is communicable with a further fluid outlet 835a when a pressure release portion 802 is aligned with the inlet 830 and outlet

835a. The pressure release portion 802 is used to relieve pressure from the working zone 733 of the actuation mechanism 700 as previously described.

Figure 16 illustrates schematically a side view of a camshaft arrangement according to an example. The camshaft shown is the intake camshaft 110. The intake camshaft 110 comprises a raised profile with two portions, each portion is described herein as a first raised profile 113b formed from a first cam lobe 112a and a second raised profile 113c formed from a second cam lobe 112b. The first raised profile 113b is more prominent that the second raised profile 113c. That is, the first raised profile 113b protrudes further from a base surface 113a that the second raised profile 113c. Therefore, when the intake camshaft 110 rotates about the camshaft axis 115 in the direction shown (clockwise), the first raised profile 113b engages with the actuator 130 before the second raised profile 113c. The rotation of the intake camshaft 110 with such a first raised profile 113b followed by such a second raised profile 113c is arranged to produce the valve timing diagram shown in Figure 18.

The camshaft arrangement shown in Figure 16 may be used without the motion controller 800. However, when the camshaft arrangement is used with the motion controller 800, the motion controller is provided in a spaced arrangement shown in Figure 17. Here, the non-return valve 860 and the spool valve 850 are both closed so that working fluid is retained in the reservoir and a size of the port 832 is maximised. In this arrangement the first part 810 and second part 820 of the motion controller 800 are spaced apart and held relative to one another by a hydraulic lock. The action of the camshaft shown in Figure 16 is therefore the dictating factor that produces the valve timing diagram of Figure 18 and particularly the lost motion region Q (i.e. a region of no valve lift). In this instance, the intake valve 515 operation is elongated and is referred to herein as Late Intake Valve Closing (LIVC).

Figures 19a and 19b schematically show cross-sectional side views of the motion controller 800 in different states of operation to highlight the different positions of the various components. The positions shown in Figures 19a and 19b are performed when the intake valve 515 is closed.

The first state is an unlocked state 800-1 of the motion controller 800. In the unlocked state 800-1, the first part 810 and second part 820 of the motion controller 800 are separated by the port 832. The port 832 is closed when the first part 810 and second part 820 are brought together as shown in the locked state 800-2. When in the unlocked state 800-1, the second part 820 is moveable towards the first part 810 in valve opening direction J by the raised profile of the cam lobe of the camshaft 111 without imparting a lifting force to the intake valve 515. A resistance to relative movement between the first part 810 and the second part 820 in the unlocked state 800-1 is provided by a resilient member such as the spring S. Figure 20 is a valve timing diagram showing reference timing 1110 of the intake valve 515 and the stunted timing 1210 brought about by the motion controller 800. The stunted timing 1210 is a reduced period of intake valve 515 opening compared to the reference timing 1110 which causes earl intake valve opening (EIVO) as well as early intake valve closing (EIVC) operations. The unlocked position is shown by notation 800-1. Here, the intake valve 515 is closed despite the raised profile of the camshaft acting on the second part 820 of the motion controller 800 and lifting the second part 820 in valve opening direction J. The intake valve 515 therefore does not open until the motion controller 800 is arranged in the locked state 800-2 shown in Figure 19b.

In the unlocked state 800-1, shown in Figure 19a, the reservoir formed by the respective cavities 811, 821 of the first part 810 and the second part 820 further comprises the port 832 that is communicable with the fluid inlet 831. However, in the locked state 800-2, as shown in Figure 19b, the switch 862 of the motion controller 800 is switched to a position at which the fluid inlet 831 becomes a two-way passageway to allow working fluid to be released as a fluid outlet from the reservoir. Therefore, as the motion controller 800 continues to move in the valve opening direction J, the intake valve 515 begins to open because the force is transmitted by mechanical coupling of the first part 810 and second part 820. Further rotation of the intake camshaft 110 causes the raised profile to open the intake valve 515. The position of the locked state 800-2 is shown on the valve timing diagram of Figure 20. As the motion controller 800 continues on the valve closing direction H the lost motion region K is not imparted on

the valve because the intake valve 515 has already closed (see Figure 20). The loss in intake valve 515 lift is shown as 3mm.

Figures 21a to 21f schematically show cross-sectional side views of the motion controller 800 in different arrangements to highlight the different positions of the various components. The positions shown in Figures 21a to 21f are performed in relation to the intake valve 515.

A first arrangement 800a of the motion controller 800 is shown in Figure 21a with the corresponding location on the valve timing diagram in Figure 22. The first arrangement 800a is the same as the unlocked state 800-1, shown in Figure 19a, expect that the switch 862 of the non-return valve 860 is closed to activate the non-return function (*i.e.* one-way flow) of the non-return valve. That is, working fluid in the fluid can enter the inlet 831 and reach the port 832 of the reservoir because the moveable part 861 can move against the spring S under a pumped flow of the working fluid by the pump (not shown). However, working fluid cannot leave the reservoir (comprising the first cavity 811, the second cavity 821 and the port 832) or the fluid inlet 831 passageway. Therefore, although the port 832 is aligned with the fluid inlet 831 the working fluid cannot leave the reservoir because of a back pressure of working fluid from the fluid inlet 831. In this instance, the first part 810 is fixed relative to the second part 820. The fixing is achieved by hydraulic lock.

Rotation of the intake camshaft 111, causes the force transmitter 601 to move relative to the housing 870 of the motion controller 800 in valve opening direction J. That is, the first part 810 and the second part 820 move in combination (*i.e.* in tandem) to open the intake valve 515 and raise the intake valve 515 away from the intake valve seat. In this example, the direction of movement of the first part 810 and second part 820 is an upward direction.

As the combined first part 810 and the second part 820 move in a direction to open the valve (*i.e.* the valve opening direction J), the port 832 becomes aligned with the fluid inlet 835b. Given that the spool valve 850 is in an open position by turning

the rotating member 851, working fluid can be transferred through an aperture in the sliding member 852 and out through the fluid outlet 835c and return line 607. As the working fluid leaves the reservoir the first part 810 and second part 820 move towards each other and directly engage by mechanical contact. The second arrangement 800b shows the situation as the port 832 becomes aligned with the fluid inlet 835b and just before the first part 810 and second part 820 move towards each other. The third arrangement 800c shows the situation as enough working fluid has left the reservoir for the first part 810 and second part 820 to directly engage by mechanical contact.

The corresponding location of the second arrangement 800b and the third arrangement 800b is shown on the valve timing diagrams of Figures 22 and Figures 23, respectively. As can be seen, a lost motion event occurs as the first part 810 and second part 820 move towards each other. During this event, the intake camshaft 110 continues to rotate but the intake valve 515 is held at a substantially fixed lift position for a given crank angle degrees. The length of the period may be determined by the spool valve 850. For example, the spool valve 850 may be partially opened to restrict a flow of the working fluid though the spool valve 850.

Figure 21d shows a fourth arrangement 800d of the motion controller 800 whereby the intake valve 515 is raised to a position of maximum lift as shown in the diagram of Figure 23. Although the position of maximum lift, in terms of crank angle degrees (*i.e.* the timing), is the same as the reference timing 1110, the amount of maximum lift of the intake valve 515 is reduced by the motion controller 800. This produces a downward shift in the intake valve 515 timing diagram, as shown in Figure 24.

As the intake camshaft 111 continues to rotate, an interface between the first part 810 and second part 820 which is where the port 832 formally existed, is moved towards the fluid inlet 831, as shown in the fifth arrangement 800e of Figure 21e. Since the working fluid is pumped by the pump through the non-return valve 860 and fluid inlet 831, the pressure of the working fluid forces the first part 810 and the second part 820 to separate by the working fluid filling the port 832. At this point, the first part 810

and the second part 820 move away from each other. The spring S encourages the separation because the spring S acts on the inside of the first part 810 and the second part 820 to naturally forces the first part 810 and the second part 820 apart. The separation of the first part 810 and the second part 820 is shown in the sixth arrangement 800f of Figure 21f.

It will be appreciated that when the intake camshaft 111 comprises the two raised profiles 113b, 113c, as shown in Figure 16, the intake valve 515 is closed in the fifth arrangement 800e of Figure 21e despite the lifter remaining on the raised profile 113c. The intake valve 515 remains closed as the first part 810 and the second part 820 move apart and the lifter returns to the base circle 113a of the camshaft. It will further be appreciated that the intake valve 115 closes earlier in the scenario indicated with respect to Figures 21 to Figures 24 (which may be referred to as Early Intake Valve Closing (EIVC) than it does in the scenario indicated with respect to Figures 17 to Figures 18 (which may be referred to as Late Intake Valve Closing (LIVC).

Although the intake camshaft 111 may comprise the two raised profiles 113b, 113c, as shown in Figure 16, the second profile 113c is not able to lift the intake valve 515 due to the relative movement of the first part 810 and second part 820 shown between the second arrangement 800b and the third arrangement 800c. When the two raised profiles 113b, 113c are used, the period between the fifth arrangement 800e and the sixth arrangement 800f corresponds to the smaller, second raised profile 113c. However, given that the intake valve 515 closes at the fifth arrangement 800e, the effect of the second raised profile 113c is not transferred to the intake valve 515.

Figure 25 shows a schematic illustration of components of an internal combustion engine 1300. The internal combustion engine 1300 is a compression ignition engine suitable for diesel fuel. The engine comprises six cylinders 1301-6. The engine 1300 comprises an engine brake system that functions to release compression gas on the compression stroke, that is when the piston moves between BDC and TDC. As shown in the timing diagram of Figure 26, the compression release begins a few degrees before top dead centre (bTDC) with a maximum valve lift after

top dead centre (aTDC). The release of compression gas from the cylinder reduces the force exerted on the piston on the downward stroke by gas that is compressed in the cylinder. This helps to assist a braking or retardation event.

As shown in Figure 25, exhaust valve cams 1330 and intake valve cams 1340 exist for each cylinder 1301-6. However, two-thirds of the cylinders, *i.e.* four cylinders 1301-4 in this example, comprise a two-stroke engine braking arrangement and one-third of the cylinders, i.e. two cylinders 1305-6, comprise a single-stroke or single-stroke engine braking arrangement. Various types of two-stroke braking arrangements and one-stroke braking arrangements are known per se that could be used in the system of Figure 25. Typically, a two-stroke braking arrangement acting on a cylinder will provide greater braking power than will a one-stroke braking arrangement acting on a cylinder. However, a two-stroke braking arrangement typically comprises a greater number of components than does a one-stroke braking arrangement and therefore is typically more complicated, more expensive and occupies more space than a one-stroke braking arrangement.

Systems such as the one illustrated in Figure 25 which comprises a single-stroke engine brake arrangement configured to provide single stroke engine braking on at least one cylinder of the plurality of cylinders and a two-stroke engine brake arrangement configured to provide two-stroke engine braking on at least one other cylinder of the plurality of cylinders are advantageous because the combination of a single-stroke engine brake arrangement acting on one cylinder and a two-stroke braking arrangement acting on another cylinder provide sufficient braking power but such systems are less costly and more space efficient than corresponding systems in which each cylinder is provided with a two-stroke engine braking arrangement.

The specific system shown in Figure 25 in which a two-stroke braking arrangement is provided for each of cylinders 1 to 4 and a one-stroke braking is arrangement is provided for each of cylinders 5 to 6 is particularly advantageous in this respect.

As shown in Figure 25, two-stroke engine brake cams 1320 for controlling the two-stroke engine brake arrangements and single-stroke engine brake cams 1310 for controlling the single-stroke engine brake arrangements exist on a single, common camshaft 1350 in a case 1360. In this example, two other cams are shown as fuel pump cams 1315.

Figure 26 illustrates schematically a valve timing diagram 1400 of a two-stroke engine brake system according to an example. A first bump 1401 exists prior to a second bump 1402. Both bumps 1401, 1402 form the exhaust valve timing. Each bump 1401, 1402 comprises a compression release event. In one engine cycle, that is 720 degrees of rotation of the crankshaft, two compression release events occur for a two-stroke engine brake system, whereas for a single-stroke engine brake system, one compression release event occurs for 720 degrees of rotation of the crankshaft. The bump 1401 comprises a first section 1401a which is a brake gas recirculation lift (i.e. when exhaust gas is recirculated back into the cylinder), a first compression release lift 1401b (i.e. the first compression release event of the cycle) and a re-breading lift 1401b. The bump 1402 represents a second compression release lift (i.e. the second compression release event of the cycle). A deactivated exhaust event T occurs when the exhaust valve is closed. This is typically where the normal exhaust gases are released by the exhaust valve. However, combustion does not occur during an engine braking event. A stunted timing 1410 event of the intake valve is shown. That is, late intake valve opening (LIVO) as described in the examples above could be used to avoid the back flow of air during the braking event.

Figure 27 illustrates schematically a top view of a valve train assembly 1500 according to an example. The valve assembly 1500 comprises an intake rocker arm assembly 1540, an exhaust rocker arm assembly 1520 and an engine brake rocker arm assembly 1530 for controlling the valves of a given cylinder, for example, one of cylinders one to four described with respect to Figure 25 above. Each of the intake rocker arm assembly 1540 and the exhaust rocker arm assembly 1520 acts on two valves. In that respect, the intake rocker arm assembly 1540 and the exhaust rocker arm assembly 1520 may be part of the valve train assembly described above, see for

example Figure 7 which can be controlled to perform any of the appropriate EEVO, EIVC, LIVC functions described above. The engine brake rocker arm assembly 1530 acts on a single one of the exhaust valves and may be controlled to cause two-stroke engine braking as described above. Also shown is a single, common camshaft 1510 comprising a LIVO controlling cam 1501, an EIVC and LIVC controlling cam 1502, an EEVO controlling cam 1503, an exhaust rocker arm deactivation cam 1504 and an engine brake controlling cam 1505. The common camshaft 1510 may be electromechanically actuated to control all of the variable valve lift functions for example: EEVO, EIVC, LIVC, single-stroke and two-stroke engine braking.

Referring now to Figures 28a to 28c, there is illustrated an engine brake rocker arm assembly 1530 that can be used, for example, as the engine brake rocker arm assembly in the valve train assembly 1500, illustrated in Figure 27.

As shown in Figure 28a, the engine brake rocker arm assembly 1530 is mounted for rotatable movement about a rocker arm shaft 2000. At a first end 1530a, the engine brake rocker arm assembly 1530 contacts a push rod 2002 and, at a second end 1530b, the engine brake rocker arm assembly 1530 is contactable with a valve stem 2004 of an exhaust valve 2006. The exhaust valve 2006 is one of a pair of exhaust valves (only the exhaust valve 2006 is illustrated) supported in a valve bridge assembly 400, as illustrated in Figure 4. The engine brake rocker arm assembly 1530 is contactable with the valve stem 2004 via an intermediary part 400a of the valve bridge 400, which is moveable by the engine brake rocker arm assembly 1530 relative to the valve bridge assembly 400 as a whole.

The engine brake rocker arm assembly 1530 comprises at the second end 1530b an engine brake control capsule 2008 (which is illustrated in isolation in Figure 28b) for selectively configuring the engine brake rocker arm assembly 1530 in an engine brake OFF configuration and an engine brake ON configuration.

The engine brake rocker arm assembly 1530 is configured in the engine brake ON configuration when the engine is operating in engine brake mode. When the engine

is operating in engine brake mode, as a camshaft rotates, for example the camshaft 1350 illustrated in Figure 25, an engine brake cam arranged on the camshaft 1350, for example one of the engine brake cams 1320 as are also illustrated in Figure 25, and which is in direct or indirect contact with the push rod 2002, causes the push rod 2002 to move in sympathy with the cam profile of the engine brake cam 1320. This movement of the push rod 2002 causes the engine brake rocker arm assembly 1530 to pivot about the rocker arm shaft 2000 and the engine brake rocker arm assembly 1530 in turn causes the exhaust valve 2006 to lift to cause an engine brake event. The cam profile of the engine brake cam 1320 may, for example, be shaped so as to cause the exhaust valve 2006 to perform the two-stroke engine brake event illustrated in Figure 26.

The engine brake rocker arm assembly 1530 is configured in the engine brake OFF configuration when the engine is operating in normal drive mode. In the engine brake OFF configuration, the movement of the push rod 2002 caused by the cam profile of the engine brake cam 1320 is absorbed as a lost motion stroke by the engine brake control capsule 2008 so that the engine brake rocker arm assembly 1530 does not transfer any movement to the exhaust valve 2006.

As is known in the art, the engine brake control capsule 2008 may be of the type that comprises a first body 2008a and a second body 2008b each comprising a circular end portion that is crenulated around its length and which end portions face each other. One of the bodies 2008a, 2008b is rotatable about it longitudinal axis relative to the other of the bodies 2008a, 2008b between a first position and a second position to configure the engine brake control capsule 2008 in the engine brake OFF configuration or the engine brake ON configuration.

When the engine brake control capsule 2008 is in the engine brake ON configuration the raised portions of each of the crenulated circular end portions face each other such that the first body 2008a and the second body 2008b act as a single unit and transfer the movement of the engine brake rocker arm assembly 1530 to the exhaust valve 2006 by means of a member 2009. When the engine brake control capsule 2008

is in the engine brake OFF configuration the crenulated circular end portions are positioned so that every raised portion faces a recessed portion so that the first body 2008a is moveable relative to the second body 2008b to absorb the movement of the engine brake rocker arm assembly 1530 as a lost motion stroke so that no movement is transferred to the exhaust valve 2006 via the member 2009. The engine brake control capsule 2008 comprises a lost motion spring 2010 for biasing the first body 2008a and the second body 2008b away from each other.

The engine brake rocker arm assembly 1530 further comprises an actuator 2012 (shown separately in Figure 28c) mounted on the side of the brake rocker arm assembly 1530 for configuring the engine brake control capsule 2008 in the engine brake ON and OFF configurations. For clarity, the actuator 2012 is not shown in Figure 28a but it should be appreciated that its longitudinal axis lies along the dashed line shown in Figure 28a. The actuator 2012 comprises a two-piece piston arrangement 2014 comprising a first piston piece 2016 having a first end 2016a slidably arranged within a first end 2018a of a second piston piece 2018.

An engine brake actuation cam 2022 is provided on a control camshaft 2024 which is rotatable 180 degrees between a first position and a second position to act on a second end 2016b of the first piston piece 2016 to drive the two-piece piston arrangement 2014 linearly to cause rotation of one of the first 2008a and second 2008b bodies, for example, the first body 2008a, relative to the other of the first 2008a and second 2008b bodies, for example, the second body 2008b, to configure the engine brake control capsule 2008 between the engine brake ON and OFF configurations. That is to say, when the actuation cam 2022 is rotated in a first sense, the two-piece piston arrangement 2014 is driven linearly in a first direction to cause rotation of one of the first 2008a and second 2008b bodies relative to the other of the bodies in a first sense to configure the brake control capsule 2008 in one of the ON and OFF configurations. And then, when the actuation cam 2022 is rotated back in the opposite sense, the two-piece piston arrangement 2014 is driven linearly back in the opposite direction to cause rotation of one of the first 2008a and second 2008b bodies relative to the other of the bodies in the opposite sense to configure the brake control capsule 2008 back into the

other of the ON and OFF configurations. In the example shown in Figure 28c, the actuator 2012 is shown in engine brake OFF position and hence is driven linearly, when the actuation cam 2022 rotates, to the engine brake ON position.

The control camshaft 2024 may be operated in any suitable way, for example, by pressurised oil, pneumatically, or electromechanically.

The two-piece piston arrangement 2014 is provided with a threaded region 2026 arranged circumferentially around a section of its outer surface and which cooperates with a threaded region of one of the first 2008a and second 2008b bodies, in this example the first body 2008a, to rotate that body between the engine brake ON and OFF configurations when the two-piece piston arrangement 2014 is driven linearly. The two-piece piston arrangement 2014 is provided with a return spring 2020 for biasing the two-piece piston arrangement 2014 to a return position (in this example engine brake OFF position) and also a compliance spring 2028 arranged between the first piston piece 2016 and the second piston piece 2018. The compliance spring 2028 is much stiffer than is the return spring 2020 and is arranged to bias the actuator 2012 to configure the engine brake control capsule 2008 in the engine brake ON configuration. In some scenarios, the control cam 2022 will rotate but the rotatable one of the first 2008a and second bodies is not in a condition to rotate. This causes the compliance spring 2028 to be compressed by the first piston piece 2016 and once the rotatable one of the first 2008a and second bodies is in a condition to rotate, the compliance spring 2028 will extend and the actuator 2012 will configure the engine brake control capsule 2008 in the engine brake ON configuration.

The engine brake control capsule 2008 may also function as a mechanical lash adjuster.

Although for clarity it is not shown in Figure 28a, it should be appreciated that there is an exhaust rocker arm, for example, one arranged like the rocker arm 300 in Figure 4 for acting on the exhaust bridge 400 during the normal engine drive mode to cause a normal exhaust event lift of the exhaust valves carried by the bridge 400 in

response to the rotation of an exhaust cam, for example cam 120 shown in Figure 4. When the engine is drive mode the exhaust rocker arm 300 is active and the engine brake rocker arm is de-active and vice versa when the engine is in engine brake mode.

Suitable means is provided for activating and deactivating the exhaust rocker arm. For example, the exhaust rocker arm 300 may be provided with a similar control capsule and actuator to that illustrated in Figure 28b and Figure 28c in the rear section of the exhaust rocker arm, i.e. the section that interfaces with the push rod 200.

Preferably, a control cam (not shown) for controlling the control capsule in the exhaust rocker arm is mounted on a common shaft 2024 as the control cam 2022 for controlling the engine brake control capsule 2008. In this way the common shaft 2024 can be used to control the engine brake control capsule 2008 to configure it into the engine brake ON configuration and to control the exhaust rocker arm control capsule to configure it into the exhaust rocker arm de-active configuration and can be used to control the engine brake control capsule 2008 to configure it into the engine brake OFF configuration and to control the exhaust rocker arm control capsule to configure it into the exhaust rocker arm active configuration.

When the engine is in normal drive mode there will be periods when the exhaust rocker arm has moved the exhaust valve bridge 400 out of contact with the exhaust brake rocker arm assembly 1530. A suitable arrangement is provided in order to maintain the connection between the exhaust brake rocker arm 1530 and the exhaust brake cam (e.g. via push rod 2002in the example of Figure 30a) under load. In the example shown in Figure 28a, the arrangement comprises a fixed support element 1540 and a spring 1542 arranged between the exhaust brake rocker arm 1530 and the fixed support element 1540 which biases the exhaust brake rocker arm 1530 towards the exhaust brake cam (not shown in Figure 28a).

Referring now to Figure 29 there is illustrated a rocker arm arrangement 2500 that can be configured to provide a normal exhaust valve lift in normal engine drive mode and an exhaust brake valve lift in exhaust brake mode.

At a first end, the rocker arm arrangement 2500 comprises a first member 2502 for engagement with a push rod (not shown) that is in contact with a rotating exhaust cam (not shown). The first member 2502 may also function as a mechanical lash adjuster. At a second end, the rocker arm arrangement 2500 comprises an exhaust brake control capsule 2504 and associated actuator (not shown) that are similar to those described above with reference to Figure 28. Also, at the second end, the rocker arm arrangement 2500 comprises a second member 2506 for engagement with a valve bridge (not shown) carrying a pair of exhaust valves (not shown). A lost motion spring 2508 is housed above the second member 2506. As described above with respect to Figure 28, the exhaust brake control capsule 2504 can act upon one of the exhaust valves (not shown) carried by the valve bridge (not shown).

In operation, the rocker arm arrangement 2500 pivots in accordance with the cam profile (not shown) of the cam (not shown) that acts on the push rod (not shown) that acts in turn on the first member 2502. In normal engine drive mode, the exhaust brake control capsule 2504 is in the engine brake OFF configuration and provides no effect. In normal engine drive mode, the rocker arm arrangement 2500 pivots through a lost motion stroke X before contacting the second member 2506 to cause the second member 2506 to move the valve bridge (not shown) and hence both exhaust valves (not shown) to provide a normal exhaust valve lift in accordance with the cam profile (not shown) of the exhaust cam (not shown).

In exhaust brake mode, the exhaust brake control capsule 2504 is in the engine brake ON configuration to provide an exhaust brake event. In this mode, as the rocker arm arrangement 2500 pivots the control capsule 2504 causes the exhaust valve (not shown) it acts upon to open first while the rocker arm arrangement 2500 pivots through the lost motion stroke X to contact the second member 2506 to cause the valve bridge (not shown) to then open the second exhaust valve (not shown). Following the engine rocker arrangement 2500 contacting the second member 2506, the lift of both of the exhaust valves (not shown) is controlled by the second member 2506 in accordance with cam profile (not shown) of the exhaust cam (not shown). The cam profile (not

shown) may, for example, provide a single stroke-exhaust lift and the arrangement may be used on cylinders 5 and 6 in the system of Figure 25.

It is to be understood that any feature described in relation to any one example may be used alone, or in combination with other features described, and may also be used in combination with one or more features of any other of the examples, or any combination of any other of the examples.

According to a first example, a cam phasing mechanism is provided. The cam phasing mechanism for a cam assembly of an internal combustion engine, the cam assembly comprising a camshaft and an actuator for opening a valve at a reference position of rotation of the camshaft. Aspects of the cam phasing mechanism are as follows:

Aspect 1: The cam phasing mechanism comprises:

a force transfer member for interposition between the camshaft and the actuator of the cam assembly for transferring force between the camshaft and the actuator; and

an adjuster for selectively moving the force transfer member to adjust the reference position of rotation of the camshaft.

Aspect 2: The cam phasing mechanism according to Aspect 1 of the first example, wherein the adjuster comprises a first member and a second member, wherein the first member is moveable relative to the second member for selectively moving the force transfer member relative to the second member to adjust the reference position of rotation of the camshaft.

Aspect 3: The cam phasing mechanism according Aspect 2 of the first example, wherein the first member is continuously moveable relative to the second member for continuously adjusting the reference position of rotation of the camshaft within a predetermined range.

Aspect 4: The cam phasing mechanism according to Aspect 2 or Aspect 3 of the first example, wherein the force transfer member is spaced from the first member by a third member.

Aspect 5: The cam phasing mechanism according to Aspect 4 of the first example, wherein the third member is pivotable about the first member.

Aspect 6: The cam phasing mechanism according to Aspect 4 or Aspect 5 of the first example, wherein the third member is Y-shaped such that a distal portion of the third member is a bifurcated portion to enclose the force transfer member.

Aspect 7: The cam phasing mechanism according to any one of Aspect 2 to Aspects 6 of the first example, comprising a driving member for driving the second member of the adjuster.

Aspect 8: The cam phasing mechanism according to Aspect 7 of the first example, wherein an axis of rotation of the driving member is perpendicular to an axis of rotation of the second member.

Aspect 9: The cam phasing mechanism according to any preceding Aspect of the first example, wherein the first member is moveable relative to the second member by translational motion of the first member.

Aspect 10: The cam phasing mechanism according to any preceding Aspect of the first example, wherein the force transfer member comprises a first roller for engagement with the camshaft of the cam assembly and a second roller for engagement with the actuator of the cam assembly.

Aspect 11: The cam phasing mechanism according to Aspect 10 of the first example, wherein the first roller and the second roller are each independently rotatable about a third roller.

Aspect 12: The cam phasing mechanism according to Aspect 10 or Aspect 11 of the first example, wherein the first roller and the second roller are coaxial.

Aspect 13: The cam phasing mechanism according to Aspect 12 of the first example, wherein the first roller and the second roller are rotatable about a common axis, and wherein the first roller is restricted to a central location along the common axis.

Aspect 14: The cam phasing mechanism according to any one of Aspect 10 to Aspect 13 of the first example, wherein the second roller comprises two rollers, wherein one of the two rollers is arranged on one side of the first roller and the other of the two rollers is arranged on another side of the first roller.

According to a second example, a cam assembly for an internal combustion engine and for controlling actuation of a valve is provided. Aspects of the cam assembly are as follows:

Aspect 1: The cam assembly comprises:

a camshaft;

an actuator moveable by rotation of the camshaft for opening the valve at a reference position of rotation of the camshaft; and

a force transfer member interposed between the camshaft and the actuator for transferring force between the camshaft and the actuator;

wherein the force transfer member is selectively moveable by an adjuster to adjust the reference position of rotation of the camshaft.

Aspect 2: The cam assembly according to Aspect 1 of the second example, wherein the force transfer member is selectively moveable either side of a reference plane between an axis of the camshaft and an axis of the actuator.

Aspect 3: The cam assembly according to Aspect 15 or Aspect 16 of the second example, wherein the actuator comprises a first surface for avoiding contact with the force transfer member and a second surface for engaging the force transfer member.

Aspect 4: The cam assembly according to Aspect 17 of the second example, wherein the force transfer member comprises a first roller for engaging the camshaft and a second roller for engaging the second surface of the actuator.

Aspect 5: The cam assembly according to Aspect 18 of the second example, wherein the first roller comprises a diameter that is greater than a diameter of the second roller.

According to a third example, a valve train assembly for an internal combustion engine is provided. The valve train assembly comprising an exhaust valve and the cam assembly according to any one of Aspects 1 to 5 of the second example.

According to a fourth example, an actuation mechanism for controlling actuation of a valve of an internal combustion engine is provided. Aspects of the actuation mechanism are as follows:

Aspect 1: The actuation mechanism comprises:

a first actuator for controlling actuation of the valve when the actuation mechanism is arranged in a first position; and

a second actuator for controlling actuation of the valve when the actuation mechanism is arranged in a second position;

wherein the first actuator and second actuator are moveable relative each other.

Aspect 2: The actuation mechanism according to Aspect 1 of the fourth example, wherein movement of the first actuator is governed by a first driver and movement of the second actuator is governed by a second driver that is different to the first driver.

Aspect 3: The actuation mechanism according to Aspect 2 of the fourth example, wherein the first driver comprises a mechanical force and the second driver comprises a hydraulic force.

Aspect 4: The actuation mechanism according to any preceding Aspect of the fourth example, comprising an engagement area for mechanical engagement with a rocker arm assembly to move a rocker arm of the rocker arm assembly, wherein the engagement area comprises a portion of the first actuator and a portion of the second actuator when the actuation mechanism is arranged in the second position.

Aspect 5: The actuation mechanism according to Aspect 4 of the fourth example wherein, the first actuator comprises a slave part and a master part that are separable from each other and the engagement area comprises a portion of the slave part of the first actuator and the portion of the second actuator and wherein the second actuator acts to maintain the valve at a substantially fixed position as the master part separates from the slave part to arrange the actuation mechanism in a third position.

Aspect 6: The actuation mechanism according to Aspect 5 of the fourth example, wherein the slave part and the master part that are separated by a gap when the actuation mechanism is arranged in the third position.

Aspect 7: The actuation mechanism according to Aspect 6 of the fourth example, wherein the gap is variable when the actuation mechanism is arranged between the third position and a fourth position.

Aspect 8: The actuation mechanism according to any one of Aspect 5 to Aspect 7 of the fourth example, wherein the actuation mechanism comprises a pressure release portion for releasing fluid pressure from a working zone acting on the second actuator of the actuation mechanism to enable the second actuator and the slave part of the first

actuator to move the actuation mechanism from the third position into the fourth position in which the valve is closed and the slave part and the master part of the first actuator are non-separated.

Aspect 9: The actuation mechanism according to any preceding Aspect of the fourth example, comprising a fluid passageway comprising a fluid inlet, a working zone and a fluid outlet; wherein a volume of fluid within the working zone is variable by movement of fluid between the fluid inlet and fluid outlet.

Aspect 10: The actuation mechanism according to any preceding Aspect of the fourth example, comprising a controller for hydraulically controlling movement of the second actuator.

Aspect 11: The actuation mechanism according to Aspect 10 of the fourth example, wherein the controller controls release of fluid from the fluid outlet to reduce the volume of fluid within the working zone.

Aspect 12: The actuation mechanism according to any preceding Aspect of the fourth example, wherein the first actuator is moveable within the second actuator.

According to a fifth example, a valve train assembly for an internal combustion engine is provided. The valve train assembly comprising an exhaust valve and the actuation mechanism according to any one of Aspects 1 to 12 of the fourth example for actuating the exhaust valve.

According to a sixth example, an actuation assembly for an internal combustion engine is provided. Aspects of the actuation assembly are as follows:

Aspect 1: The actuation assembly comprises:

an actuation mechanism according to any one of Aspect 1 to Aspect 12 of the fourth example for controlling actuation of an exhaust valve; and

a motion controller for controlling actuation of an intake valve;

wherein the motion controller comprises a pressure release portion for releasing fluid pressure from a working zone acting on the second actuator of the actuation mechanism.

Aspect 2: The actuation assembly according to Aspect 1 of the sixth example, wherein the pressure release portion is activatable by an intake camshaft.

Aspect 3: The actuation assembly according to Aspect 15 of the sixth example, wherein the pressure release portion is independent of the opening timing of the exhaust valve.

Aspect 4: The actuation assembly according to Aspect 15 or Aspect 16 of the sixth example, wherein the pressure release portion is a channel for communication between a fluid outlet of the actuation mechanism and a return line of a hydraulic circuit.

Aspect 5: The actuation assembly according to any one of Aspect 14 to Aspect 17 of the sixth example, wherein the pressure release portion is configured to release pressure from the working zone between 0.5 and 0.7mm of lift of the exhaust valve.

According to a seventh example, a motion controller for controlling movement of a valve of an internal combustion engine is provided. Aspects of the motion controller are as follows:

Aspect 1: The motion controller comprises:

a first part for engagement with a rocker arm assembly; and

a second part for engagement with a camshaft;

wherein the motion controller is arrangeable between an unlocked state and a locked state before the valve is opened;

wherein in the unlocked state the second part is moveable towards the first part by the camshaft without imparting a lifting force to the valve to thereby delay an opening of the valve.

Aspect 2: The motion controller according to Aspect 1 of the seventh example wherein, after the second part has been moved a pre-defined distance by the camshaft without imparting a lifting force to the valve, the second part contacts the first part to arrange the motion controller in the locked state wherein the first part and the second part are moveable as a unit by the camshaft to impart a lifting force to the valve.

Aspect 3: The motion controller according to Aspect 1 or Aspect 2 of the seventh example, wherein a resistance to relative movement between the first part and the second part in the unlocked state is provided by a resilient member.

Aspect 4: The motion controller according any preceding Aspect of the seventh example, wherein the first part and second part form a reservoir having a port

communicable with a fluid inlet and the motion controller comprises a switch for switching the fluid inlet to a fluid outlet to release fluid from the reservoir.

According to an eighth example, a valve train assembly for an internal combustion engine is provided. Aspects of the valve train assembly are as follows:

Aspect 1: The valve train assembly comprising an intake valve and the motion controller according to any one of Aspects 1 to 4 of the seventh example for actuating the intake valve.

Aspect 2: The valve train assembly according to Aspect 1 of the eight example, wherein a raised profile of a camshaft is configured to move the motion controller between the unlocked state and the locked state before the intake valve is opened.

Aspect 3: The valve train assembly according to Aspect 2 of the eight example, wherein the intake valve opens at a greater rate of lift than when a corresponding rate of lift when the intake valve is closed.

According to a ninth example, an engine braking system for an internal combustion engine comprising a plurality of engine cylinders is provided. Aspects of the engine braking system are as follows:

Aspect 1: The engine braking system comprising a single-stroke engine brake arrangement configured to provide single stroke engine braking on at least one cylinder of the plurality of cylinders and a two-stroke engine brake arrangement configured to provide two-stroke engine braking on at least one other cylinder of the plurality of cylinders.

Aspect 2: An engine braking system according to Aspect 1 of the ninth example wherein the single-stroke engine brake arrangement is configured to provide single-stroke engine braking on each of N_1 cylinders of the plurality of cylinders and the two-stroke engine brake arrangement is configured to provide two-stroke engine braking on each of N_2 other cylinders of the plurality of cylinders and wherein N_1 is greater than N_2.

Aspect 3: An engine braking system according to Aspect 2 of the ninth example where N_1 is a whole multiple of N_2.

Aspect 4: An engine braking system according to Aspect 2 or Aspect 3 of the ninth example wherein $N_1 = 4$ and $N_2 = 2$.

Aspect 5: An engine braking system according to Aspect 4 of the ninth example wherein the internal combustion engine comprises 6 cylinders arranged in a sequence and the single-stroke engine brake arrangement is configured to provide single stroke engine braking on cylinders one to four in the sequence and the two-stroke engine brake arrangement is configured to provide two-stroke engine braking on cylinders five to six in the sequence.

It is to be understood that any Aspect described in relation to any one of the first to ninth examples may be used alone, or in combination with other Aspects described, and may also be used in combination with one or more Aspects of any other of the first to ninth examples, or any combination of any other of the first to ninth examples.

Reference Signs List

1	cam phasing mechanism
2a	force transfer member
2b	adjuster
21	first roller
22	second roller
23	third roller
3	third member
31	lever arm
32	proximal portion
33	distal portion
4, 4', 2502	first member
41	fourth threaded portion
5, 2506	second member
51, 71, 81	locating member
52	second threaded portion
53	third threaded portion
6, 6'	bearing
7, 124, 604, 770	housing
8, 1360	case
10	driving member
11	first threaded portion
100	cam assembly
110, 120, 1350, 1510	camshaft
111, 121, 1501-5	cam
112a, 112b, 122	cam lobe
113a, 123a	base surface
113b, 123b, 113c	raised profile
115, 125	camshaft axis
130, 2012	actuator
131	first surface

132	second surface
135	axis of actuator
200, 210, 220, 2002	push rod
300, 310, 320, 1520, 1530, 1540	rocker arm assembly
311, 321	joint
312, 322	ball
313, 323	socket
323a, 721	engagement face
400, 410, 420	valve bridge assembly
400a	intermediary part
500, 510, 520, 1500	valve assembly
501, 511, 521, 2004	valve stem
502, 512, 522	valve head
505, 515, 525	valve
600	actuation assembly
601	accumulator
602, 603	supply line
605	accumulator piston
606, 607	return line
608	common passageway
610, 620	force transmitter
700	actuation mechanism
700-1	first position
700-2	second position
700-3	third position
700-4	fourth position
704, 740, 840	engagement area
705	damper
710	first actuator
710a	slave part
710b	master part
720	second actuator

730, 830, 831, 835b	fluid inlet
731	intermediate passageway
733, 833	working zone
734	reserve passageway
735, 835a., 835c	fluid outlet
750, 850	spool valve
751, 851	rotating member
752, 852	sliding member
760, 860	non-return valve
761, 861	moveable part
762	base
800	motion controller
800-1	unlocked state
800-2	locked state
800a	first arrangement
800b	second arrangement
800c	third arrangement
800d	fourth arrangement
800e	fifth arrangement
800f	sixth arrangement
802	pressure release portion
810	first part
811, 821	cavity
820	second part
832	port
862	switch
1000, 2000	valve train assembly
1100, 1110, 1120	reference timing
1101	early phasing
1102	late phasing
1111, 1121	valve opening
1112, 1122	valve closing

1113, 1123	maximum lift
1200	elongated timing
1210, 1410	stunted timing
1300	internal combustion engine
1301-6	engine cylinder
1310	single-stroke engine brake cams
1315	fuel pump cams
1320	two-stroke engine brake cams
1330	exhaust valve cams
1340	intake valve cams
1400	two-stroke engine brake valve timing
1401	first bump
1402	second bump
1530	engine brake rocker arm assembly
1530a, 2016a, 2018a	first end
1530b, 2016b	second end
1540	fixed support element
1542	spring
2000	rocker arm shaft
2006	exhaust valve
2008	engine brake control capsule
2008a	first body
2008b	second body
2009	member
2010, 2508	lost motion spring
2014	two-piece piston arrangement
2016	first piston piece
2018	second piston piece
2020	return spring
2022	engine brake actuation cam
2024	control camshaft
2026	threaded region

2028	compliance spring
2500	rocker arm arrangement
2504	exhaust brake control capsule
A	roller assembly region
B	first direction
C	reciprocation path
D	second direction
E1, E2	region of overlap
F	valve phasing range
G	gap
H	valve closing direction
J	valve opening direction
K, Q	lost motion region
L	translation axis
M1, M2, M3	motion axis
N	abutment area
P	reference plane
R1, R2, R3	rotation direction
S	spring
S1	first side
S2	second side
T	deactivated exhaust event
X	lost motion stroke

CLAIMS

1. An engine braking system for an internal combustion engine comprising a plurality of engine cylinders, the engine braking system comprising a single-stroke engine brake arrangement configured to provide single stroke engine braking on at least one cylinder of the plurality of cylinders and a two-stroke engine brake arrangement configured to provide two-stroke engine braking on at least one other cylinder of the plurality of cylinders.

2. An engine braking system according to claim 1 wherein the single-stroke engine brake arrangement is configured to provide single-stroke engine braking on each of N_1 cylinders of the plurality of cylinders and the two-stroke engine brake arrangement is configured to provide two-stroke engine braking on each of N_2 other cylinders of the plurality of cylinders and wherein N_1 is greater than N_2.

3. An engine braking system according to claim 2 where N_1 is a whole multiple of N_2.

4. An engine braking system according to claim 2 or claim 3 wherein $N_1 = 4$ and $N_2 = 2$.

5. An engine braking system according to claim 4 wherein the internal combustion engine comprises 6 cylinders arranged in a sequence and the single-stroke engine brake arrangement is configured to provide single stroke engine braking on cylinders one to four in the sequence and the two-stroke engine brake arrangement is configured to provide two-stroke engine braking on cylinders five to six in the sequence.

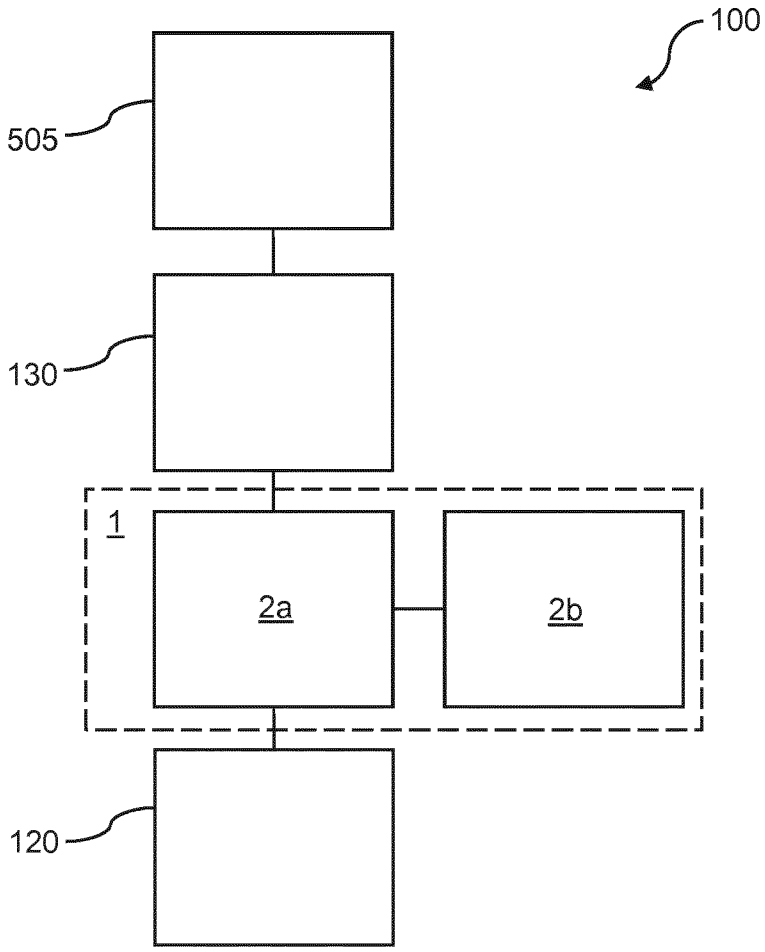


FIG. 1

FIG. 2

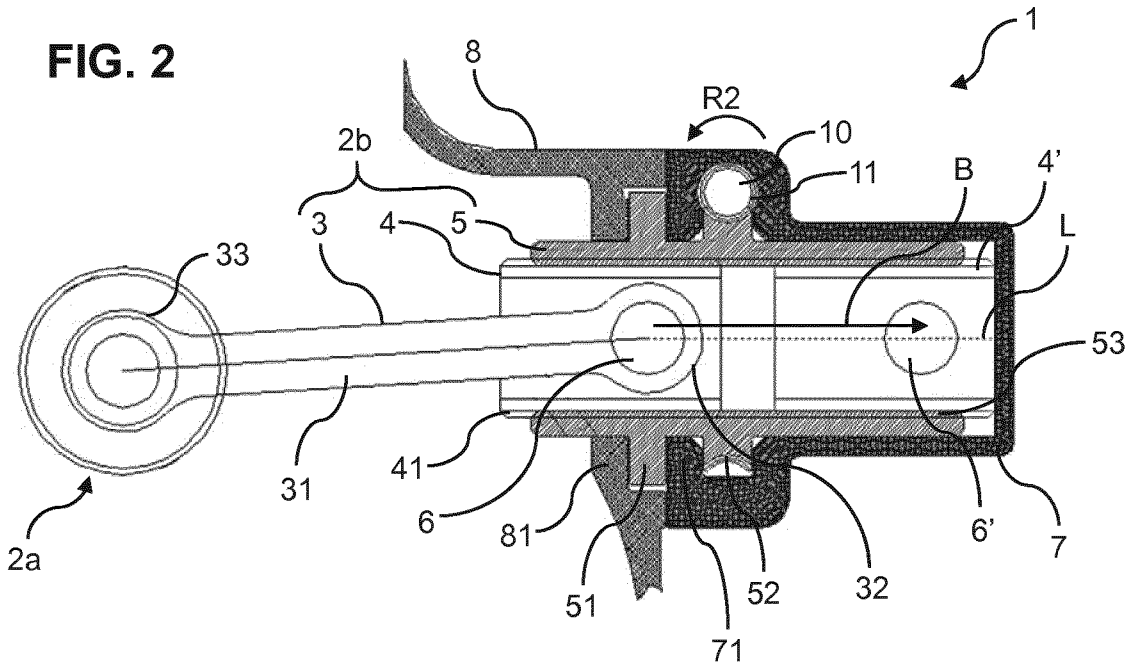
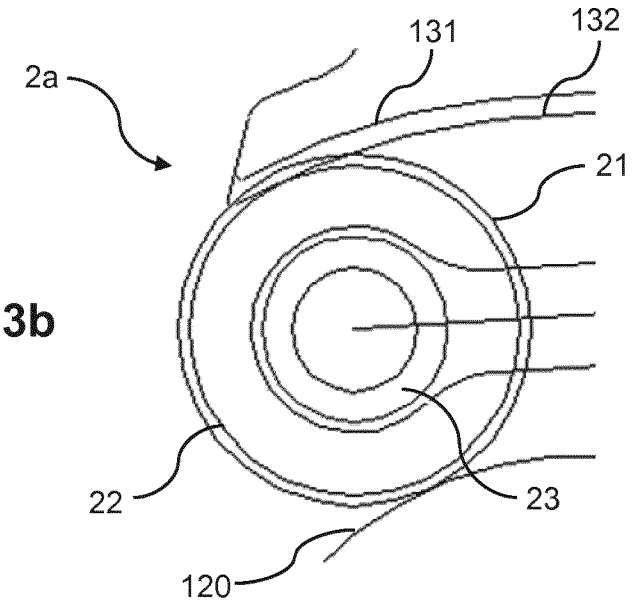

1
8
R2
10
11
B
4'
2b
3
4
5
L
33
53
31
41
6
81
51
52
32
6'
7
2a
71

FIG. 3b


131
132
2a
21
22
23
120

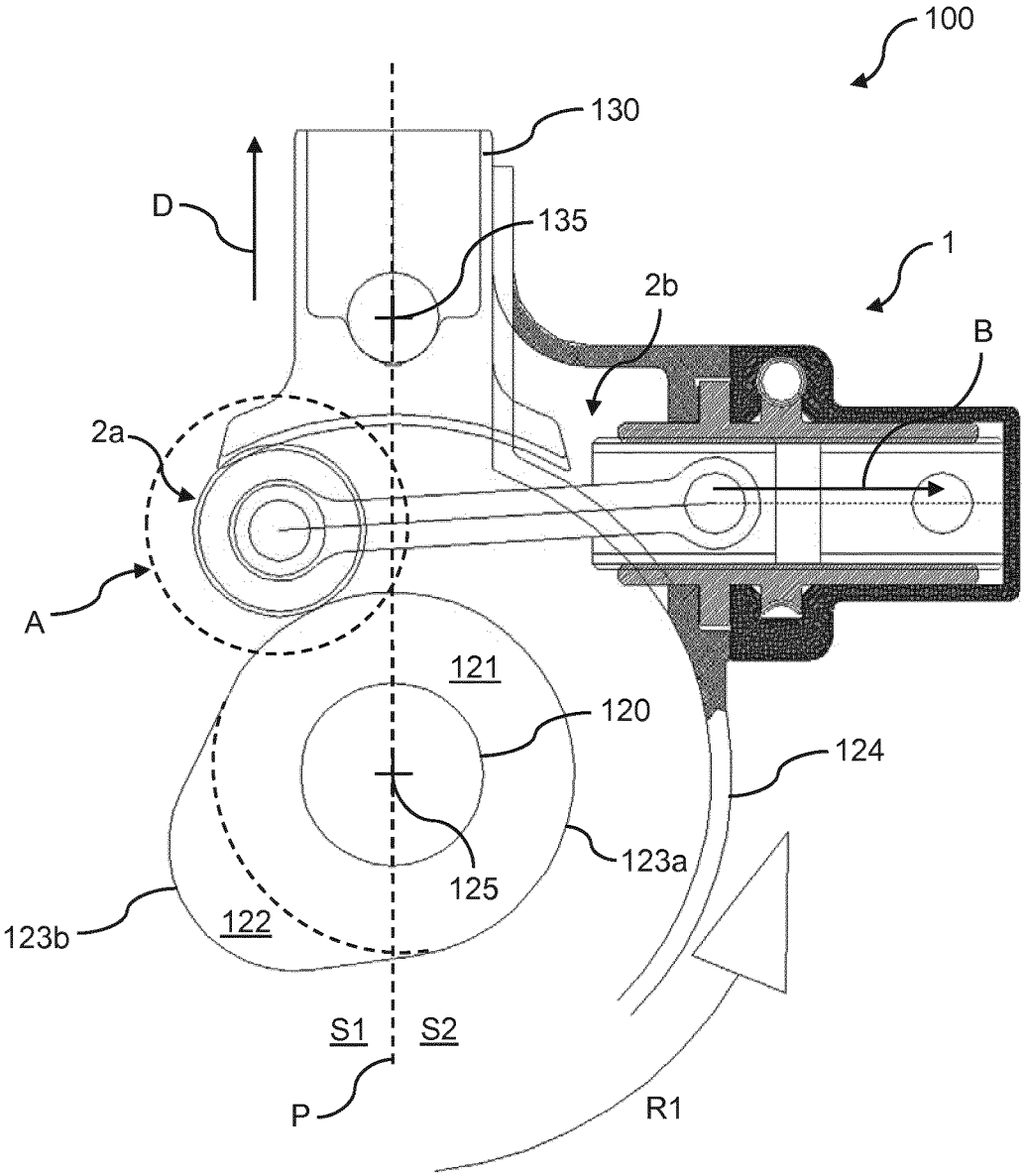


FIG. 3a

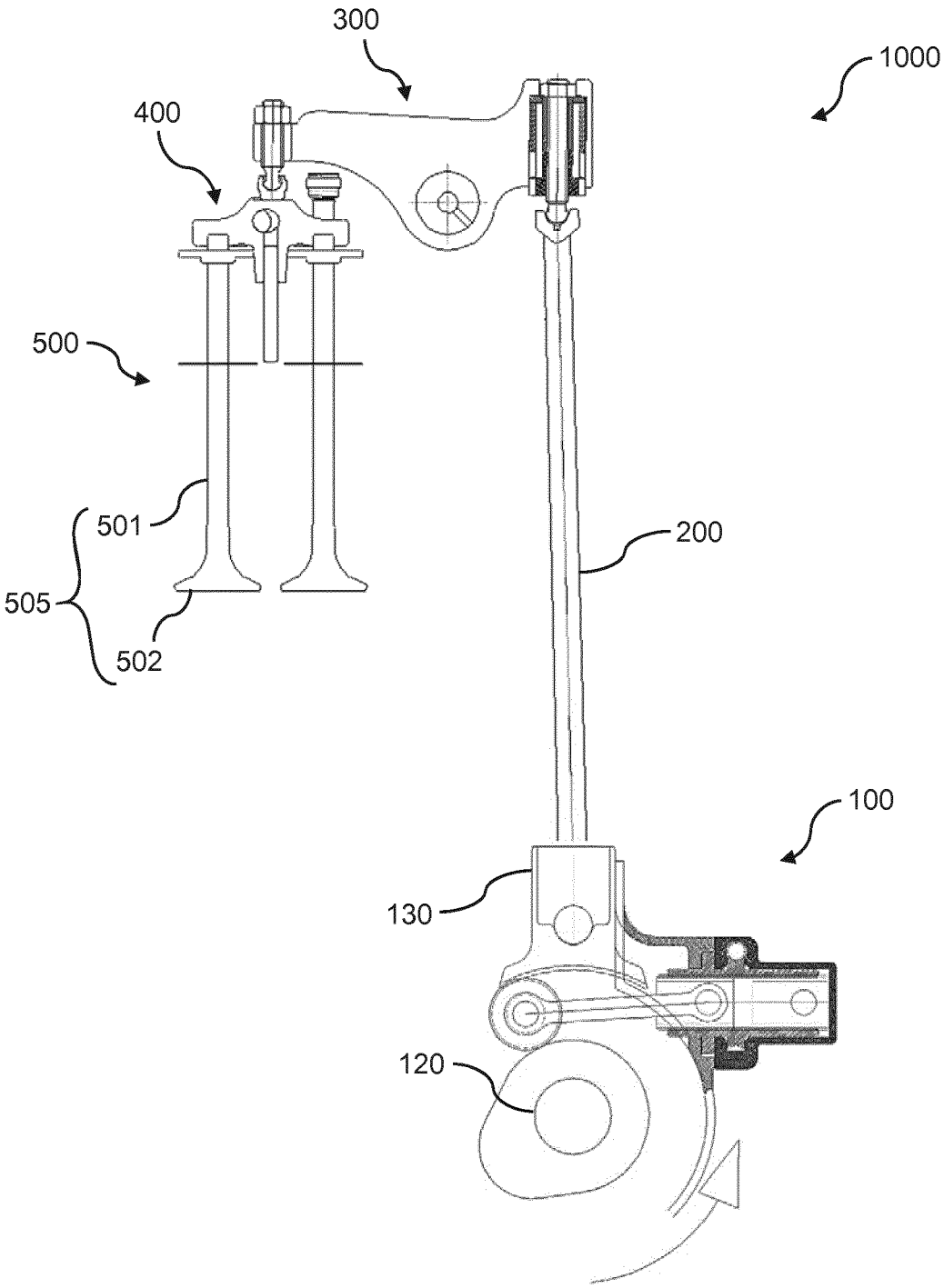


FIG. 4

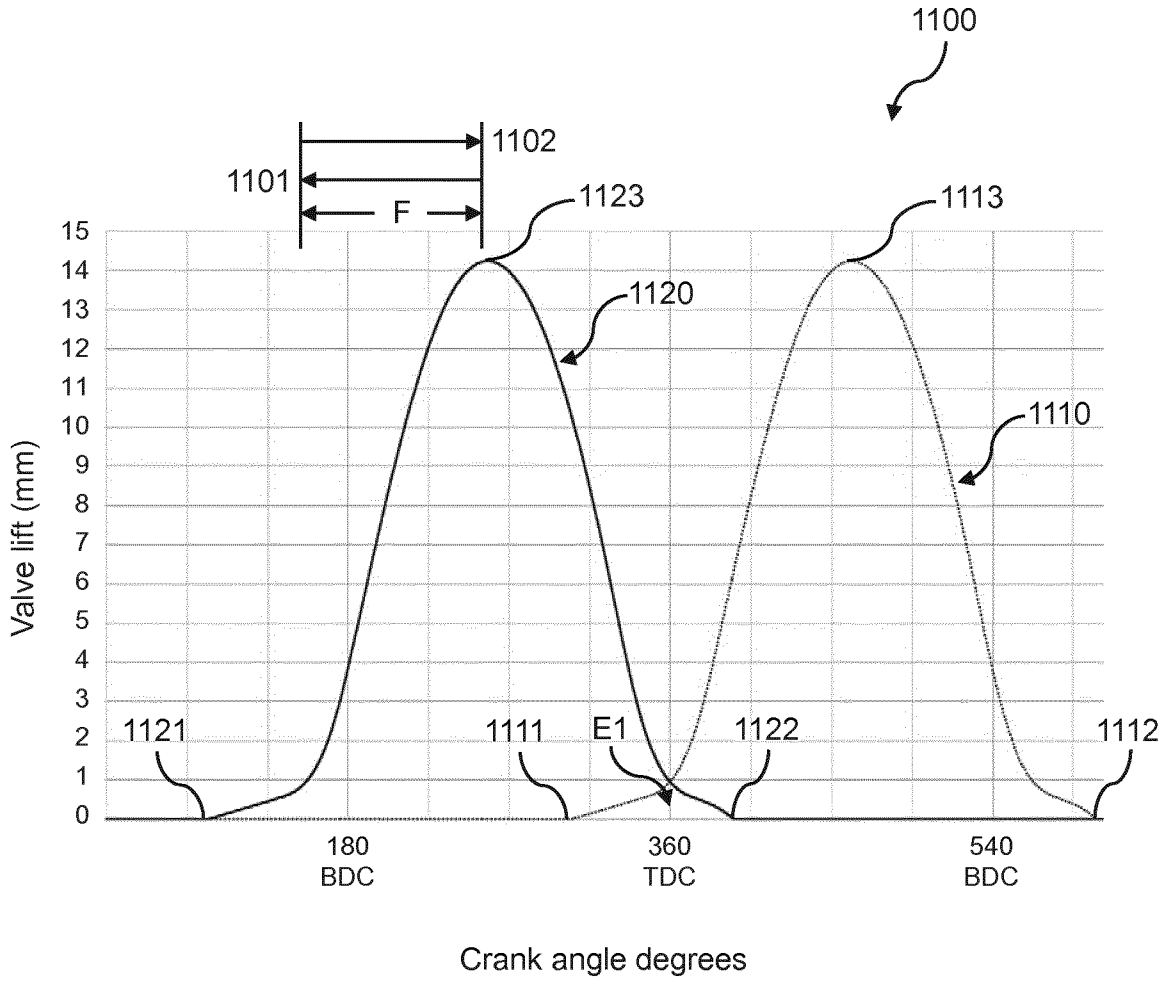

1100
1102
1101
F
1123
1113
1120
1110
1121
1111
E1
1122
1112
Valve lift (mm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
180
BDC
360
TDC
540
BDC
Crank angle degrees

FIG. 5

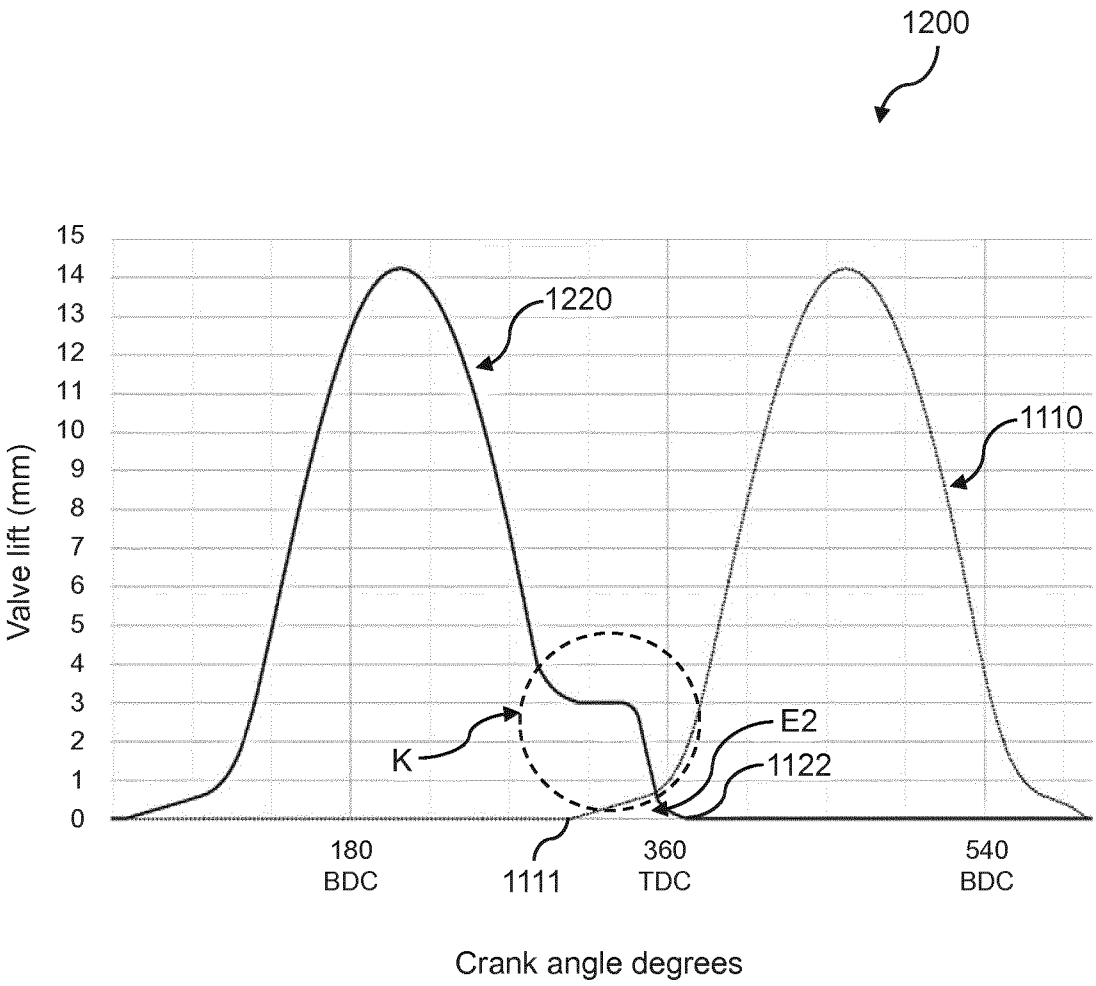

1200
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Valve lift (mm)
1220
1110
K
E2
1122
180
BDC
1111
360
TDC
540
BDC
Crank angle degrees

FIG. 6

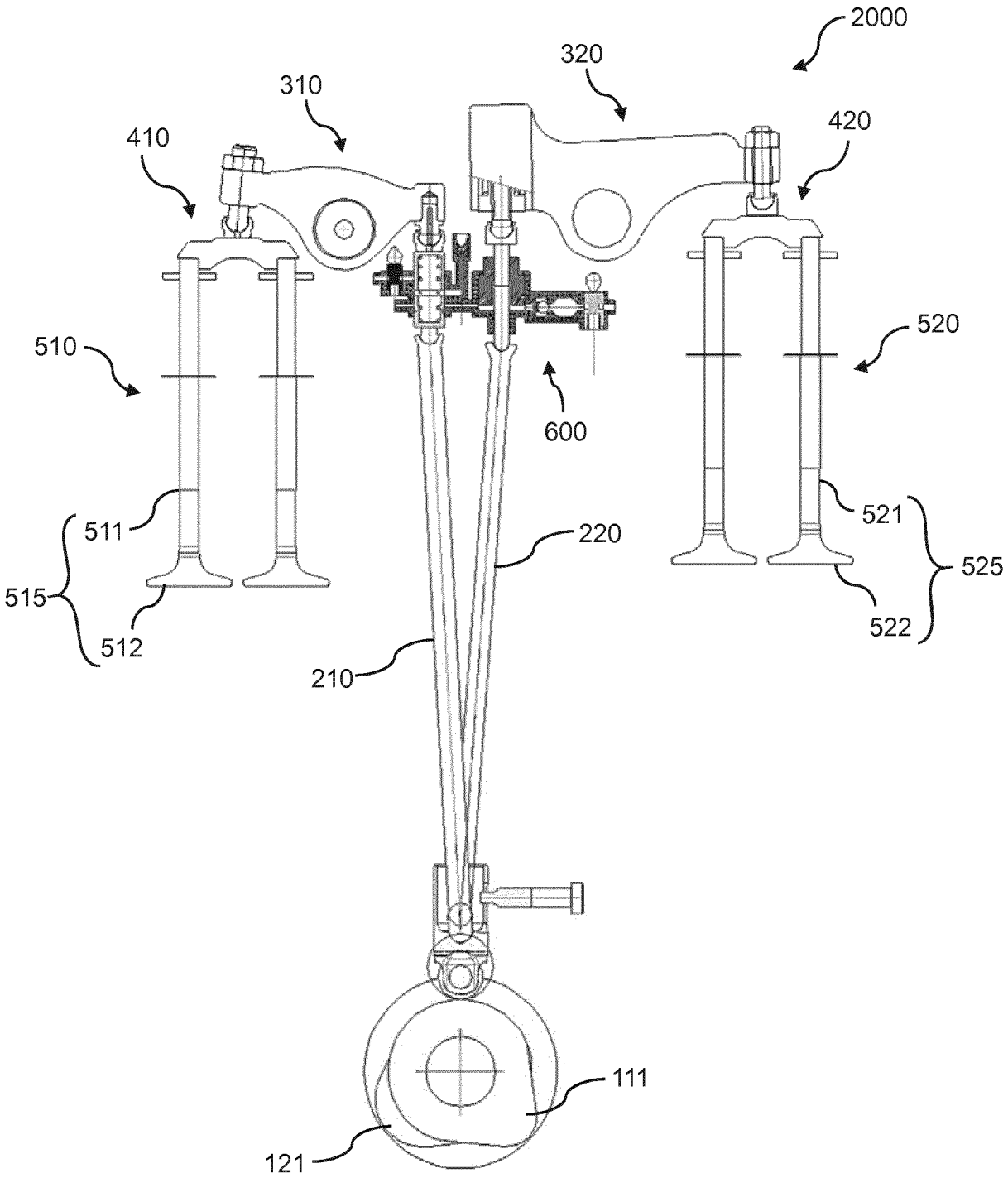

2000
320
310
410
420
510
520
600
511
521
525
515
220
512
522
210
111
121

FIG. 7

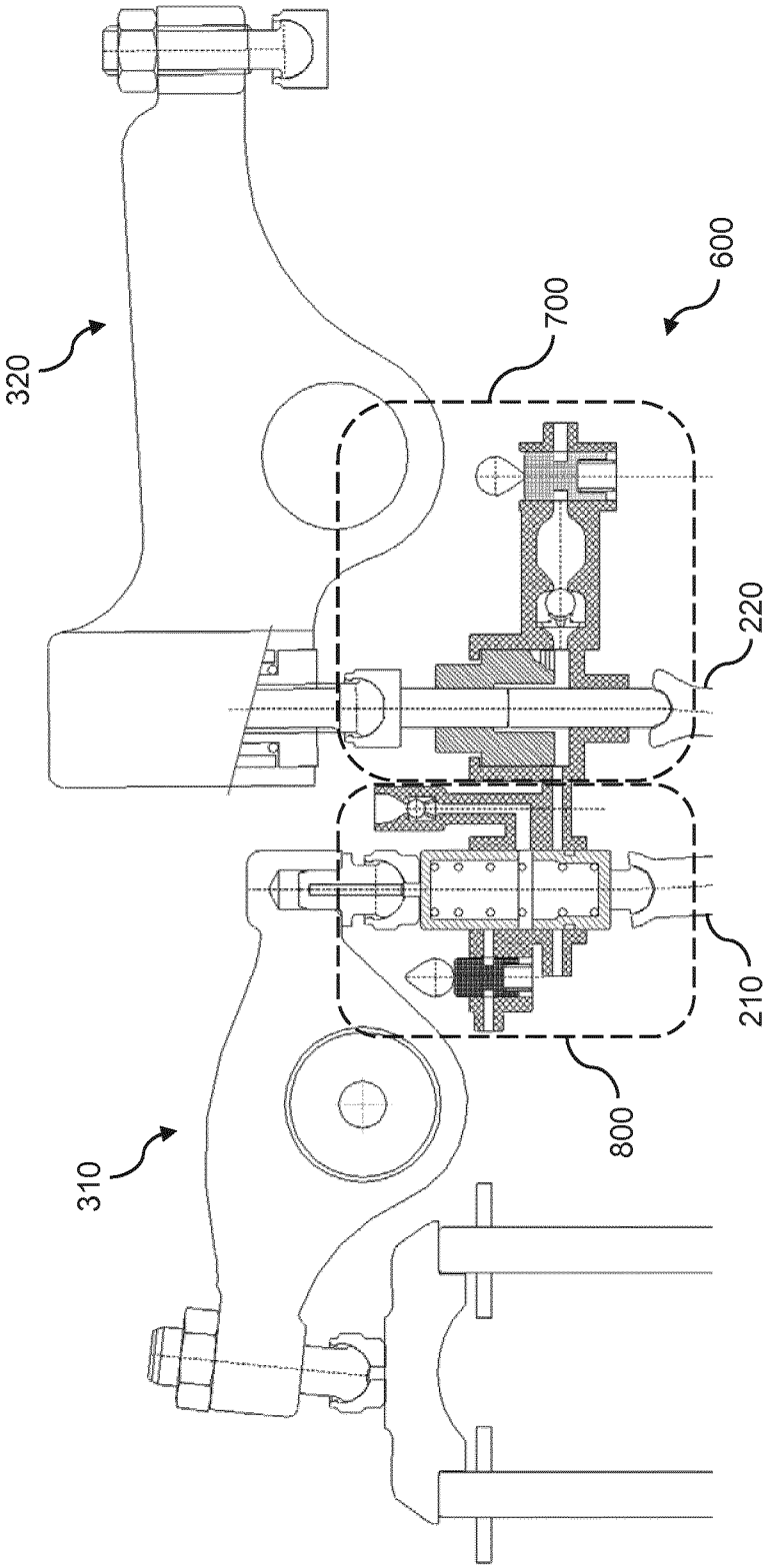


FIG. 8

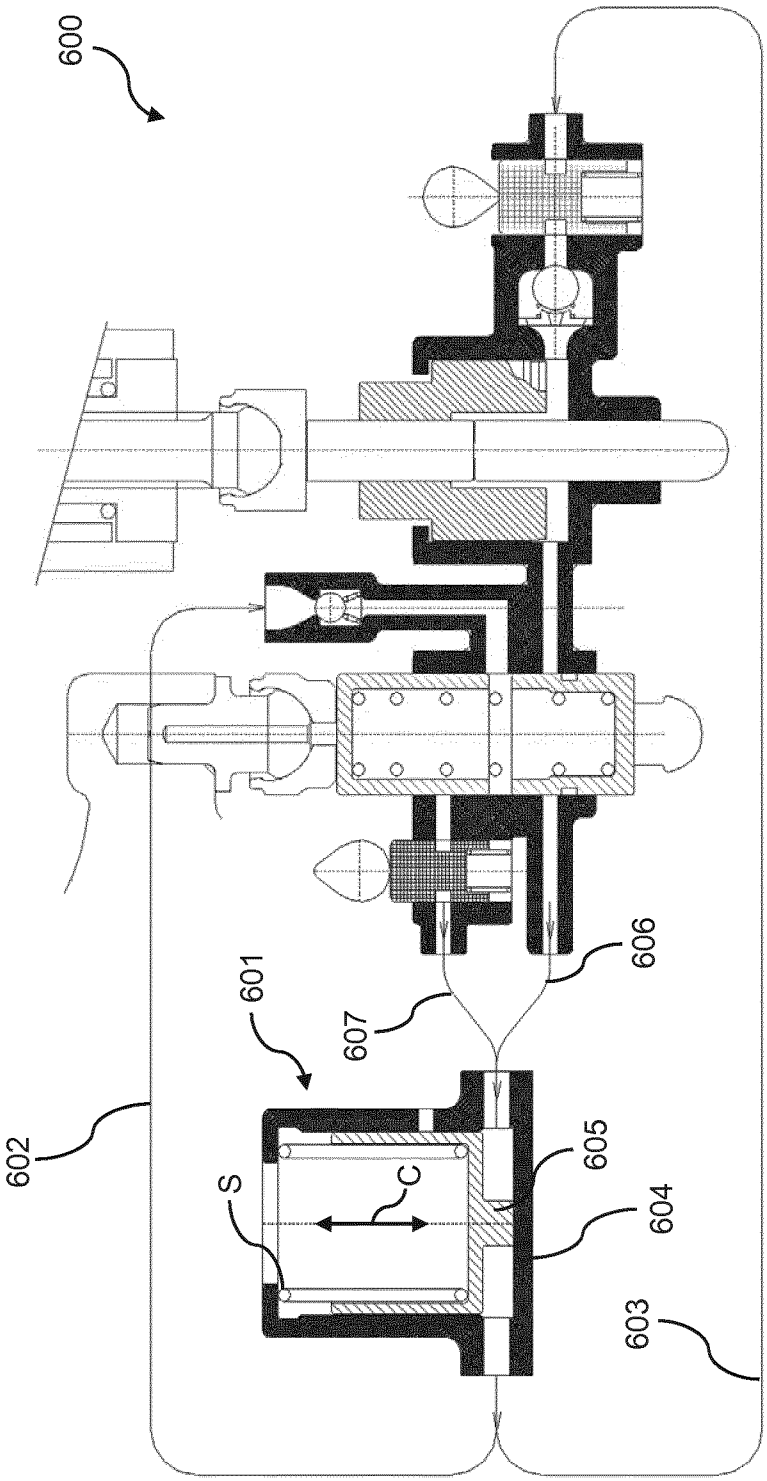


FIG. 9

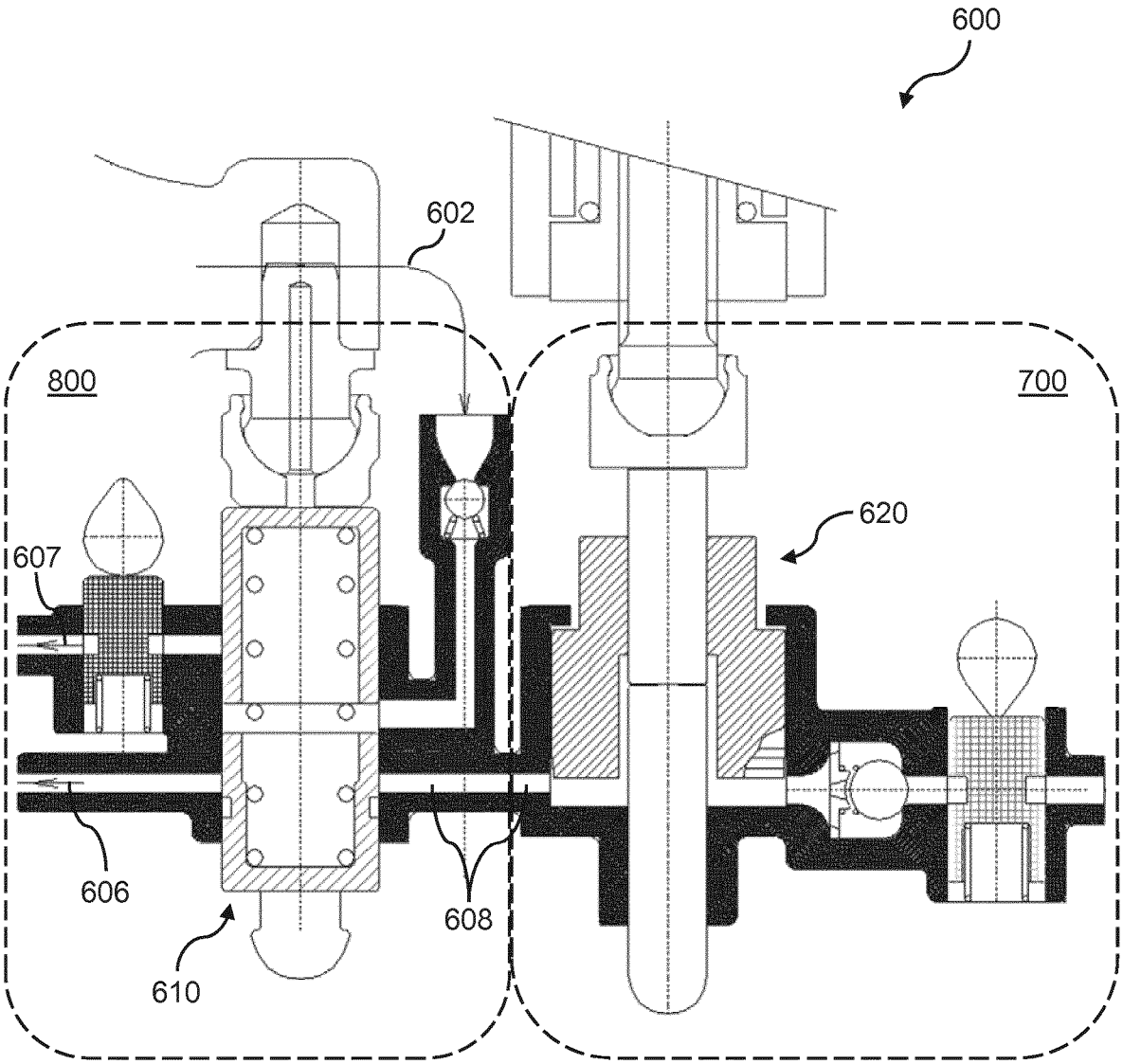


FIG. 10

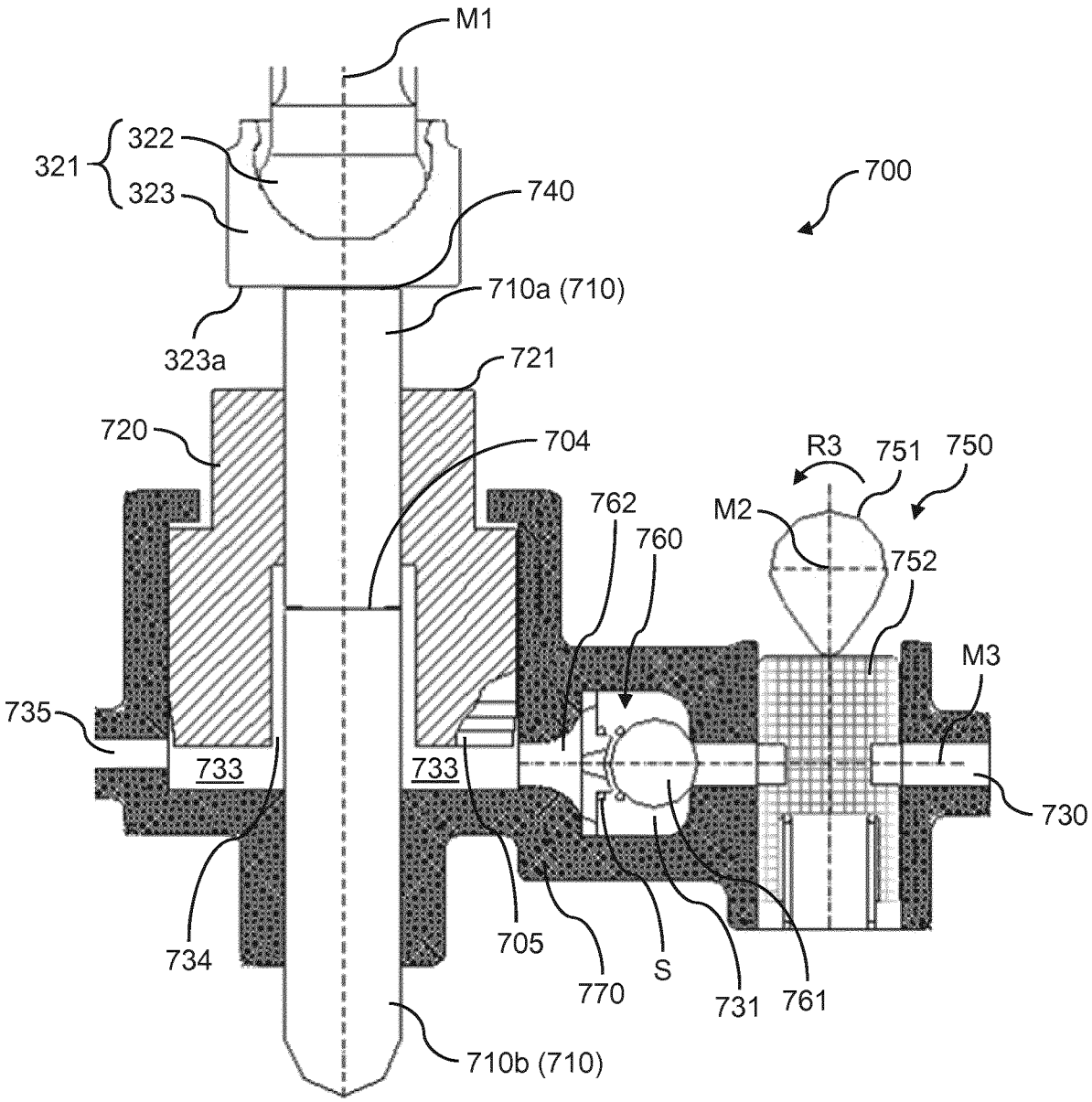

M1
321
322
323
740
700
710a (710)
323a
721
720
704
R3
751
750
762
760
M2
752
M3
735
733
733
730
734
705
770
S
731
761
710b (710)

FIG. 11

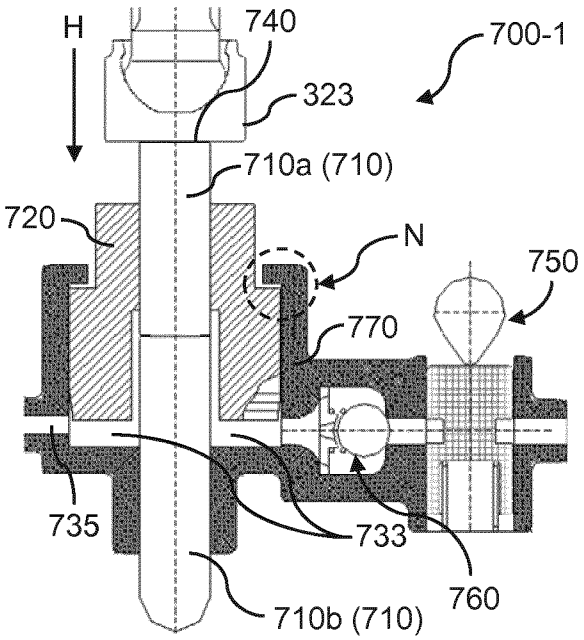


FIG. 12a

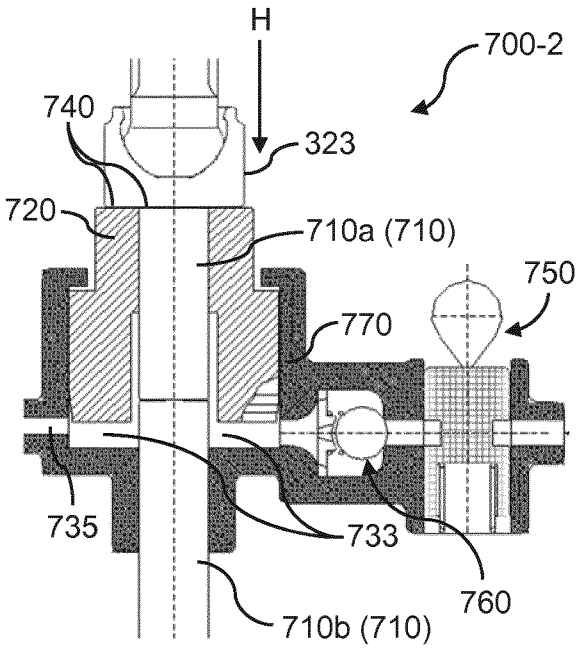


FIG. 12b

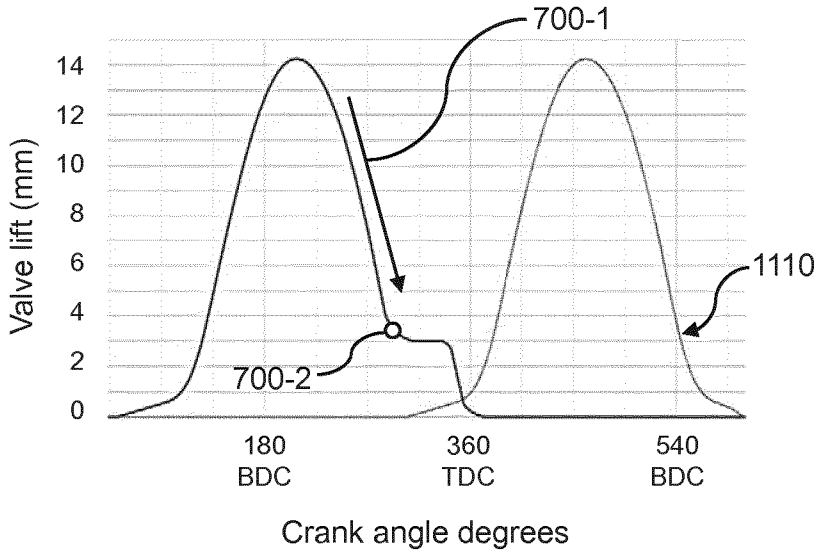


FIG. 13

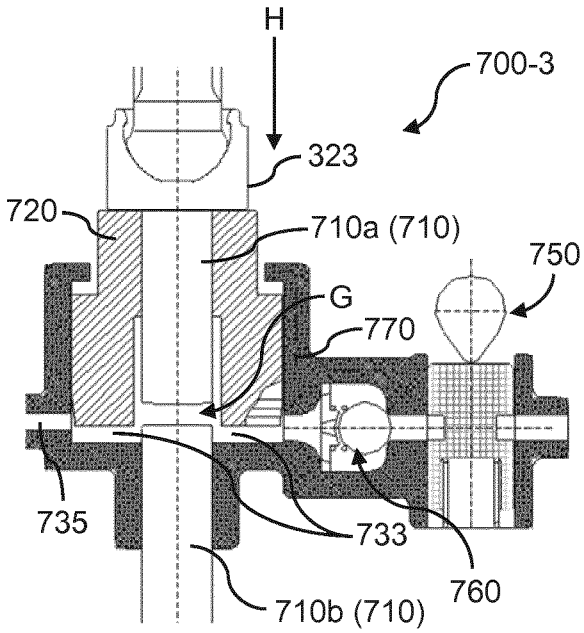


FIG. 12c

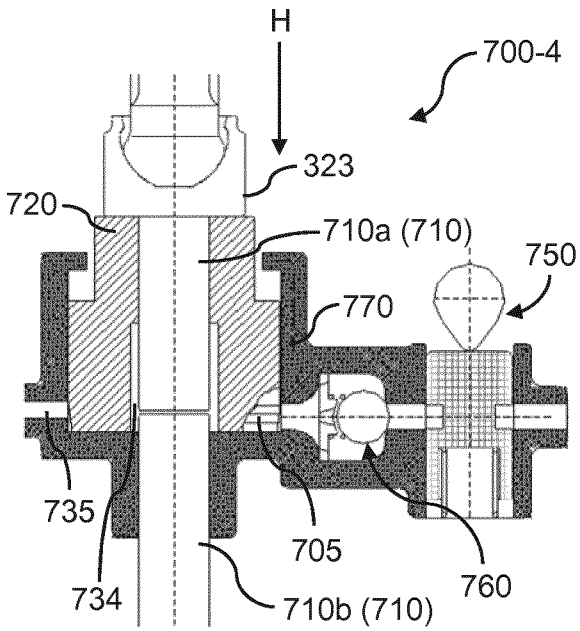


FIG. 12d

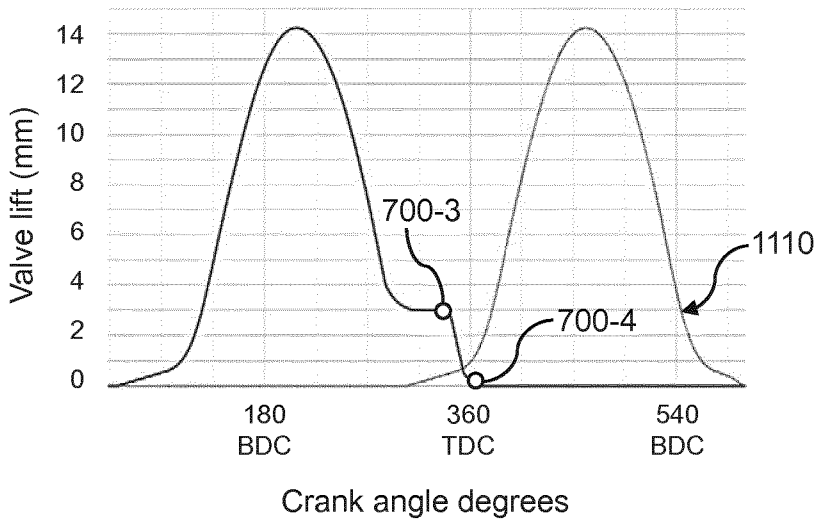


FIG. 14

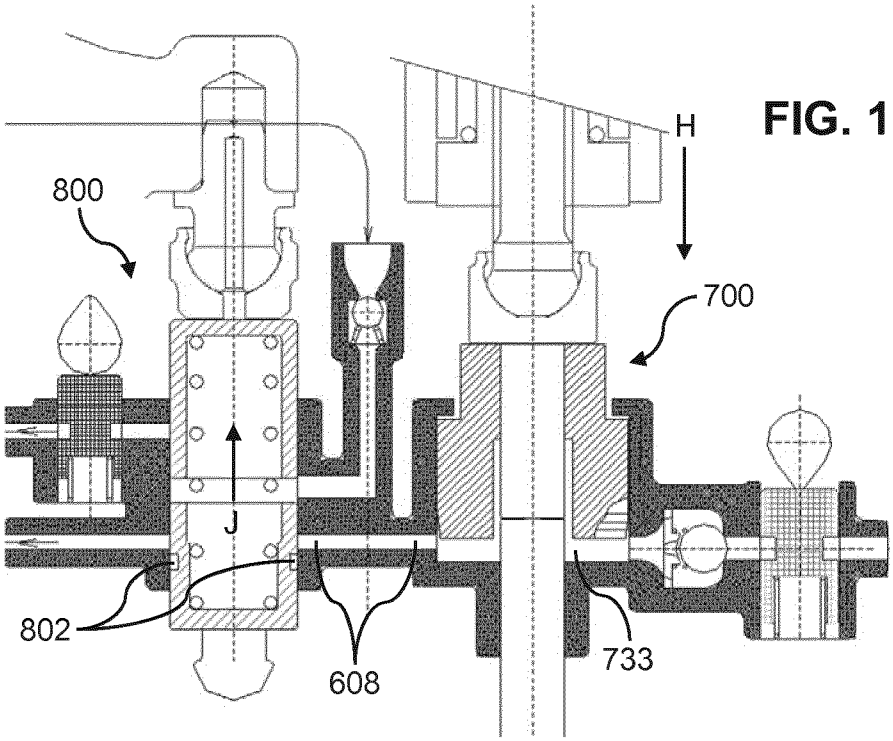


FIG. 12B

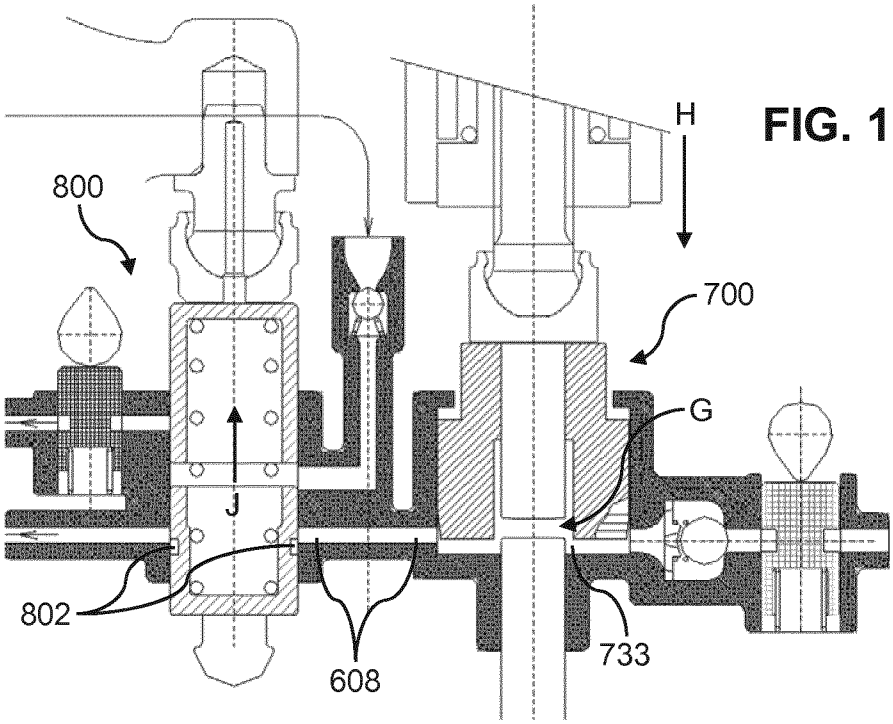


FIG. 12C

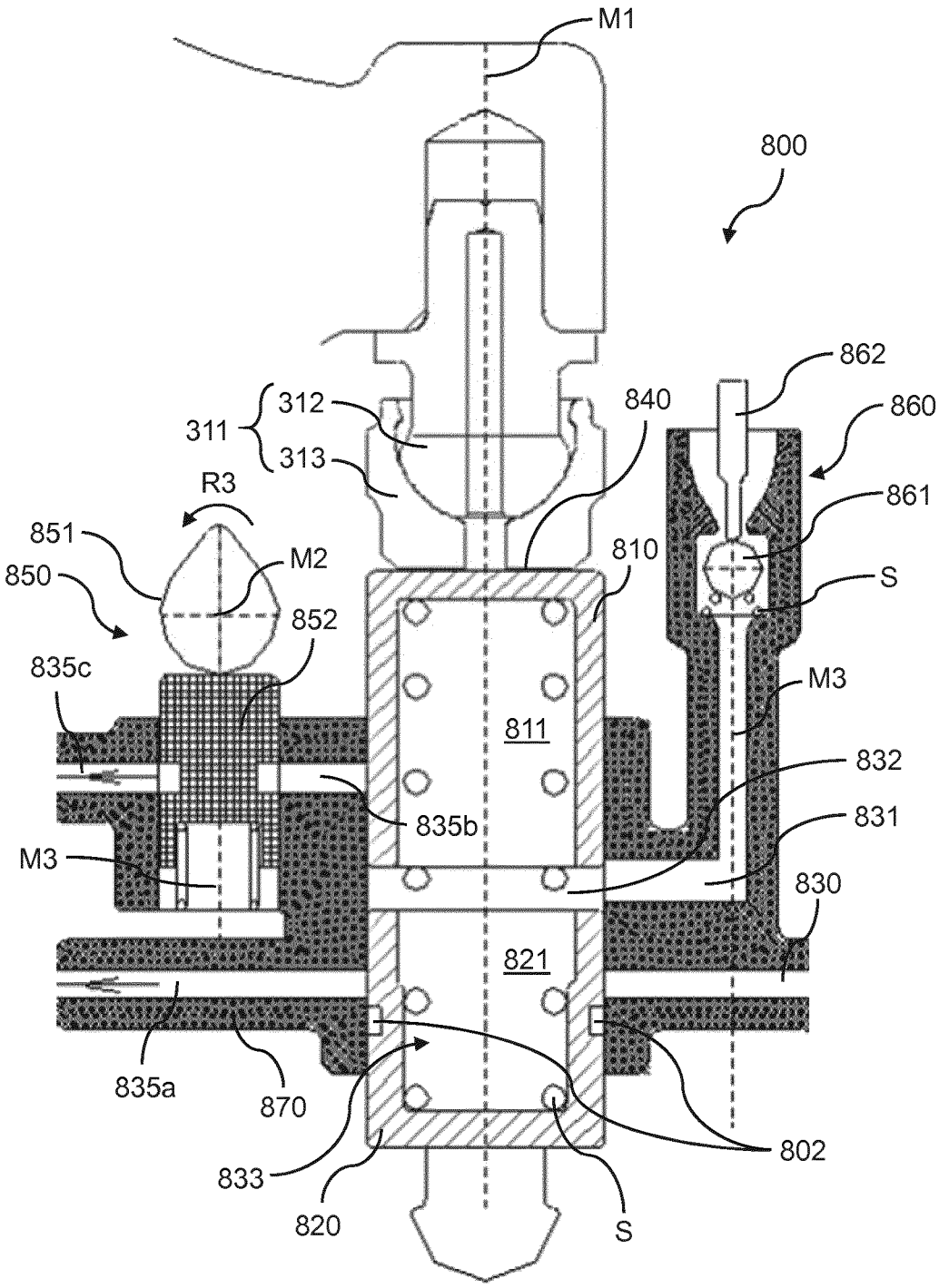

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311
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861
R3
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M2
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S
852
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M3
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832
835b
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M3
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835a
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820
S

FIG. 15

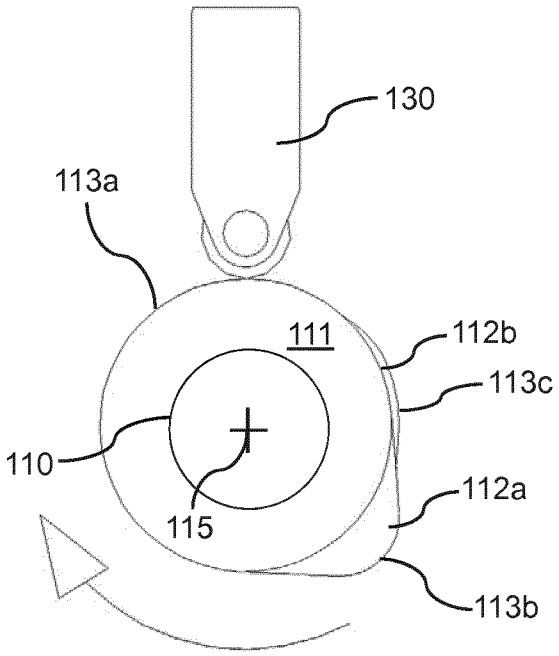


FIG. 16

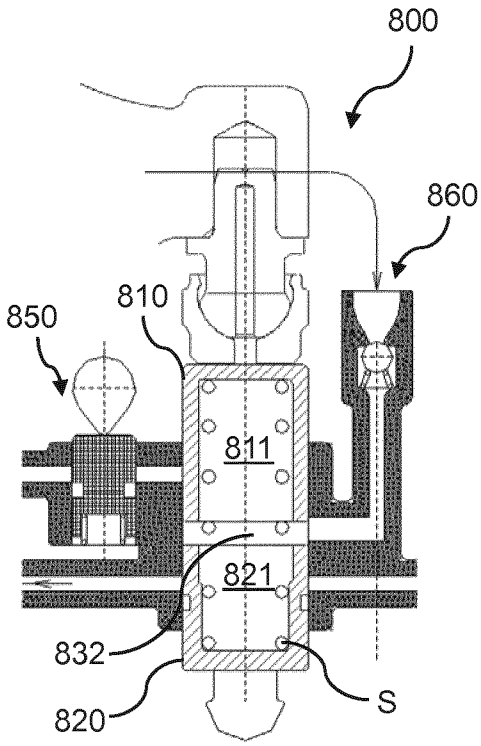


FIG. 17

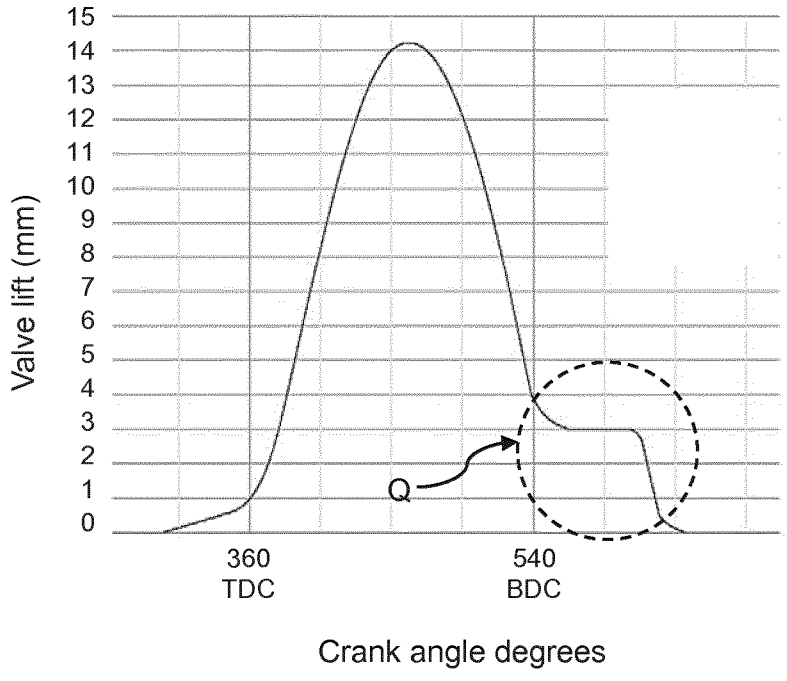


FIG. 18

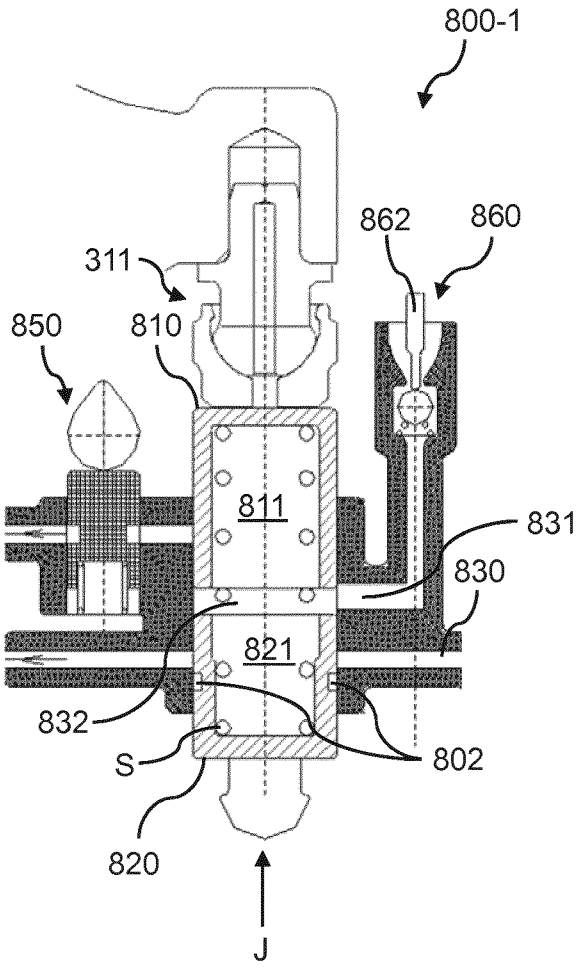


FIG. 19a

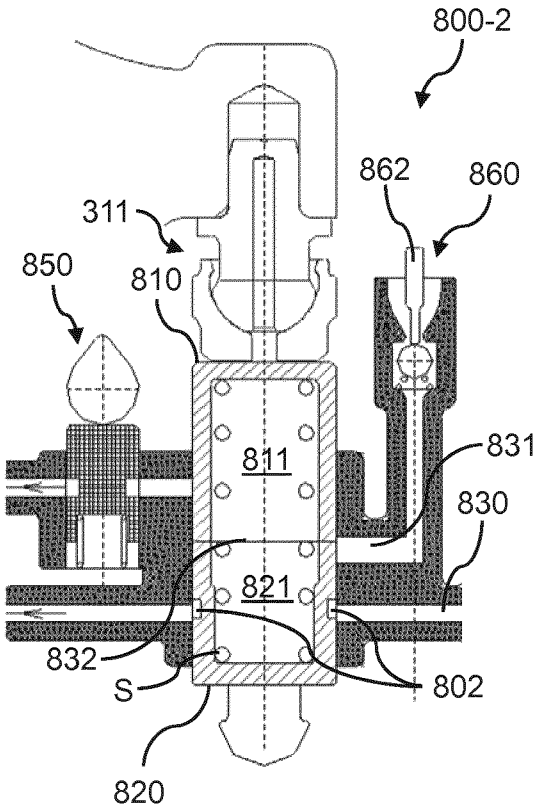


FIG. 19b

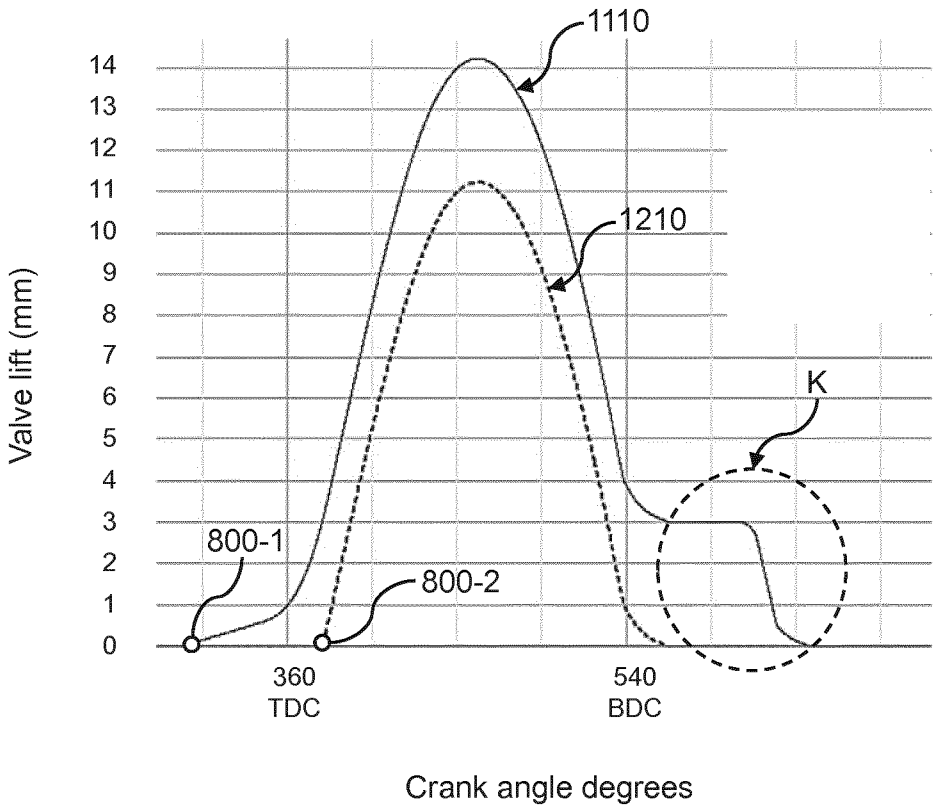

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1210
K
800-1
800-2
Valve lift (mm)
14
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5
4
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2
1
0
360
TDC
540
BDC
Crank angle degrees

FIG. 20

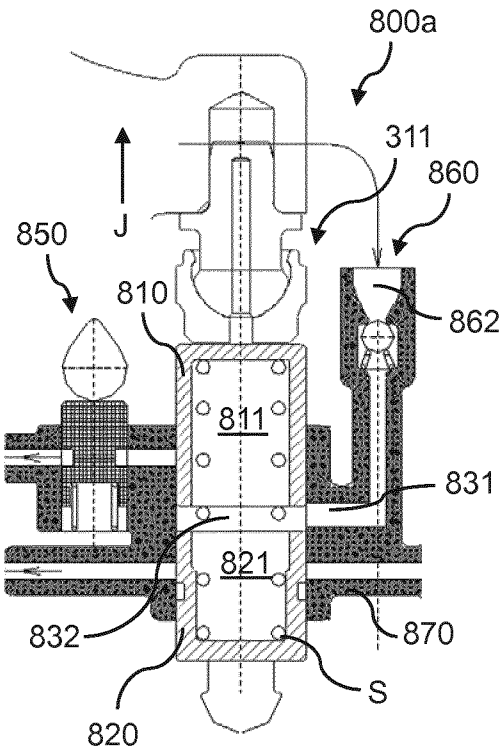


FIG. 21a

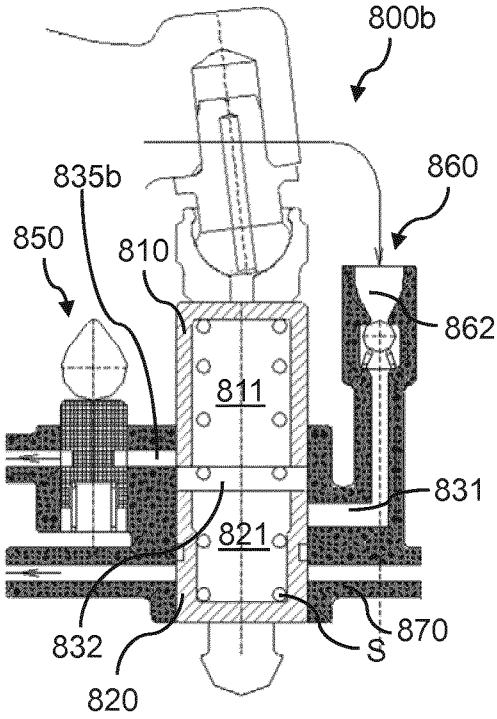


FIG. 21b

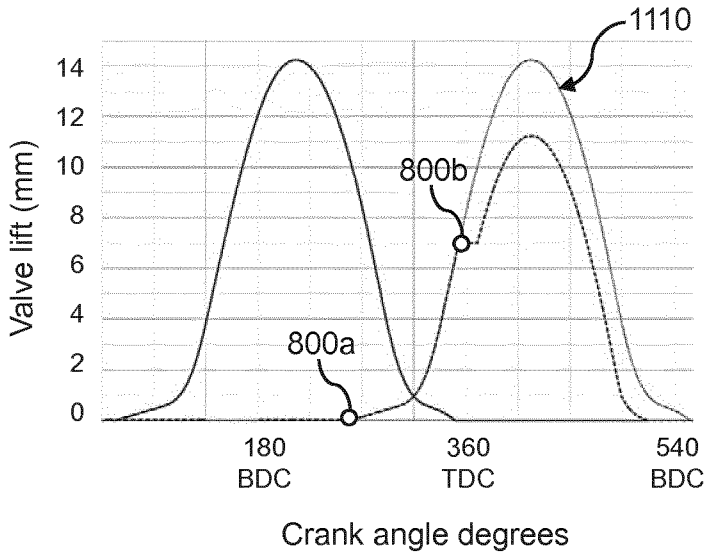


FIG. 22

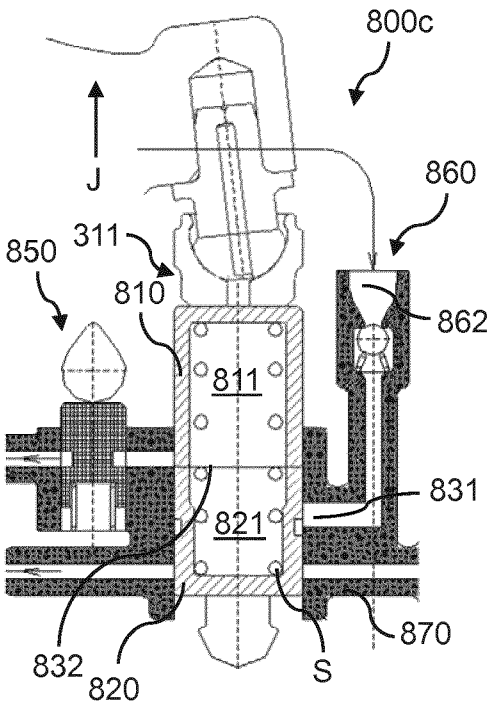


FIG. 21c

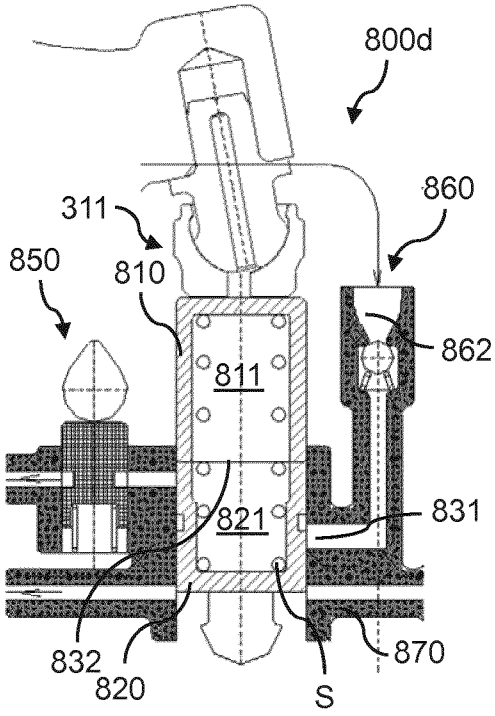


FIG. 21d

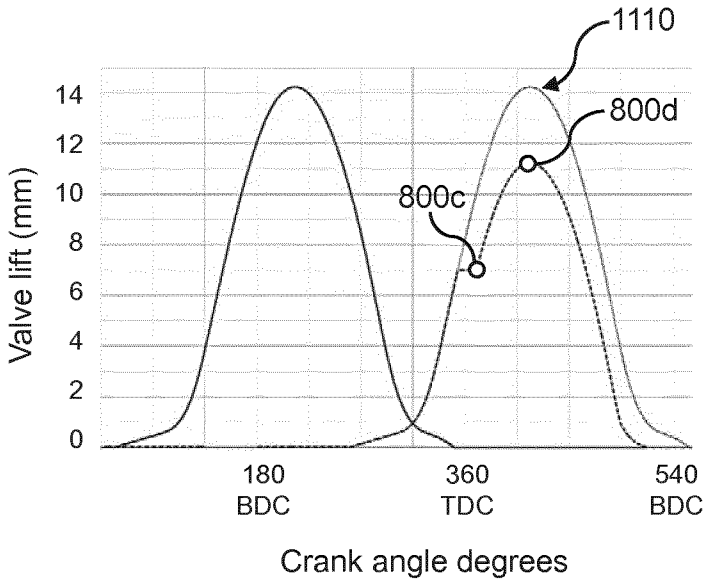


FIG. 23

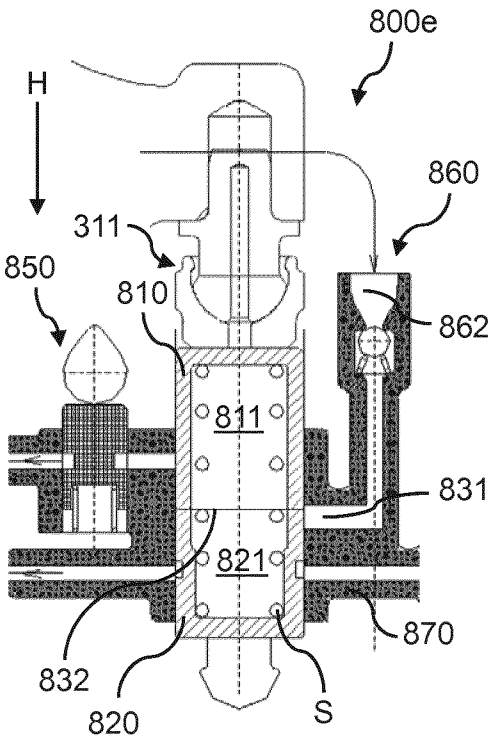


FIG. 21e

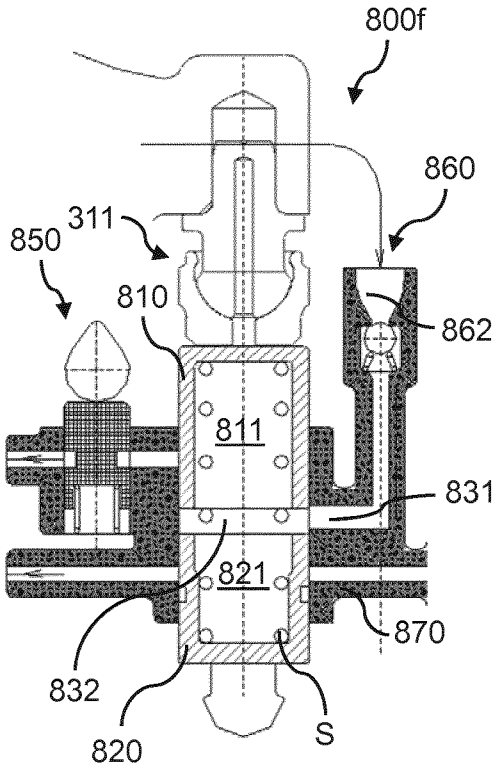


FIG. 21f

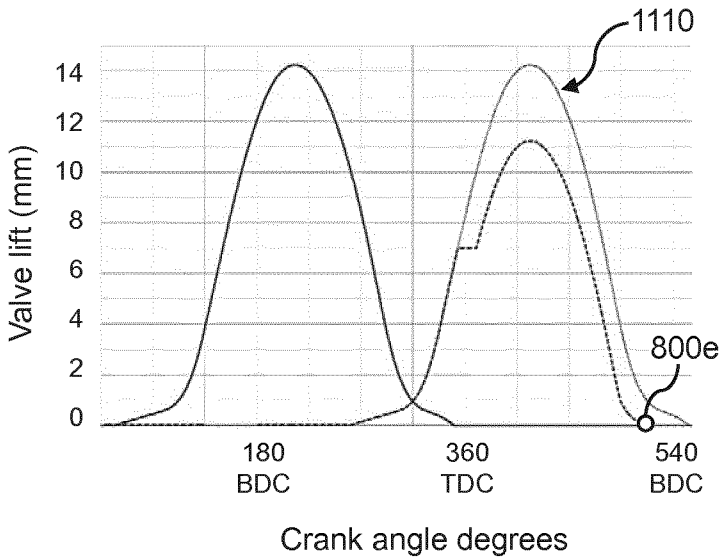


FIG. 24

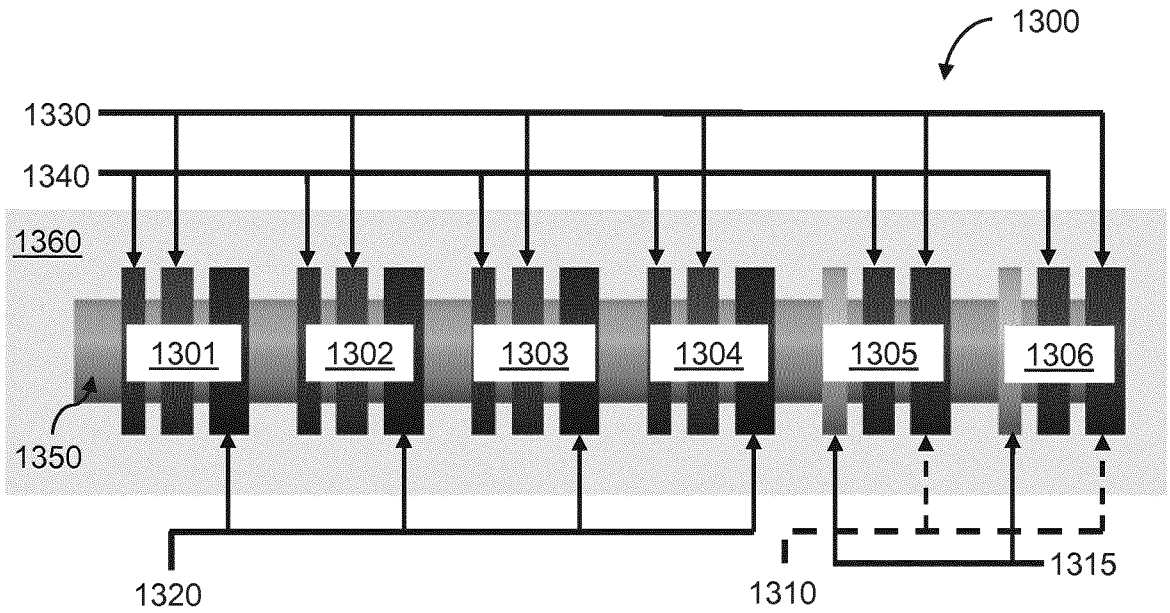

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FIG. 25

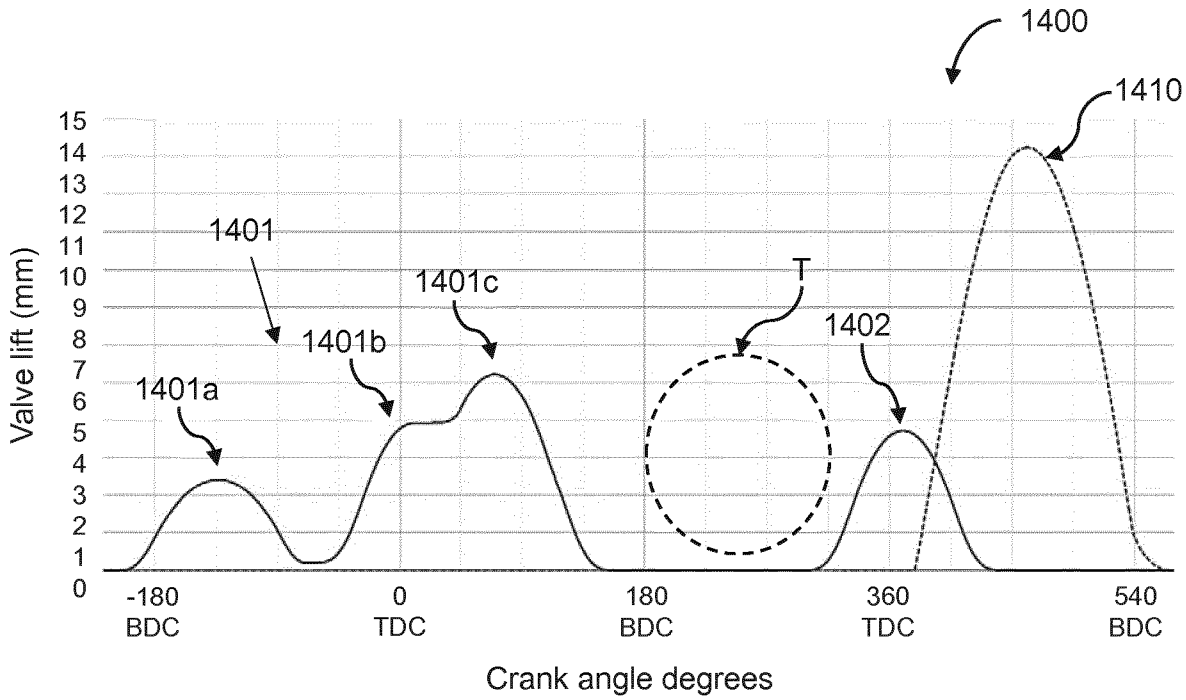

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Valve lift (mm)
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180 BDC
360 TDC
540 BDC
Crank angle degrees

FIG. 26

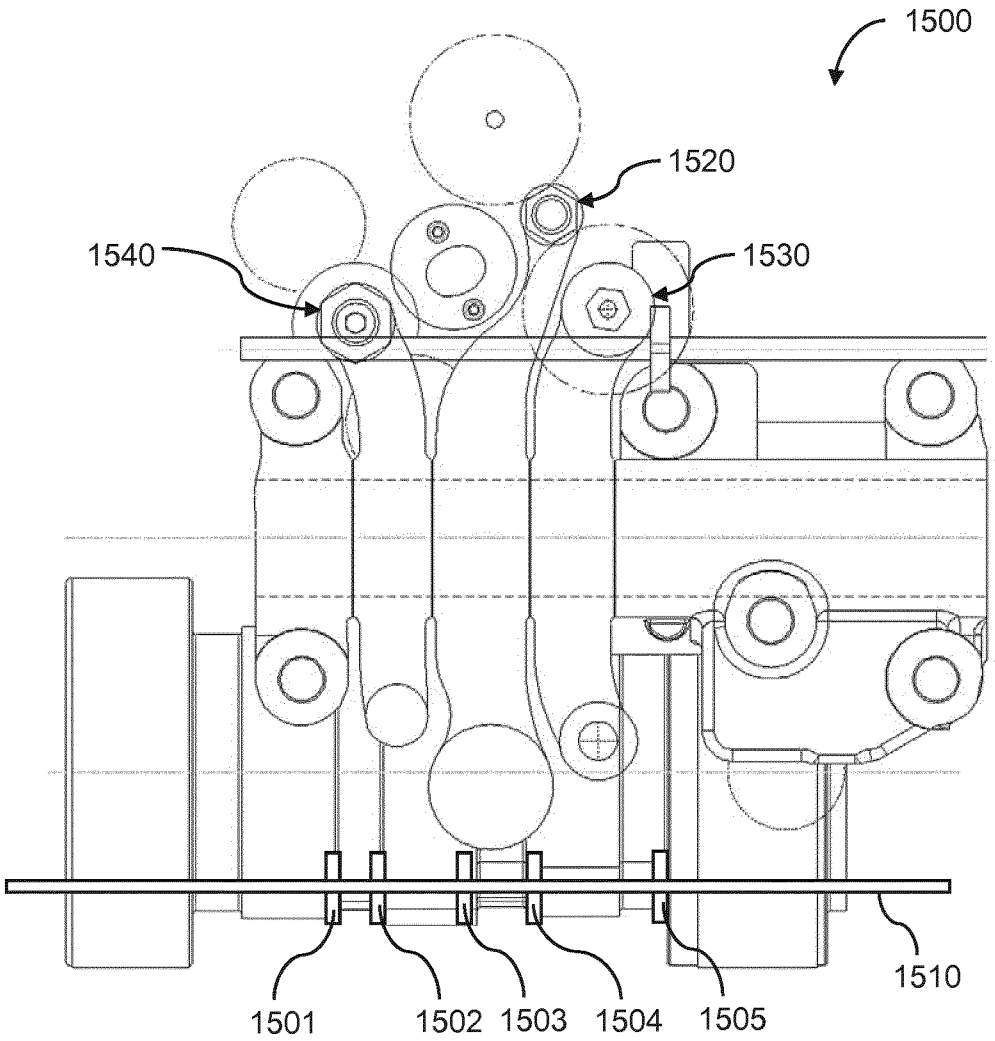


FIG. 27

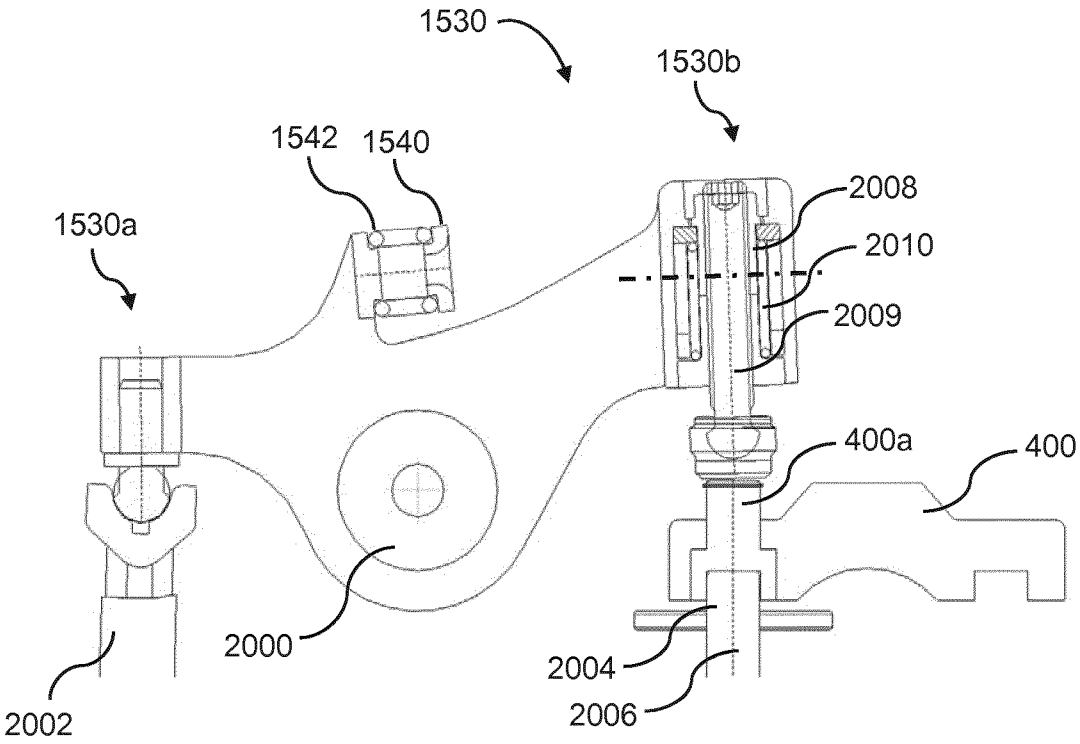

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FIG. 28a

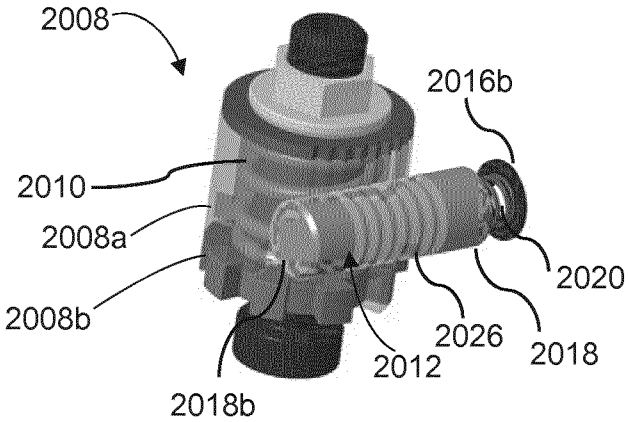


FIG. 28b

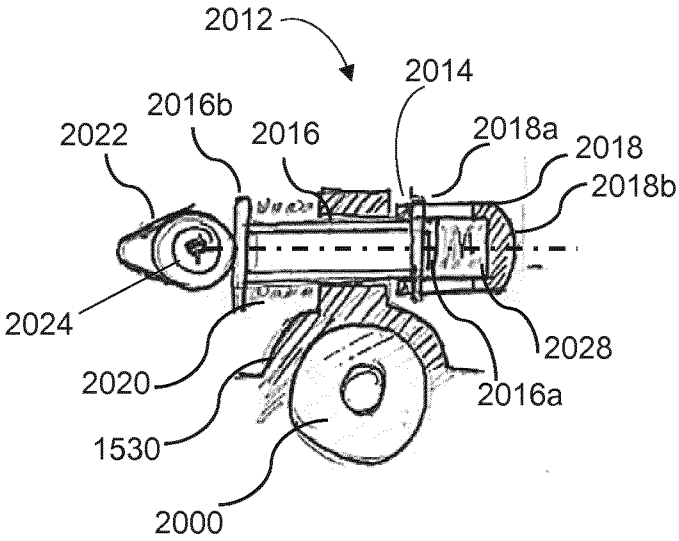


FIG. 28c

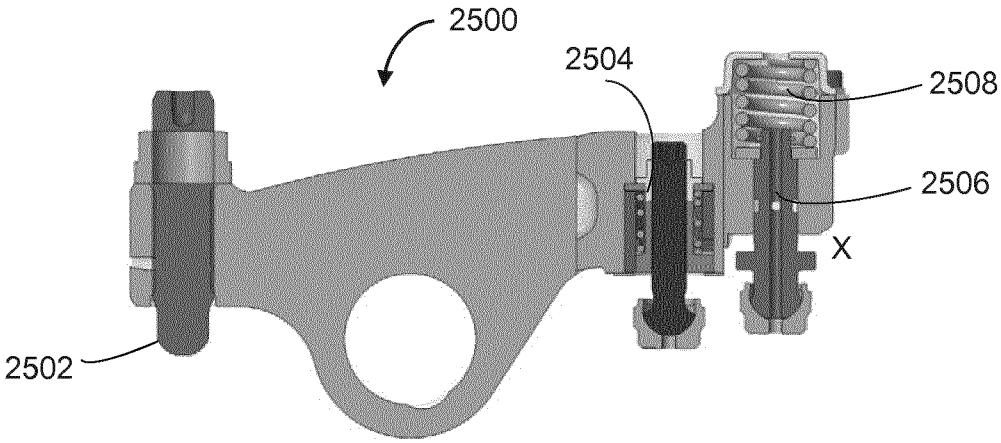


FIG. 29

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/075192

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02D13/04 F01L13/06
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)
F02D 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.
X	EP 1 217 193 A2 (CATERPILLAR INC [US]) 26 June 2002 (2002-06-26) paragraphs [0003] - [0014], [0026]; figures	1-5
X	WO 2013/126873 A1 (JACOBS VEHICLE SYSTEMS INC [US]; ERNEST STEVEN N [US] ET AL.) 29 August 2013 (2013-08-29) paragraph [0036]; figures	1-5
A	CN 107 060 941 A (UNIV DALIAN TECHNOLOGY) 18 August 2017 (2017-08-18) abstract; figures	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 December 2019	12/12/2019

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	Klinger, Thierry

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/075192

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 1217193 A2	26-06-2002	EP 1217193 A2	26-06-2002
		US 6609495 B1	26-08-2003
WO 2013126873 A1	29-08-2013	BR 112014020714 A2	04-07-2017
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		US 2016146072 A1	26-05-2016
		WO 2013126873 A1	29-08-2013
CN 107060941 A	18-08-2017	CN 107060941 A	18-08-2017
		WO 2018223798 A1	13-12-2018