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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
10 February 2011 (10.02.2011)

PCT

(10) International Publication Number
WO 2011/017631 A1

(51) International Patent Classification:
F01L 1/24 (2006.01)

(21) International Application Number:
PCT/US2010/044739

(22) International Filing Date:
6 August 2010 (06.08.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/232,296 7 August 2009 (07.08.2009) US

(71) Applicant *(for all designated States except US)*: **JACOBS VEHICLE SYSTEMS, INC.** [US/US]; 22 East Dudley Road, Bloomfield, CT 06002 (US).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **SCHWOERER, John, A.** [US/US]; 480 Woodland Road, Storrs, CT 06268 (US).

(74) Agent: **YOHANNAN, David, R.**; Kelley Drye & Warren LLP, 3050 K Street, NW, Suite 400, Washington, DC 2007 (US).

(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, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, 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, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, 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, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

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

(54) **Title**: LOST MOTION VARIABLE VALVE ACTUATION SYSTEM WITH VALVE CATCH PISTON

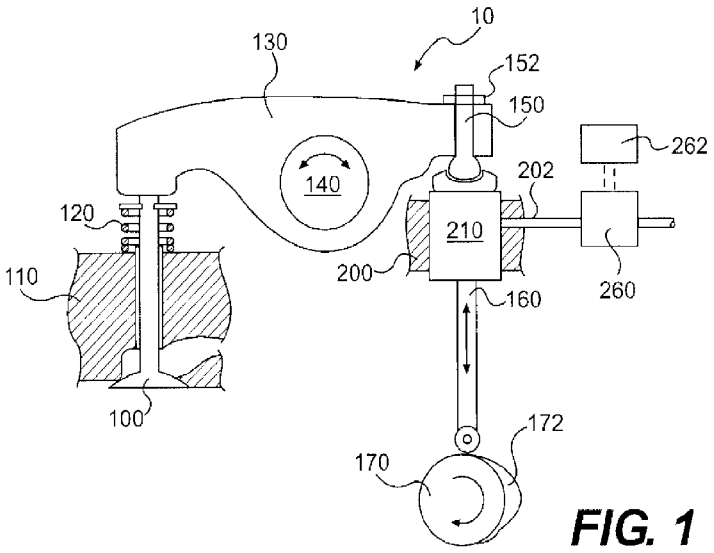

FIG. 1

(57) **Abstract**: Hydraulic lost motion systems and methods for actuating an internal combustion engine valve include a master piston slidably disposed in a housing. One or more master piston fluid passages extend from a bore provided in the master piston and register with a fluid passage extending through the housing. A slave piston is slidably disposed in a lower portion of the master piston bore and a valve catch piston is slidably disposed in an upper portion of the master piston bore. The valve catch piston may have a hollow interior, a lower end orifice extending from the hollow interior through a lower end of the valve catch piston, one or more side passages extending through a side portion of the valve catch piston, and one or more seating passages extending through the valve catch piston wall.

WO 2011/017631 A1

LOST MOTION VARIABLE VALVE ACTUATION SYSTEM WITH VALVE CATCH PISTON

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application relates to, and claims the priority of, United States Provisional Patent Application Serial Number 61/232,296, filed August 7, 2009, which is entitled "Lost Motion Variable Valve Actuation System With Valve Catch Piston."

FIELD OF THE INVENTION

[0002] The present invention relates generally to a system for actuating one or more engine valves in an internal combustion engine. In particular, the invention relates to systems and methods for controlling valve seating velocity.

BACKGROUND OF THE INVENTION

[0003] Internal combustion engines typically use either a mechanical, electrical or hydro-mechanical valve actuation system to actuate the engine valves. These systems may include a combination of camshafts, rocker arms and push rods that are driven by the engine's crankshaft rotation. When a camshaft is used to actuate the engine valves, the timing of the valve actuation may be fixed by the size and location of the lobes on the camshaft.

[0004] Hydraulic lost motion valve actuation systems may be driven with a cam, particularly those used for an internal combustion engine. The hydraulic displacement of an engine valve in such a lost motion system is directly proportional to the displacement provided by the cam during normal operation. In some applications, however, the engine

valve must be closed at an earlier time than that provided by the cam profile. This earlier closing may be carried out by rapidly releasing hydraulic fluid to an accumulator in the lost motion system or to the oil sump. In such instances engine valve seating control may be required because the rate of closing the valve is governed by the hydraulic flow to the accumulator or sump instead of by the fixed cam profile. Engine valve seating control may also be required for applications (e.g. centered lift) in which the engine valve seating occurs on a high velocity region of the cam. Still further, engine valve seating control may be required in common rail Variable Valve Actuation (VVA) designs, in which all seating events occur as a result of the release of hydraulic fluid, possibly to an accumulator.

[0005] An example of known systems and methods for controlling valve seating velocity are disclosed in U.S. Patent No. 6,302,370 to Schwoerer et al., which is hereby incorporated by reference.

[0006] It is an advantage of some, but not necessarily all, embodiments of the present invention to provide methods and systems for seating an engine valve using hydraulically actuated components.

SUMMARY OF THE INVENTION

[0007] Responsive to the need for systems and methods for controlling valve seating velocity, Applicant has developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve comprising: a housing having a housing bore extending through the housing; a housing fluid passage extending through the housing and connecting with the housing bore; a master piston disposed in the housing bore, said master piston having a master piston bore extending into the master piston defined by a

master piston side wall; one or more master piston fluid passages extending through the master piston side wall and connecting with the master piston bore, wherein the one or more master piston fluid passages are adapted to selectively register with the housing fluid passage; a slave piston disposed in a lower portion of the master piston bore; a valve catch piston disposed in an upper portion of the master piston bore, said valve catch piston having a hollow interior defined by a valve catch piston wall, a lower end orifice extending from the hollow interior through a lower end of the valve catch piston wall, one or more side passages extending through a side portion of the valve catch piston wall, and one or more seating passages extending through the valve catch piston wall, wherein the lower end orifice is located so as to be selectively occluded by the slave piston, the one or more side passages are located so that hydraulic fluid communication between the one or more side passages and the one or more master piston fluid passages is selectively occluded by the master piston side wall, and the one or more seating passages are located so as to remain in hydraulic communication with the one or more master piston fluid passages; and a valve catch spring disposed in the valve catch piston hollow interior.

[0008] Applicant has further developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve as set forth above in paragraph 0006 wherein the master piston bore includes an upper master piston bore in which the valve catch piston is disposed and a lower master piston bore in which the slave piston is disposed, and wherein a diameter of the lower piston master piston bore is greater than a diameter of the upper master piston bore.

[0009] Applicant has further developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve as set forth above in paragraph 0006 further comprising a slave piston spring disposed between the housing and the slave piston, said slave piston spring biasing the slave piston away from the housing.

[0010] Applicant has further developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve as set forth above in paragraph 0006 wherein the one or more seating passages extend from the valve catch piston hollow interior through the valve catch piston side wall.

[0011] Applicant has further developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve as set forth above in paragraph 0006 wherein at least one of the one or more seating passages extend from at least one of the one or more side passages through the lower end of the valve catch piston wall.

[0012] Applicant has further developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve as set forth above in paragraph 0006 wherein the one or more master piston fluid passages include a lower master piston fluid passage and an upper master piston fluid passage, and wherein the valve catch piston wall forms a valve catch piston shoulder adapted to occlude hydraulic fluid communication between the one or more side passages and the upper master piston fluid passage.

[0013] Applicant has further developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve as set forth above in paragraph 0011 wherein the one or more master piston fluid passages includes a mid master piston fluid

passage disposed along the master piston side wall between the lower master piston fluid passage and the upper master piston fluid passage.

[0014] Applicant has further developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve as set forth above in paragraph 0006 further comprising a hydraulic fluid control valve in hydraulic communication with the housing fluid passage.

[0015] Applicant has further developed an innovative hydraulic lost motion system for actuating an internal combustion engine valve as set forth above in paragraph 0006 further comprising a hydraulic fluid accumulator in hydraulic communication with the hydraulic fluid valve.

[0016] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only, and are not restrictive of the invention as claimed. The accompanying drawings, which are incorporated herein by reference, and which constitute a part of this specification, illustrate certain embodiments of the invention and, together with the detailed description, serve to explain the principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] In order to assist the understanding of this invention, reference will now be made to the appended drawings, in which like reference numerals refer to like elements. The drawings are exemplary only, and should not be construed as limiting the invention.

[0018] FIG. 1 is a schematic diagram illustrating a first valve actuation system in which an embodiment of the present invention may be used.

[0019] FIG. 2 is a schematic diagram illustrating a second valve actuation system in which an embodiment of the present invention may be used.

[0020] FIG. 3 is a side view in cross-section of a hydraulic lost motion system in accordance with a first embodiment of the present invention.

[0021] FIG. 4 is a side view in cross-section of a hydraulic lost motion system in accordance with a second embodiment of the present invention.

[0022] FIG. 5 is a side view in cross-section of a hydraulic lost motion system in accordance with a third embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0023] Reference will now be made in detail to embodiments of the present invention, examples of which are illustrated in the accompanying drawings. With reference to Fig. 1, a first engine valve actuation system **10** is shown in which the hydraulic lost motion systems **210** constructed in accordance with embodiments of the present invention may be used. The engine valve actuation system **10** may include an engine valve **100**, such as an exhaust, intake or auxiliary engine valve, which is slidably disposed in an engine valve head **110**. The engine valve **100** may be biased by one or more valve springs **120** into a closed position, as shown.

[0024] A rocker arm **130** may be pivotally mounted on a rocker shaft **140** adjacent to the engine valve **100**. The rocker arm **130** may have a first end in contact with the upper end or stem of the engine valve **100** and a second end having an elephant foot assembly **150**. The elephant foot assembly **150** may include a nut **152** which permits the position of the elephant foot assembly to be adjusted relative to the rocker arm **130**. The elephant foot

assembly **150** may permit the rocker arm **130** to receive linear motion from a hydraulic lost motion system **210** used to pivot the rocker arm.

[0025] The hydraulic lost motion system **210** may be slidably disposed in a lost motion system housing **200** and may have an end in contact with the elephant foot assembly **150**. The end of the lost motion system **210** which is opposite from the end in contact with the elephant foot assembly **150** (i.e., the lower end in Fig. 1) may be in contact with a push tube **160**, which in turn may be in contact with a cam **170**. The cam **170** may include one or more lobes or bumps **172** which impart motion to the push tube **160** and lost motion system **210**. The bumps **172** may provide one or more intake valve actuations or one or more exhaust valve actuations, such as engine braking and exhaust gas recirculation motions, for example.

[0026] The lost motion system **210** may be in hydraulic fluid communication with a hydraulic fluid valve **260**, such as a high-speed trigger valve, via a housing fluid passage **202**. If the hydraulic fluid valve **260** is a high-speed trigger valve, it may be capable of being opened and closed at least once per engine cycle. Hydraulic fluid may be provided to, and released from, the lost motion system **210** under the control of the hydraulic fluid valve **260**. The fluid passage **202** may also be directly or indirectly in hydraulic fluid communication with a hydraulic fluid accumulator **262** in an alternative embodiment of the present invention. The accumulator **262** may be used to rapidly receive hydraulic fluid vented from the lost motion system **210** by the hydraulic fluid valve **260**, as well as to rapidly refill the lost motion system **210** with hydraulic fluid under the control of the hydraulic fluid valve **260**.

[0027] With reference to Fig. 2, a second engine valve actuation system **12** is shown in which a hydraulic lost motion system **210** in accordance with an embodiment of the present invention may be used. The engine valve actuation system **12** may include an engine valve **100**, such as an exhaust, intake or auxiliary engine valve, slidably disposed in an engine valve head **110**. The engine valve **100** may be biased by one or more valve springs **120** into a closed position, as shown.

[0028] A lost motion system **210** may be slidably disposed in a lost motion system housing **200** adjacent to and in contact with the upper end or stem of the engine valve **100**. The lost motion system **210** may have an end (i.e., the upper end in Fig. 2) in contact with an elephant foot assembly **150**. The elephant foot assembly **150** may be adjustably mounted in the first end of a rocker arm **130** and may be locked into position by a nut **152**.

[0029] The rocker arm **130** may be pivotally mounted on a rocker shaft **140** adjacent to the lost motion system **210** so as to be able to impart linear motion to the lost motion system **210**. The rocker arm **130** may have a cam roller **132** mounted on a second end of the rocker arm and in contact with a cam **170**. The cam **170** may include one or more lobes or bumps **172** which impart motion to the rocker arm **130** and lost motion system **210**. The bumps **172** may provide one or more intake valve actuations or one or more exhaust valve actuations, such as engine braking and exhaust gas recirculation motions, for example.

[0030] The lost motion system **210** may be in hydraulic fluid communication with a hydraulic fluid valve **260**, such as a high-speed trigger valve, via a housing fluid passage **202**. If the hydraulic fluid valve **260** is a high-speed trigger valve, it may be capable of

being opened and closed at least once per engine cycle. Hydraulic fluid may be provided to, and released from, the lost motion system **210** under the control of the hydraulic fluid valve **260**. The housing fluid passage **202** may also be directly or indirectly in hydraulic fluid communication with a hydraulic fluid accumulator **262** in an alternative embodiment of the present invention. The accumulator **262** may be used to rapidly receive hydraulic fluid vented from the lost motion system **210** by the hydraulic fluid valve **260**, as well as to rapidly refill the lost motion system **210** with hydraulic fluid under the control of the hydraulic fluid valve **260**.

[0031] With reference to Figs. 1 and 2, it is appreciated that variations to the systems **10** and **12** may be made without departing from the intended scope of the invention. For example, in an alternative embodiment of the invention, the rocker arm **130** or the lost motion system **210** may contact the engine valve(s) **100** through a valve bridge (not shown) or other intervening valve train element. Further, the cam **170** may act directly on the lost motion system **210** instead of through an intervening push tube **160** and/or rocker arm **130** with respect to Fig. 1, and the cam **170** may act on the rocker arm **130** through a push tube with respect to Fig. 2.

[0032] Reference will now be made to a first embodiment of the lost motion system **210**, shown in Fig. 3, which may be used with the valve actuation systems **10** and **12**, and variations thereof, illustrated in Figs. 1 and 2. With reference to Fig. 3, the lost motion system **210** may include a master piston **220** which is slidably disposed in a housing bore **206** provided in the lost motion system housing **200**. The master piston **220** is shown to be in contact with the elephant foot assembly **150** at the upper end of the master piston. It is

appreciated that in alternative embodiments, however, the master piston **220** may be in contact with a cam **170** or a rocker arm **130**, directly. The master piston **220** may have a hollow interior comprised of an upper master piston bore **223** and lower master piston bore **221**. The upper master piston bore **223** may have a smaller diameter than the lower master piston bore **221** in a preferred embodiment such that the intersection of the upper master piston bore **223** and the lower master piston bore **221** form a master piston shoulder **228**. The upper master piston bore **223** is also referred to herein as a valve catch plenum and the lower master piston bore **221** is also referred to herein as a tappet plenum.

[0033] The master piston **220** may include one or more master piston fluid passages **222** extending from the tappet plenum **221** to the exterior of the master piston. The master piston fluid passages **222** may be located along the side wall of the master piston **220** so as to register with an annular recess **204** provided in the housing **200** as part of the housing fluid passage **202**. The annular recess **204** may be sized so as to remain in hydraulic communication with the hydraulic fluid valve **260** and the one or more master piston fluid passages **222** throughout the stroke of the master piston **220**.

[0034] A slave piston **230** may be slidably disposed in the tappet plenum **221**. The slave piston **221** may biased by one or more springs **232** into a contact with a push tube **160** (as shown in Fig. 1) or into contact with an engine valve **100** (as shown in Fig. 2). It is appreciated that in alternative embodiments, the slave piston **230** may be biased towards or into contact with a valve bridge (not shown). The slave piston **230** may include a slave piston recess **234** for receiving a valve **100** stem or push tube **160**. The slave piston **230** may have an upper surface adapted to seal a lower end orifice **246** provided in a valve

catch piston **240**.

[0035] With continued reference to Fig. 3, the lost motion system **210** may further include a valve catch piston **240** slidably disposed in the valve catch plenum **223**. The valve catch piston **240** may include a hollow interior **241** in which a valve catch spring **242** may be disposed. The valve catch spring **242** may bias the valve catch piston **240** towards the slave piston **230**. The valve catch piston **240** may include a lower end which is slightly convex shaped and a lower end orifice **246** extending from the hollow interior **241** through the valve catch piston wall. The lower end orifice **246** is preferably sized to be selectively blocked or occluded by the slave piston **230** when the slave piston and the valve catch piston **240** are in contact with each other. The valve catch piston may further include one or more side passages **248** and one or more seating passages **250**. Both the side passages **248** and the seating passages **250** may extend through the side wall of the valve catch piston **240**. The one or more side passages **248** may be located further from the lower end of the valve catch piston lower wall than the one or more seating passages **250**, or in other words, the one or more seating passages **250** may be located lower along the side wall of the valve catch piston **240** than the one or more side passages **248**. The side passages **248** may be located so as to be selectively occluded by the master piston shoulder **228** as a result of the valve catch piston **240** sliding in the valve catch plenum **223**. The one or more seating passages **250** may be located so as to remain unoccluded by the master piston **220** and more specifically by the master piston shoulder **228** as a result of the valve catch piston **240** sliding in the valve catch plenum **223**. The one or more seating passages **250** may be sized so as to permit a selective amount of hydraulic fluid to

vent through them to seat the engine valve **100** after the one or more side passages **248** and the lower end orifice **246** are blocked.

[0036] The lost motion system **210** shown in Fig. 3 may be used to actuate and seat an engine valve, such as shown in Figs. 1 and 2, as follows. With reference to Figs. 1-3, the hydraulic fluid valve **260** may be opened when the cam **170** is on base circle (i.e., when the cam **170** does not have a bump **172** in contact with a valve train element such as the push tube **160** or rocker arm **130**) to fill the system **10** or **12** with hydraulic fluid. As a result of the cam **170** being on base circle, low pressure (e.g., less than 100 psi) hydraulic fluid from a hydraulic fluid supply (not shown) and potentially from an accumulator **262**, may flow from the hydraulic fluid valve **260** into the lost motion system **210**, and more specifically, through the housing fluid passage **202**, the annular recess **204**, and the master piston fluid passage **222**, into the tappet plenum **221**. The hydraulic fluid may fill the valve catch plenum **223** through the one or more seating and side passages **248** and **250** and the lower end orifice **246**. The valve catch spring **242** may cause the valve catch piston **240** to slide downward into the tappet plenum **221**. The slave piston **230** may also slide downward in the tappet plenum **221** as a result of the introduction of hydraulic fluid into the lost motion system **210** by the hydraulic fluid valve **260**.

[0037] Once the hydraulic lost motion system **210** is charged with hydraulic fluid, the hydraulic fluid valve **260** may be closed so that the separation of the master piston **220** from the slave piston **230** is maintain due to the tappet plenum **221** being hydraulically sealed. Thereafter motion imparted from the cam **170** to the lost motion system may be transferred from the master piston **220** to the slave piston **230**, and in turn to the engine

valve **100**. In order to terminate the actuation of the engine valve **100** before the time prescribed by the one or more bumps **172** on the cam **170**, the hydraulic fluid valve **260** may be selectively opened. When the hydraulic fluid valve **260** is opened, hydraulic fluid may escape from the lost motion system **210** past the hydraulic fluid valve **260** to the low pressure fluid supply (not shown) and/or potentially to an accumulator **262**.

[0038] When the hydraulic fluid valve **260** is opened, the engine valve springs **110** may push the engine valve **100** upward which in turn may cause the slave piston **230** to be pushed into the fluid in the tappet plenum **221**. The fluid in the tappet plenum **221** may be displaced and flow out of the lost motion system **210** through the one or more master piston fluid passages **222** and the housing fluid passage **202**. As the fluid vents through the housing fluid passage **202**, the slave piston **230** may slide into the tappet plenum **221** relatively rapidly until it contacts the valve catch piston **240** at which time the slave piston upper surface may occlude the lower end orifice **246**. As fluid continues to vent through the housing fluid passage **202**, the valve catch piston **240** may be pushed upward into the valve catch plenum **223** against the bias force of the valve catch spring **242**. As the valve catch piston **240** is pushed upwards fluid in the valve catch piston plenum **223** must vent through the one or more side passages **248** and the one or more seating passages **250**. The rate at which the engine valve **100**, the slave piston **230**, and the valve piston **240** move upward (i.e., the engine valve seating velocity) may be decreased relative to the initial engine valve seating velocity because the valve catch plenum **223** must vent through the one or more side passages **248** and the one or more seating passages **250** in order for the valve catch piston **240** to move upward. As the valve catch piston continues to move

upward, the engine valve seating velocity may be further reduced as the one or more side passages **248** are occluded by the master piston shoulder **228**. The occlusion of the one or more side passages **248** may prevent fluid from escaping from the valve catch plenum **223** through the side passages, and may force any additional venting of fluid from the valve catch plenum **223** to occur through the one or more seating passages **250** which remain unblocked or un-occluded by the master piston shoulder **228** throughout the stroke of the valve catch piston **240**. The seating passages **250** may be selectively sized to permit venting of the correct amount of fluid from the valve catch plenum **223** that will result in an acceptable valve seating velocity for the engine valve **100** across a range of expected hydraulic fluid operating conditions. Thereafter, the process may be repeated by refilling the valve catch plenum **223** and the tappet plenum **221** with hydraulic fluid.

[0039] With reference to Fig. 4, the lost motion system **210** shown therein may include the same elements as the lost motion system shown in Fig. 3, with the following exceptions. The valve catch piston **240** in the lost motion system illustrated in Fig. 4 may include a lower end which is relatively flat through which a lower end orifice **246** extends from the hollow interior **241** through the lower end of the valve catch piston **240** wall. The lower end orifice **246** is preferably sized to be selectively blocked or occluded by the slave piston **230** when the slave piston and the valve catch piston **240** are in contact with each other. The valve catch piston **240** may further include one or more side passages **248** and one or more seating passages **250**. The one or more side passages **248** may extend through the side wall of the valve catch piston **240**. The one or more seating passages **250** may extend from the one or more side passages **248** through the lower end of the valve

catch piston wall. The one or more side passages **248** may be located so as to be selectively occluded by the master piston shoulder **228** as a result of the valve catch piston **240** sliding in the valve catch plenum **223**. The one or more seating passages **250** may be located so as to remain unoccluded by the master piston **220**, and more specifically by the master piston shoulder **228**, as a result of the valve catch piston **240** sliding in the valve catch plenum **223**. The one or more seating passages **250** may be sized so as to permit a selective amount of hydraulic fluid to vent through them to seat the engine valve **100** after the one or more side passages **248** and the lower end orifice **246** are blocked or occluded.

[0040] The lost motion system **210** shown in Fig. 4 may be used to actuate and seat an engine valve, such as shown in Figs. 1 and 2, in the same manner as the lost motion system shown in Fig. 3, which is described above.

[0041] With reference to Fig. 5, the lost motion system **210** shown therein may include the same elements as the lost motion systems shown in Figs. 3 and 4, with the following exceptions. With reference to Fig. 5, the lost motion system **210** may include a master piston **220** having a hollow interior comprised of an upper master piston upper bore **223** and lower master piston bore **221** which have a uniform diameter and thus do not form a master piston shoulder.

[0042] The master piston **220** may include one or more upper fluid passages **224**, one or more mid fluid passages **225** and one or more lower fluid passages **226** extending from the tappet and valve catch plenums **221** and **223** to the exterior of the master piston. The upper, mid and lower fluid passages **224**, **225** and **226** may be located along the side wall of the master piston **220** so as to register with an annular recess **204** provided in the

housing **200** as part of the housing fluid passage **202**. The annular recess **204** may be sized so as to remain in hydraulic communication with the hydraulic fluid valve **260** and the one or more upper, mid and lower fluid passages **224**, **225** and **226** throughout the stroke of the master piston **220**. At a minimum, the lower fluid passage **226** should be located so as to remain in hydraulic fluid communication with the annular recess **204**.

[0043] The valve catch piston **240** in the lost motion system illustrated in Fig. 5 may include a lower end which is relatively flat through which a lower end orifice **246** extends from the hollow interior **241** through the lower end of the valve catch piston **240** wall. The lower end orifice **246** is preferably sized to be selectively blocked or occluded by the slave piston **230** when the slave piston and the valve catch piston **240** are in contact with each other. The valve catch piston **240** may have a stepped shape which forms a valve catch piston shoulder **252** and a valve catch piston recess **253**. The valve catch piston **240** may include one or more side passages **248** located above the valve catch piston shoulder **252** and one or more seating passages **250** located along the valve catch piston recess **253**. The one or more side passages **248** and the one or more seating passages may extend through the side wall of the valve catch piston **240**. The one or more side passages **248** may be located so as to be selectively occluded by the valve catch piston shoulder **252** as a result of the valve catch piston **240** sliding in the valve catch plenum **223**, first past the mid fluid passage **225** and thereafter past the upper fluid passage **224**. The one or more seating passages **250** may be located so as to remain un-occluded by the master piston **220** as a result of the valve catch piston **240** sliding in the valve catch plenum **223**. The one or more seating passages **250** may be sized so as to permit a selective amount of

hydraulic fluid to vent through them to seat the engine valve **100** after the one or more side passages **248** and the lower end orifice **246** are blocked or occluded.

[0044] The lost motion system **210** shown in Fig. 5 may be used to actuate and seat an engine valve, such as shown in Figs. 1 and 2, in the same manner as the lost motion systems shown in Figs. 3 and 4 with the following exceptions. The valve catch piston **240** shown in Fig. 5 may throttle the flow of hydraulic fluid out of the valve catch plenum **223** by progressively occluding or blocking first the one or more mid fluid passages **225** and thereafter the one or more upper fluid passages **224**. This progressive throttling of the venting of fluid from the valve catch plenum **223** may be used to progressively decrease the engine valve seating velocity over the course of the upward stroke of the valve catch piston **240**.

[0045] It will be apparent to those skilled in the art that variations and modifications of the present invention can be made without departing from the scope or spirit of the invention. Thus, it is intended that the present invention cover all such modifications and variations of the invention, provided they come within the scope of the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A hydraulic lost motion system for actuating an internal combustion engine valve comprising:

a housing having a housing bore extending through the housing;

a housing fluid passage extending through the housing and connecting with the housing bore;

a master piston disposed in the housing bore, said master piston having a master piston bore extending into the master piston defined by a master piston side wall;

one or more master piston fluid passages extending through the master piston side wall and connecting with the master piston bore, wherein the one or more master piston fluid passages are adapted to selectively register with the housing fluid passage;

a slave piston disposed in a lower portion of the master piston bore;

a valve catch piston disposed in an upper portion of the master piston bore, said valve catch piston having a hollow interior defined by a valve catch piston wall, a lower end orifice extending from the hollow interior through a lower end of the valve catch piston wall, one or more side passages extending through a side portion of the valve catch piston wall, and one or more seating passages extending through the valve catch piston wall, wherein the lower end orifice is located so as to be selectively occluded by the slave piston, the one or more side passages are located so that hydraulic fluid communication between the one or more side passages and the one or more master piston fluid passages is selectively occluded by the master piston side wall, and the one or more seating passages are located so as to remain in hydraulic communication with the one or more master piston fluid

passages; and

a valve catch spring disposed in the valve catch piston hollow interior.

2. The system of Claim 1, wherein the master piston bore includes an upper master piston bore in which the valve catch piston is disposed and a lower master piston bore in which the slave piston is disposed, and wherein a diameter of the lower piston master piston bore is greater than a diameter of the upper master piston bore.

3. The system of Claim 2, further comprising a slave piston spring disposed between the housing and the slave piston, said slave piston spring biasing the slave piston away from the housing.

4. The system of Claim 2, wherein the one or more seating passages extend from the valve catch piston hollow interior through the valve catch piston side wall.

5. The system of Claim 2, wherein at least one of the one or more seating passages extend from at least one of the one or more side passages through the lower end of the valve catch piston wall.

6. The system of Claim 1, wherein the one or more master piston fluid passages include a lower master piston fluid passage and an upper master piston fluid passage, and

wherein the valve catch piston wall forms a valve catch piston shoulder adapted to

occlude hydraulic fluid communication between the one or more side passages and the upper master piston fluid passage.

7. The system of Claim 6, wherein the one or more master piston fluid passages includes a mid master piston fluid passage disposed along the master piston side wall between the lower master piston fluid passage and the upper master piston fluid passage.

8. The system of Claim 1 further comprising a hydraulic fluid control valve in hydraulic communication with the housing fluid passage.

9. The system of Claim 8 further comprising a hydraulic fluid accumulator in hydraulic communication with the hydraulic fluid valve.

10. A valve catch piston for a hydraulic lost motion system, said valve catch piston comprising:

a hollow interior defined by a valve catch piston wall;

a lower end orifice extending from the hollow interior through a lower end of the valve catch piston wall;

one or more side passages extending through a side portion of the valve catch piston wall; and

one or more seating passages extending through the valve catch piston wall,

wherein the one or more side passages are located further away from the lower end

of the valve catch piston wall than the one or more side passages.

11. A hydraulic lost motion system for actuating an internal combustion engine valve comprising:

a housing having a housing bore extending through the housing;

a housing fluid passage extending through the housing and connecting with the housing bore;

a master piston disposed in the housing bore, said master piston having a master piston bore extending into the master piston defined by a master piston side wall;

one or more master piston fluid passages extending through the master piston side wall and connecting with the master piston bore, wherein the one or more master piston fluid passages are adapted to selectively register with the housing fluid passage;

a slave piston disposed in a lower portion of the master piston bore;

a valve catch piston disposed in an upper portion of the master piston bore, said valve catch piston having a hollow interior defined by a valve catch piston wall, a lower end orifice extending from the hollow interior through a lower end of the valve catch piston wall, one or more side passages extending through a side portion of the valve catch piston wall, and one or more seating passages extending through the valve catch piston wall, wherein the one or more side passages are located further from the lower end of the valve catch piston wall than the one or more seating passages; and

a valve catch spring disposed in the valve catch piston hollow interior.

12. The system of Claim 11, wherein the master piston bore includes an upper master piston bore in which the valve catch piston is disposed and a lower master piston bore in which the slave piston is disposed, and wherein a diameter of the lower piston master piston bore is greater than a diameter of the upper master piston bore.

13. The system of Claim 12, further comprising a slave piston spring disposed between the housing and the slave piston, said slave piston spring biasing the slave piston away from the housing.

14. The system of Claim 12, wherein the one or more seating passages extend from the valve catch piston hollow interior through the valve catch piston side wall.

15. The system of Claim 12, wherein at least one of the one or more seating passages extend from at least one of the one or more side passages through the lower end of the valve catch piston wall.

16. The system of Claim 11, wherein the one or more master piston fluid passages include a lower master piston fluid passage and an upper master piston fluid passage, and

wherein the valve catch piston wall forms a valve catch piston shoulder adapted to occlude hydraulic fluid communication between the one or more side passages and the upper master piston fluid passage.

17. The system of Claim 16, wherein the one or more master piston fluid passages includes a mid master piston fluid passage disposed along the master piston side wall between the lower master piston fluid passage and the upper master piston fluid passage.

18. The system of Claim 11 further comprising a hydraulic fluid control valve in hydraulic communication with the housing fluid passage.

19. The system of Claim 18 further comprising a hydraulic fluid accumulator in hydraulic communication with the hydraulic fluid valve.

WO 2011/017631 PCT/US2010/044739

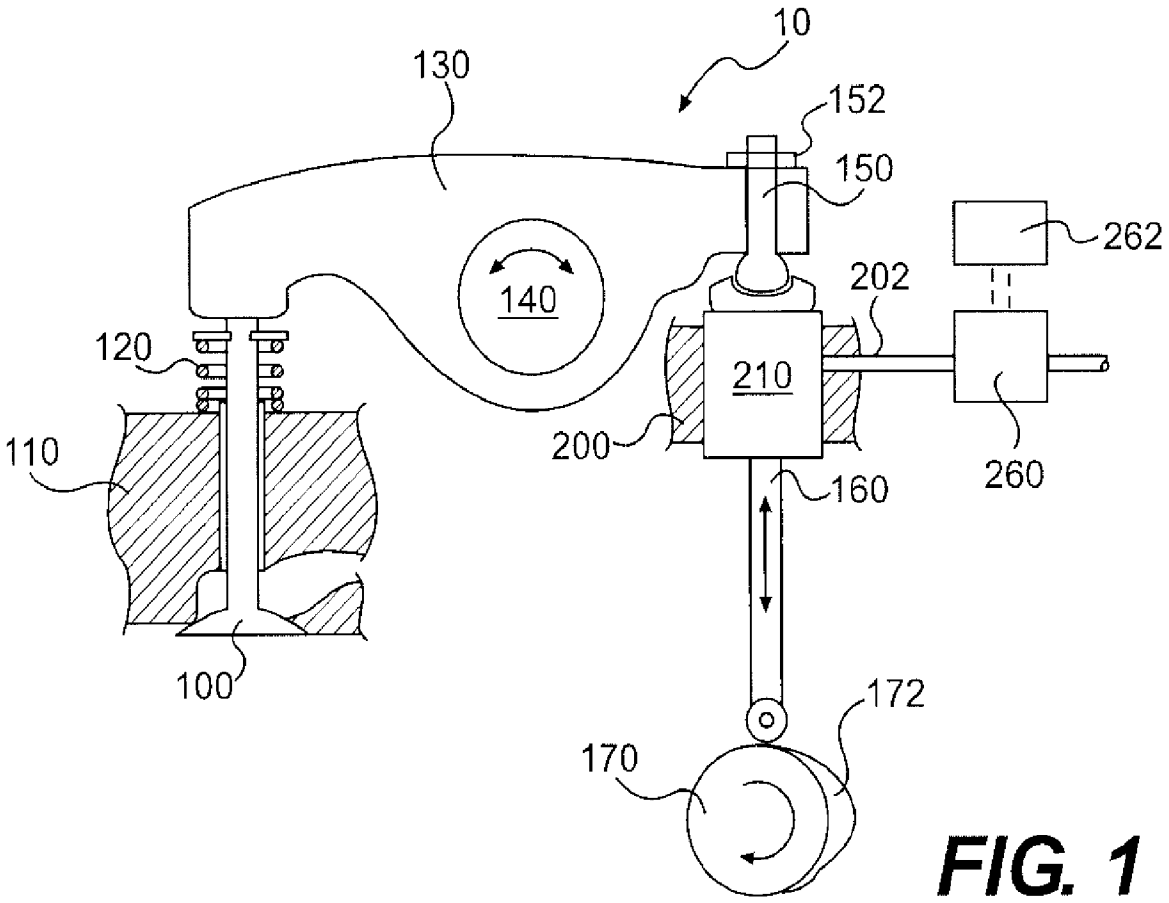

FIG. 1

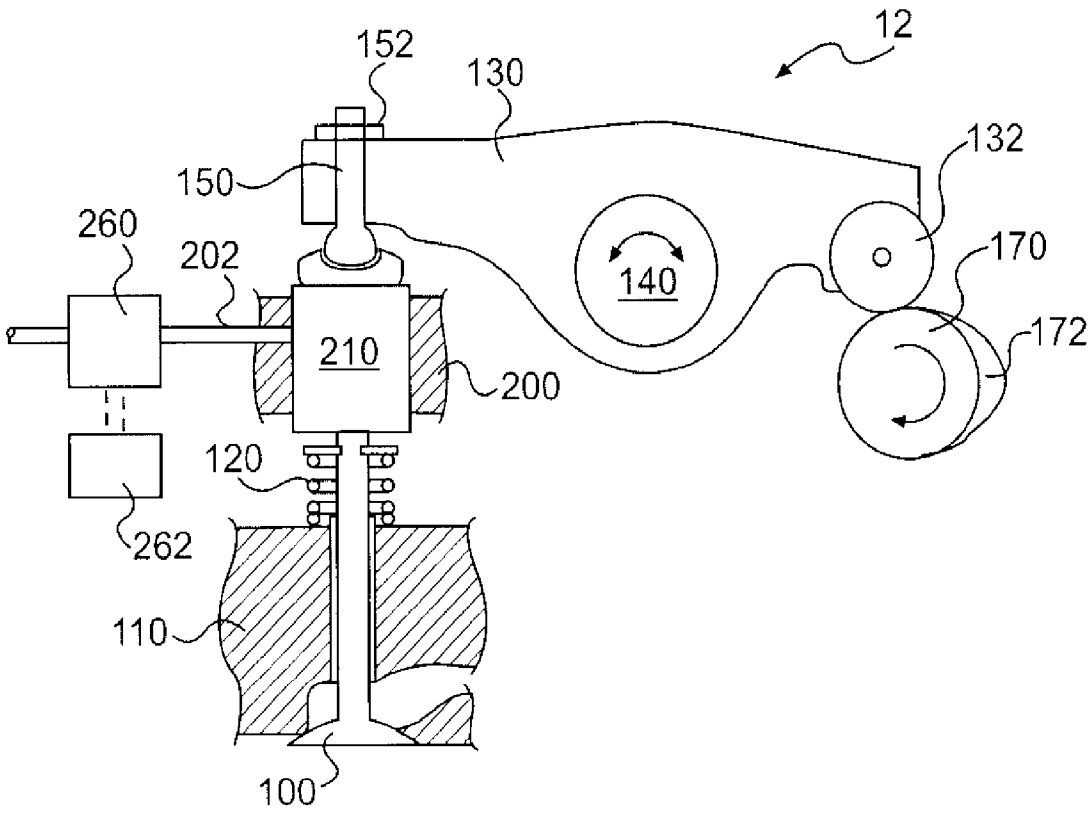

FIG. 2

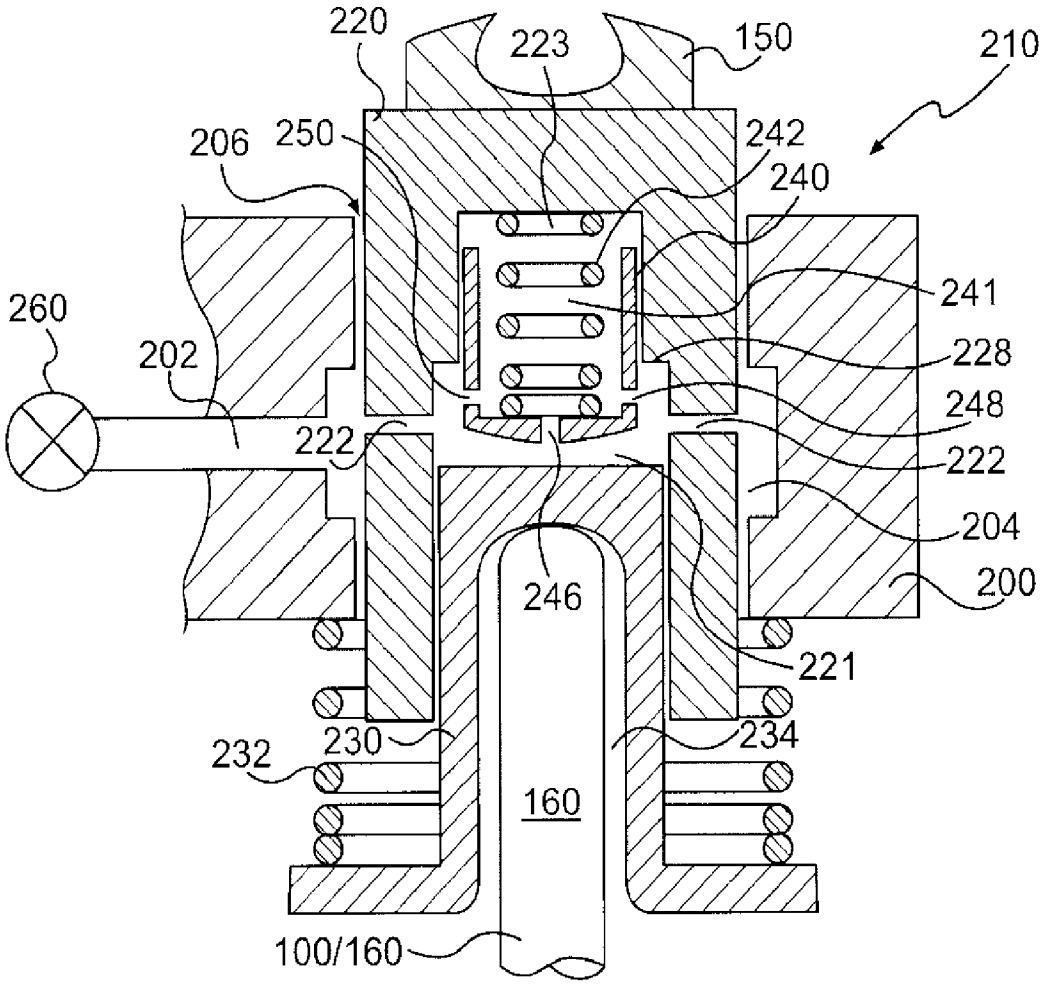
220
223
150
210
206
250
242
240
260
241
202
228
248
222
222
204
246
200
221
232
230
234
160
100/160

FIG. 3

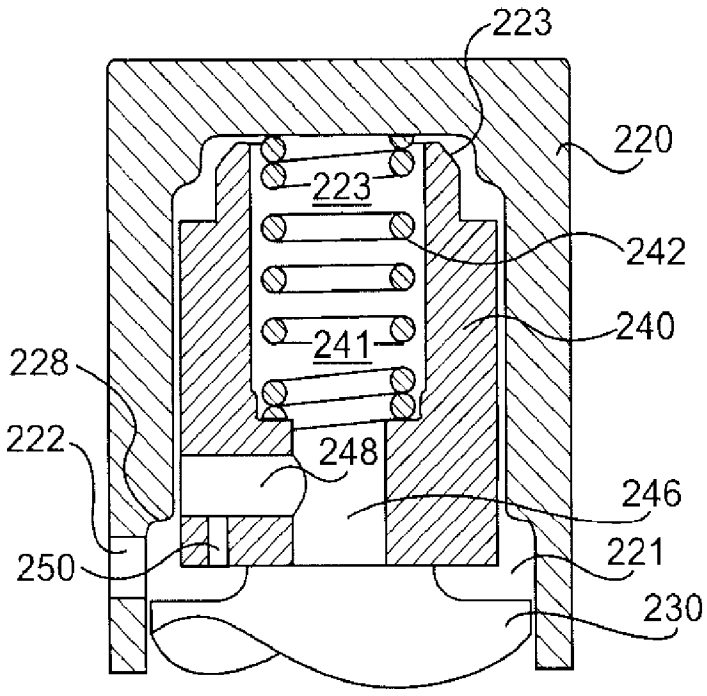
223
220
223
242
240
241
228
222
248
246
250
221
230

FIG. 4

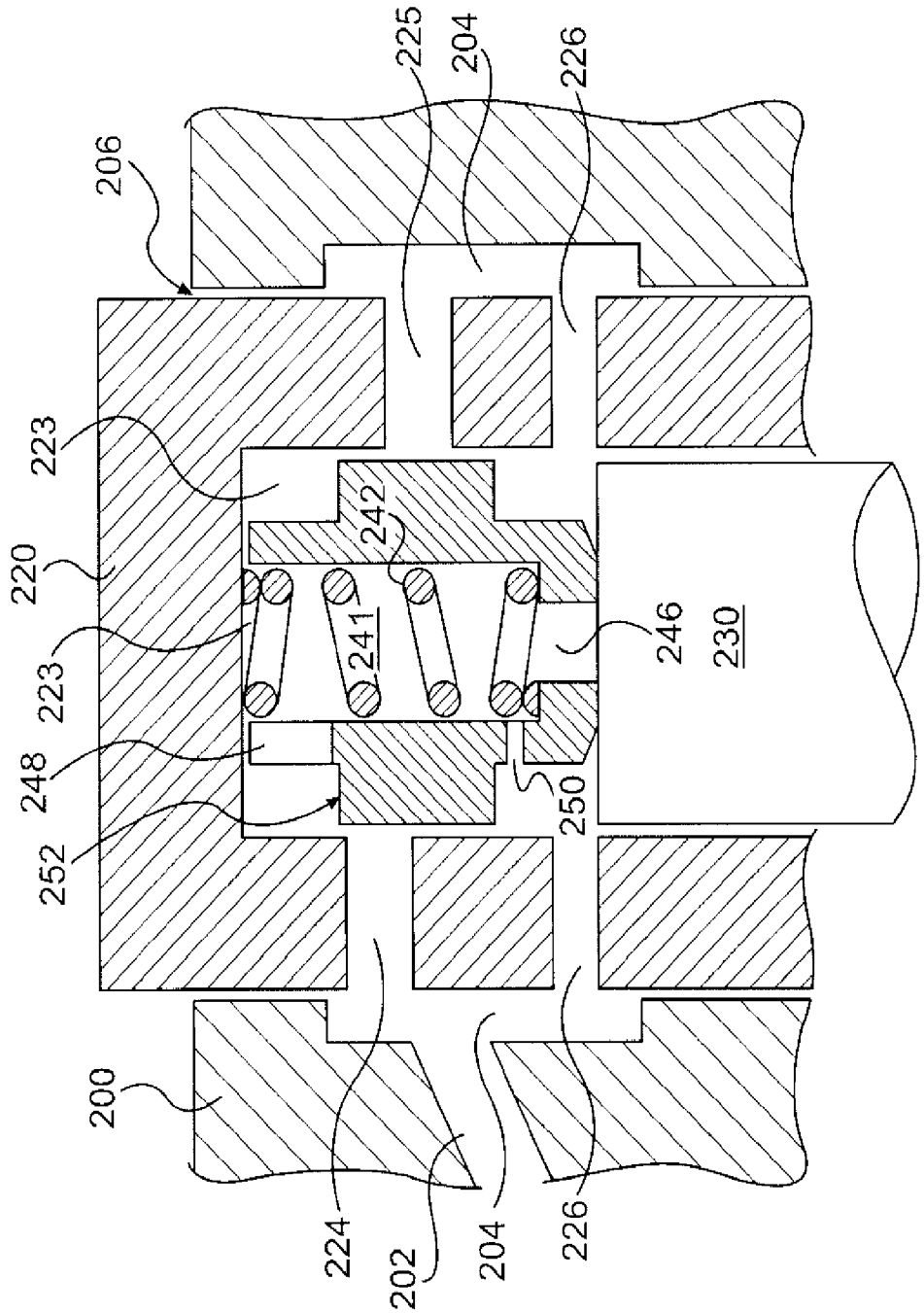
225
204
226
206
223
220
242
241
223
246
230
248
250
252
200
224
202
204
226

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/044739

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F01L 1/24 (2010.01)
USPC - 123/90.16
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)
IPC(8) - F01L 1/14, 1/16, 1/24 (2010.01)
USPC - 123/47AA, 90.1, 90.12, 90.15, 90.16, 90.55; 251/63.4, 63.6

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)
PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	GB 564,507 A (EATON MFG. CO.) 02 October 1944 (02.10.1944) entire document	1-9, 11-19
Y	US 4,796,573 A (WAKEMAN et al) 10 January 1989 (10.01.1989) entire document	1-19
Y	GB 1,063,499 A (ROBERT BOSCH GMBH) 30 March 1967 (30.03.1967) entire document	1-19
Y	US 2005/0132986 A1 (CHANG) 23 June 2005 (23.06.2005) entire document	7, 17

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 September 2010	30 SEP 2010
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)