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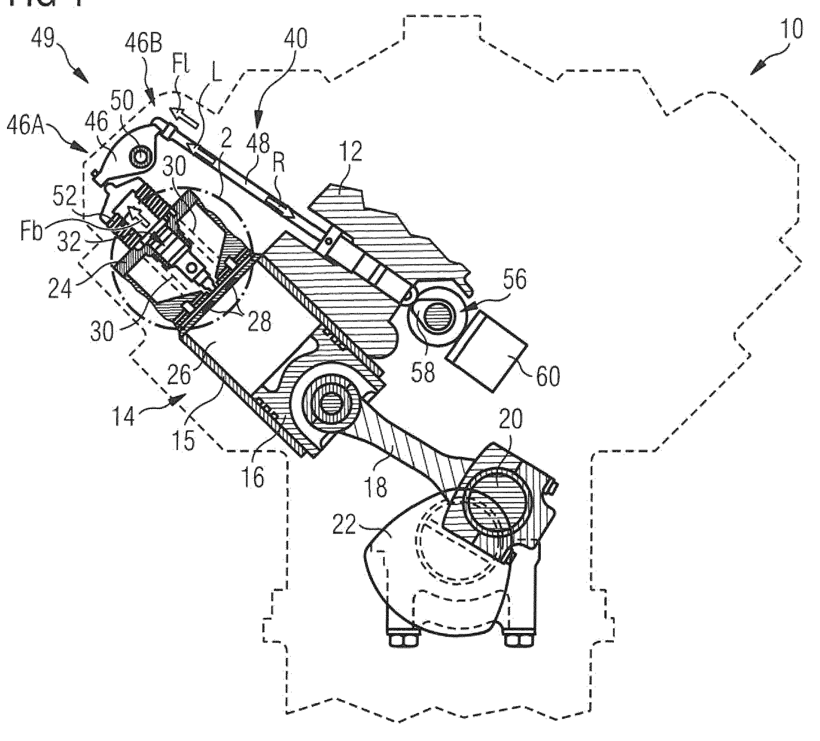
(54) **CAMSHAFT TORQUE BASED VALVE TIMING ADJUSTMENT**

(57) In an aspect of the present disclosure, a method for deriving a control parameter for a variable valve actuation assembly (40, 140, 240) using a valve spring driven /cam decoupled valve closing process comprises the steps of providing a camshaft driven valve actuation assembly (40, 140, 240) that is configured to provide a cam driven valve opening procedure and the valve spring driven / cam decoupled valve closing process, rotating the camshaft through a sequence of the cam driven valve opening process and the valve spring driven / cam decoupled valve closing process, during the rotation, measuring a torque to be provided for the rotation, and deriving the control parameter from the detected torque.

FIG 1



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Description

[0001] The present disclosure generally relates to valve operation systems for an internal combustion engine and, more particularly, to controlling valve closing in variable valve timing configurations.

Background

[0002] In internal combustion engines, rocker arm configurations are used to operate intake and exhaust valves. In particular several valves are provided, for example, within a cylinder head, each being operated by a respective rocker arm configuration. For example, an intake and an exhaust rocker arm configuration may control the opening and closing of two intake valves and two exhaust valves, respectively.

[0003] A common camshaft driving the rocker arm configurations may, for example, ensure respective timings. In some embodiments, intake and exhaust valves are driven by specifically shaped cams, thereby enforcing a specific valve timing that provides, for example, a Miller timing with a respective valve overlap.

[0004] There is a variety of valve timing adjustment mechanism known that allow, for example, an operation mode specific adjustment of valve timings.

[0005] The present disclosure is directed, at least in part, to improving or overcoming one or more aspects of prior systems.

Summary of the Disclosure

[0006] In an aspect of the present disclosure, a method for deriving a control parameter for a variable valve actuation assembly using a valve spring driven /cam decoupled valve closing process comprises the steps of providing a camshaft driven valve actuation assembly that is configured to provide a cam driven valve opening procedure and the valve spring driven / cam decoupled valve closing process, rotating the camshaft through a sequence of the cam driven valve opening process and the valve spring driven / cam decoupled valve closing process, during the rotation, measuring a torque to be provided for the rotation, and deriving the control parameter from the detected torque.

[0007] In another aspect, a camshaft driven valve actuation assembly configured to provide a cam driven valve opening process and a valve spring driven / cam decoupled valve closing process comprises a camshaft system with a camshaft, a cam lobe, and a push rod, an engine valve comprising a valve stem with a valve head, and a valve spring, a rocker system comprising a rocker arm with a valve actuation section and a push rod section, and a rocker shaft unit, a cam decoupling unit configured for decoupling the valve stem from being driven by the cam lobe, and a torque measurement unit for measuring a torque applied to the camshaft for operating the engine valve.

[0008] In another aspect, an internal combustion engine comprises a plurality of cylinder units with a plurality of engine valves, a plurality of camshaft driven valve actuation assemblies as summarized above for respectively operating one or more engine valves of the for the plurality of engine valves of the plurality of cylinder units, and a control unit configured to control the cam decoupling units to adapt the closing process of the engine valves for in particular synchronizing the valve closing times of the plurality of engine valves.

[0009] Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

Brief Description of the Drawings

[0010] The accompanying drawings, which are incorporated herein and constitute a part of the specification, illustrate exemplary embodiments of the disclosure and, together with the description, serve to explain the principles of the disclosure. In the drawings:

- Fig. 1 shows a schematic cross-sectional view of an internal combustion engine with a camshaft driven rocker arm based valve drive;
- Fig. 2 shows a schematic illustration of exemplary valve lift curves;
- Figs. 3 and 4 show exemplary torque distribution for a single camshaft rotation for an internal combustion engine with four and eight cylinder units;
- Fig. 5 shows a first example for a camshaft decoupled valve actuation; and
- Fig. 6 shows a second example for a camshaft decoupled valve actuation.

Detailed Description

[0011] The following is a detailed description of exemplary embodiments of the present disclosure. The exemplary embodiment described herein and illustrated in the drawings are intended to teach the principles of the present disclosure, enabling those of ordinary skill in the art to implement and use the present disclosure in many different environments and for many different applications. Therefore, the exemplary embodiments are not intended to be, and should not be considered as, a limiting description of the scope of patent protection. Rather, the scope of patent protection shall be defined by the appended claims.

[0012] The present disclosure may be based in part on the realization that in certain VVT (variable valve drive) concepts, valves are decoupled from the cam contour when closing the valve. Exemplarily, it is referred to the European patent applications entitled "VARIABLE VALVE TIMING BY ROCKER ARM ROTATION AXIS DISPLACEMENT" and "PUSH ROD BASED VARIABLE VALVE TIMING SYSTEMS" filed by the applicant on the same day as the present application, which are incorporated herein by reference. In those VVT concepts (being based on a decoupling from the camshaft system), it is the valve spring of the respective valve that defines the closing process because the closing of the valve is no longer controlled by the contour of the cam, but by the biasing force provided by the valve spring.

[0013] The present disclosure may further be based in part on the realization that valve spring forces for different valve springs of engine valves operated by such a VVT concept may differ. Accordingly, the distribution of differing valve spring forces may have an influence on the closing of the inlet valves employed within an engine as closing times of those valves differ, e.g. they are not sufficiently synchronized. It was further realized that a measurement of the valve spring forces may be used to take proper action. For example, one may "uncouple" - e.g. by feedback control - the valves at different times from the cam contour so that they are closing essentially at the same time (with respect to the OT of every station) and the respective areas (flows) during the valve activation stays essentially the same.

[0014] In the above mentioned application "PUSH ROD BASED VARIABLE VALVE TIMING SYSTEMS", this may be achieved by displacing an intermediate guidance element for guiding a tilt connection of a split push rod, to thereby vary the crank angle (time) at which a tilt angle of 180° of the split push rod is reached and the decoupling is initiated.

[0015] Similarly, in the above mentioned application "VARIABLE VALVE TIMING BY ROCKER ARM ROTATION AXIS DISPLACEMENT", this may be achieved by displacing the position of the second cylinder (and thus the control opening) with respect to the rocket arm pivot movement, to thereby vary the crank angle (time) at which the displacement movement of the rocker arm mount and, thus, the decoupling is initiated.

[0016] Referring to the drawings, exemplary embodiments are disclosed that illustrate the control concepts, which use the measurement of the torque provided via the camshaft to operate engine valves. The control concepts can be employed, for example, in internal combustion engines such as the one schematically illustrated in of Fig. 1. Specifically, the control concepts are configured to provide adjustable valve timings as illustrated in Fig. 2. Figs. 3 and 4 illustrate the torque as it is present at the camshaft for multi-cylinder engines, e.g. four and eight cylinder engines. Referring also to the above identified European patent applications, exemplary cam decoupled valve closing mechanisms are disclosed in connection with Figs. 5 and 6.

[0017] In Fig. 1 an exemplary embodiment of an internal combustion engine 10 is illustrated that uses a camshaft driven rocker arm system for valve actuation exemplarily for a pre-combustion chamber ignited gaseous fuel operation. As will be also discuss in combination with Figs. 5 and 6, the valve actuation of engine 10 provides for a cam decoupled operation mode in which the rocker arm system is decoupled from the camshaft system such that in particular the closing process of the valve depends essentially on the valve spring configuration.

[0018] Engine 10 may include features not shown, such as a fuel system, an air system, a cooling system, drivetrain components, etc. For the purpose of the present disclosure, engine 10 is exemplarily considered to be a four-stroke gaseous fuel internal combustion engine. One skilled in the art will recognize, however, that engine 10 may be any type of engine (two-stroke, turbine, gas, diesel, natural gas, propane, etc.). Furthermore, engine 10 may be of any size, with any number of cylinders, and in any configuration ("V", in-line, radial, etc.). Engine 10 may be used to power any machine or other device, including locomotive applications, on-highway trucks or vehicles, off-highway trucks or machines, earth moving equipment, generators, aerospace applications, marine applications, pumps, stationary equipment, or other engine powered applications.

[0019] Engine 10 includes an engine block 12 having a plurality of cylinder units 14 (one of which is illustrated in Fig. 1). A piston 16 is slidably disposed within cylinder unit 14 (e.g. within a cylinder liner 15) to reciprocate between a top-dead-center position (TDC) and a bottom-dead-center position (BDC). A connecting rod 18 connects piston 16 to an eccentric crankpin 20 of a crankshaft 22 such that reciprocating motion of piston 16 results in rotation of crankshaft 22.

[0020] Engine 10 includes further a cylinder head 24 (enlarged in Fig. 1) that is mounted to engine block 12 and covers cylinder unit 14, thereby delimiting a main combustion chamber 26. Cylinder head 24 provides intake and exhaust openings 28 to charge main combustion chamber 26, for example, with a charge air-gaseous fuel mixture and to release exhaust gases out of main combustion chamber 26 into an exhaust gas system (not shown). Engine valves 30 are configured to selectively open and close respective openings 28, e.g. by a valve stem with a valve head (see also Fig. 3). Each cylinder unit 14 may include multiple intake and exhaust openings 28 and respectively multiple intake and exhaust valves 30.

[0021] Engine 10 further may include an assembly configured to initiate a combustion event. As exemplarily shown in Fig. 1, engine 10 may include a pre-combustion chamber assembly 32 (also referred to as pre-combustion chamber ignition device), which is positioned within cylinder head 24, for example between valves 30. Pre-combustion chamber assembly 32 may be configured in a variety of ways. In general, it is an assembly configured to initiate a combustion event within a pre-combustion chamber, and to direct the combustion into main combustion chamber 26.

[0022] The internal combustion engine 10 may include a series of valve actuation assemblies 40 (one of which is exemplarily illustrated in Fig. 1). Multiple valve actuation assemblies 40 may be provided per cylinder unit 14, e.g. for different valve types (e.g. intake or exhaust valve). For example, valve actuation assembly 40 is used to open and close the intake valve(s) and another, for example similar, valve actuation assembly 40 may be provided to open and close the exhaust valve(s).

[0023] Valve actuation assembly 40 includes a rocker arm 46. Rocker arm 46 is pivotally mounted on cylinder head 24 by a rocker shaft unit 49 via a rocker shaft 50 and interacts with engine valves 30 at a valve actuation section 46A and with a push rod 48 at a push rod section 46B.

[0024] Push rod section 46B engages with one end of push rod 48, the other end engages (as exemplarily shown in Fig. 1) with a cam lobe 58 disposed on camshaft 56 to drive (lift) push rod 48 when camshaft 56 is rotated. Camshaft 56 may be driven by crankshaft 22. Camshaft 56 may be connected with crankshaft 22 in any manner readily apparent to one skilled in the art where rotation of crankshaft 22 may result in a rotation of camshaft 56. For example, camshaft 56 may be connected to crankshaft 22 through a gear train (not shown).

[0025] The displacement of push rod 48 corresponds to an actuation movement of push rod 48 that may result in a conventional activation of valve 30, which is herein referred to as a blocked operation mode (e.g. a conventional valve operation via push rod/camshaft configurations having a blocked, i.e. spatially fixed position of rocker shaft 50 with respect to cylinder unit 14). Specifically, the actuation movement includes a lifting movement L and a return movement R. Lifting movement L is caused by the shape of cam lobe 58 and results in a lifting force Fl onto rocker arm 46 redirected via the pivot mounting onto the valve stem. Thus, due to engagement with valve actuation section 46A, the valve stem of valve 30 moves from a closed position C to an open position O during lifting movement L (see also Figs. 5 and 6).

[0026] Assuming non-fixed connections between rocker arm 46 and push rod 48 as well as rocker arm 46 and the valve stem, return movement R will not automatically result in a closing of the valve (e.g. return of the valve stem into closed position C of valve 30). Therefore, valve actuation assembly 40 may include - as a biasing force providing unit - for example, a valve spring 52 that provides a biasing force Fb onto the valve stem of valve 30 towards the closed position and, thus, generally counteracts against lifting force Fl. Once the maximum extension of cam lobe 58 is reached, biasing force Fb enforces closing of the valve as well as return movement R. In consequence, opening 28 is closed via the respective valve head.

[0027] Thus, the blocked operation results in an oscillation of rocker arm 46 about its pivot point in dependence of the shape of cam lobe 58 and in respective opening duration of valve(s) 30.

[0028] One skilled in the art may recognize that camshaft 56 may include additional cam lobes to engage with additional push rods in order to actuate additional engine valves.

[0029] Fig. 2 shows a plot of exemplary valve lift curves. In particular, Fig. 2 shows an exhaust valve curve 72 extending from about 140° to 370° crankshaft angle during an exhaust stroke, and an intake valve curve 74 extending from about 350° to 490° crankshaft angle during an intake stroke. The schematically indicated valve lift curves 72 and 74 illustrate as an example an extreme Miller valve timing that reaches a high efficiency and may be applied, for example, at full load. In Fig. 2, the operation at full load is indicated by reference F. However, those valve lift curves 72 and 74 may not be optimal to start engine 10 or to operate the same at part load as then a relative small load acceleration may be present.

[0030] As an example for part load operation (start of the engine), a filling optimized lift curve 76 for an intake valve is schematically included in Fig. 2. Filling optimized lift curve 76 extends, for example, from 350° to 570° crankshaft angle and allows to increase the filling of main combustion chamber with charge air. Filling optimized operation may reduce the risk of knocking at part load such that a larger power output and improved load acceleration may be achieved. In particular when operated as a separate power supply, this aspect may affect the combustion tuning.

[0031] As an exemplary configuration, for part load operation, the cam based operation mode (indicated with reference B in Fig. 2) is implemented by a specific shape (broad shape) of cam lobe 58. Accordingly, during start of the engine (part load operation) blocked operation mode is activated.

[0032] Cam decoupled configurations as explained exemplarily in connection with Figs. 5 and 6 may allow adaptation of valve timings, for example, for the full load operation of engine 10 in Miller-like manner. In general, the decoupling shifts the closing process away from a dependence of the cam shape to a dependence from delay force Fd provided by valve spring 52. Moreover, the decoupling modifies the torque acting onto camshaft 56. In particular, the starting point and end point of the decoupling may result in some kind of discontinuity of the torque development during the rotation of camshaft 56. In some embodiments, the decoupling may not be complete such that a remaining force will act onto camshaft 56, thereby smoothing the discontinuity. Moreover, in the presence of multiple cylinders with different and identical combustion cycles, the torque may further be subject to an averaging process due to the respective mechanical boundary conditions.

[0033] Referring again to Fig. 1, a torque measurement device 60 is provided to measure a torque acting onto camshaft 56 during the rotation of camshaft 56. Torque measurement device 60 may comprise, for example, one or more strain gauges. Strain gauges may be positioned at the gear train and/or next to one or all of cylinder units 14. During the rotation of camshaft 56, a torque distribution as shown in Figs. 3 and 4 may be detected that provides information on the torque needed to turn the camshaft. The torque varies during the stages of the actuation movement of the various valves (lifting movement L and return movement R). Moreover as mentioned above, the torque depends on various mechanical components such as valve springs 52, joints between the various parts, the temperature of the engine (affecting the lubrication) etc.

[0034] In some embodiments, torque measurement device 60 is provided for measuring the torque development of each valve actuation assembly without and/or without combustion and setting the control parameters, which are available for the respective decoupled operation mode, to ensure desired valve closing processes. Thereby the closing processes of a single cylinder unit as well as the synchronization of the closing processes for multiple cylinder units may be achieved.

[0035] In some embodiments, torque measurement device 60 is provided for continuously measuring the torque development during the operation of the engine. This may allow a continuous control of the closing process of each valve actuation assembly individually as well as with respect to the other valve actuation assemblies.

[0036] To further illustrate the torque measurement, torque measurement device 60 may screwed to engine block 12 once during the installation of engine 10 or it maybe continuously installed. Torque measurement device 60 may turn the gear system of camshaft 56 one round and store a measured torque characteristics as illustrated in Figs. 3 and 4 exemplarily for four and eight cylinder engines during a cam based actuation. In dependency of the cam contour, the kinematics of the valve drive, and the firing order, valve spring force of every valve system may essentially be derived from the torque characteristics.

[0037] To simplify the situation of the torque characteristics, a negative torque may be generated at the closing side of the cam, e.g. the camshaft would continue rotating due to the biasing force, if a negative torque is not supplied. for multiple cylinder units, positive and negative sections may be generated due to the differing cam lobe interactions on the opening and closing sides. It is further noted that asymmetries in the torque characteristic mac be caused by engine configurations such as V-engine configurations as well as cam shapes and spring types.

[0038] In general, the torque based information can be used to initially adapt the valve actuation configuration and/or it can be used as an input parameter for the control of variable valve timing systems. It may further allow taking actions against any initial and/or during operation (due to wear out, clearance changes, or relaxations) growing deviations of the various valve spring forces.

[0039] As mentioned above, torque measurement device 60 may be removed in case of an initial setting or the measurement of the torque characteristics may be integrated in the camshaft system (for example using strain gauges), so the measurement can take place during operation and/or at every start of the engine.

[0040] In general, the herein disclosed torque based approach may include the whole chain of tolerances in its measurement, which may play a role for the valve actuation such as engine block, camshaft, valve drive etc. Furthermore, the torque characteristics may allow determining in which position the middle of the cam contour is located to even consider the same for the setting of the cam based valve actuation mode.

[0041] With reference to Fig. 5, a schematic illustration of a valve actuation assembly 140 is exemplarily illustrated. Valve actuation assembly 140 includes inter alia components such as a camshaft 156, a cam lobe 158, and a push rod 148 (camshaft system exemplarily shown in Fig. 1).

[0042] Moreover, valve actuation assembly 140 includes a rocker system 144 including a rocker arm 146 and a rocker shaft unit 149 comprising a rocker shaft 150 configured to provide an axis 150A of rotation for the pivot movement of rocker arm 146.

[0043] Rocker shaft unit 149 further comprises a rocker shaft mount 149A for mounting rocker shaft 150. Specifically, rocker shaft mount 149A is configured to provides the possibility to displace rocker shaft 150 to vary the position of rocker shaft 150 such as the relative position with respect to valve opening 128 and the distance to the cover face of main combustion chamber 126 (the latter illustrated by arrow 149' in Fig. 5).

[0044] Rocker shaft unit 149 may further comprise a guide structure 149B for guiding rocker shaft mount 149A during such a displacement movement.

[0045] In some embodiments, rocker shaft unit 149 may further comprise a force generating unit 149C, which is configured to provide a biasing force Fb' counter-acting a hydraulic force Fh as discussed below in more detail. Biasing force Fb' may in particular be set for enforcing the displacement and allowing a return movement and/or may be provided to supplement biasing force Fb generated by valve spring 152.

[0046] In addition, valve actuation assembly 140 comprises a hydraulic valve timing adjustment system 160. Hydraulic valve timing adjustment system 160 of Fig. 3 is based on a hydraulic system that is configured, for example, to be fluidly connected to an engine oil system (not shown) and/or to be part of a separate hydraulic system. Hydraulic valve timing adjustment system 160 is configured to control the position of rocker shaft mount 149A, and in particular decouple the pivot movement of rocker arm 146 from the camshaft system. Specifically, hydraulic valve timing adjustment system 160 is configured to position rocker shaft 150 in a spatially fixed position with respect to valve opening 128. A respective blocked state B' is shown in Fig. 5. Moreover, hydraulic valve timing adjustment system 160 is configured to bring rocker shaft mount 149A in a flexible state. The flexible state enables a displacement movement of rocker shaft 150.

[0047] For example, hydraulic valve timing adjustment system 160 comprises a first piston 164A housed in a first cylinder 164B, for example a hollow-cylinder. First piston 164A is mounted to rocker shaft unit 149, for example to rocker shaft mount 149A on top of rocker shaft

50 as shown in Fig. 5.

[0048] Hydraulic valve timing adjustment system 160 may further comprise a second piston 166A housed in a second cylinder 166B. Second piston 166A is connected to rocker arm 46 at an eccentric position with respect to axis 150A of rotation. For example, second piston 166A may be connected to valve actuation section 146A (as shown in Fig. 3) such as via a mechanical connection 165. In some embodiments, it may be connected to push rod section 146B of rocker arm 146. The eccentric connection may provide a cyclical synchronization of hydraulic valve timing adjustment system 160 with camshaft 156.

[0049] Moreover, second cylinder 166B comprises at least one control opening 167 to release hydraulic fluid from second cylinder 166B. Specifically, control opening 167 is position within the sidewalls of second cylinder 166B to be covered (as shown in Fig. 3) and uncovered (not shown) by second piston 166A during the pivoting movement of rocker arm 146. In addition, second cylinder 166B may itself be mounted in a displaceable manner to allow for adjusting the relative position between control opening 167 and second piston 166A during the pivoting movement of rocker arm 146 and the corresponding movement of piston 166A. A respective displacement unit 167A is indicated in Fig. 5.

[0050] Moreover, hydraulic valve timing adjustment system 160 comprises an exemplary hydraulic connection 168 hydraulically connecting first cylinder 164B and second cylinder 166B (specifically the inner volume thereof), thereby providing a hydraulic interaction between rocker shaft unit 149 and the eccentric position at rocker arm 146.

[0051] In some embodiments, hydraulic valve timing adjustment system 160 may further comprise a supply valve 168A for a fluid connection with a hydraulic fluid source 169 (e.g. the engine oil system). In addition or alternatively, a block valve 168B may be provided to be able to block or even to control the release of hydraulic fluid through control opening 167. This may allow, in particular, adjusting the dynamics of the closing of valve 130. A further block valve 168B' may be provided between first cylinder 164B and second cylinder 166B.

[0052] As further shown in Fig. 5, supply valve 168A and block valves 168B, 168B' may be connected to a control unit 180 via control lines 182. In general, control unit 180 may be configured to activate the valves to take on/ to support taking on blocked state B or flexible state. Similarly, displacement unit 167A may be controlled by control unit 180.

[0053] In general, the geometries of the joints between rocker arm 146 and valve stem 170 as well as rocker arm 146 and push rod 148 may be configured such that, during the respective mechanical movements of rocker arm 146 and push rod 148, the respective joint parts will be brought into or maintained in proper position with respect to each other to properly interact as a joint when needed.

[0054] In general, any tilt of push rod 148 may vary in dependence of the displacement. To ensure that push rod 148 and rocker arm 146 will be properly positioned during the operation, one of the joint parts may comprise, for example, a cone-like shape. Alternative configurations may be apparent to the skilled person to maintain proper joint alignment despite temporal introduction of a gap between the joint parts.

[0055] With respect to the in connection with Fig. 5 described decoupled closing process (referred to as the flexible state), control unit 180 may use the information gained from the torque measurement to set control parameters such as the displacement of second cylinder 166B by displacement unit 167A and/or the operation of block valves 168A, 168B, 168B' and/or the pressure within the hydraulic system and/or any supporting delay force Fd' by force generating unit 149C. Further control parameters will be apparent to the skilled person in view of specific implementations.

[0056] In connection with Fig. 6, a further approach to use the information derived from the torque measurement in a valve actuation assembly 240 is exemplarily illustrated. Valve actuation assembly 240 includes inter alia a camshaft system 260 with components such as a camshaft 256, a cam lobe 258, and a split push rod 248. Moreover, valve actuation assembly 240 includes a rocker arm 246 mounted to a rocker shaft 250, and a biasing force generating unit. The biasing force generating unit is configured, for example, as a valve spring 252, which provides a biasing force Fb redirected via the pivotably mounted rocker arm counter-acting lifting force Fl, in particular for enforcing return movement R.

[0057] As shown in Fig. 6, valve actuation assembly a40 is based on split push rod 248 that interacts with cam lobe 258 to be displaced, during a rotation of camshaft 256, in accordance with a desired actuation movement during cam driven operation mode. Split push rod 248 comprises a rocker part 248A and a cam part 248B connected at tilt connection 249. Tilt connection 249 is configured to allow for an adjustment of tilt angle α between rocker part 248A and cam part 248B.

[0058] Moreover, upper end 248A" of rocker part 248A interacts with push rod section 246B, in particular for providing lifting force Fl onto rocker arm 246 during lifting movement L. Similarly, a lower end 248B' of cam part 248B interacts with cam lobe 258, in particular via a roller follower configuration 284 described below.

[0059] Camshaft system 260 comprises further an intermediate guidance element 262 providing an intermediate guidance face 263 for guiding tilt connection 249. In general, the contour of intermediate guidance face 263 may be plane (for example extending essentially along the direction between push rod section 246B and camshaft 256 or at a desired angle). The contour may alternatively be shaped in a curved manner in same section as described below.

[0060] In particular, the shape of cam lobe 258 and the contour of intermediate guidance face 263 may define the movement of rocker arm 246 during cam driven operation. During cam driven operation tilt connection moves back and forth along a cam control section 263A of intermediate guidance face 263, wherein tilt angle α is maintained below 180°.

[0061] Moreover, intermediate guidance face 263 comprises a decoupling section 263B being shaped to provide in combination with the shape of cam lobe 258 a desired lifting movement L in the decoupled operation mode. However, at the end of lifting movement L, decoupling section is configured and arranged such that tilt angle α increases up to and beyond 180° such that biasing force Fb forces tilt connection 249 to loose contact with intermediate guidance face 263 and further increase tilt angle α. In other words, tilt connection 249 bends over a straight alinement - indicated as dashed line 251 - of rocker part 248A and cam part 248B.

[0062] In Fig. 6, cam control section 263A is configured to be plane, while decoupling section 263B is curved to move tilt connection 249 towards (and in some embodiments slightly beyond) the straight alignment. For positioning a respective section 263A, 263B to interact with tilt connection 249 in a guiding manner, a positioning unit 264 allows displacement of intermediate guidance element 262.

[0063] In general, the contour of cam control section 263A can also be configured to affect the actuation movement. In some embodiment, the contour may be shaped such that a displacement of cam part 248B of push rod 248 will result in a corresponding displacement of push rod section 246B of rocker arm 246, thereby essentially maintaining the actuation movement as defined by cam lobe 258. Specifically, when tilt connection 249 is guided by intermediate guidance face 263 along a path such that tilt angle α between rocker part 248A and cam part 248B is essentially constant during the actuation movement, the actuation movement is defined by cam lobe 258.

[0064] In the decoupled operation mode, the shape of the contour will define in combination with a shape of cam lobe 258 the displacement of push rod section 246B during the lifting movement. For example, when tilt connection 249 is guided by intermediate guidance face 263 along a path such that tilt angle α between rocker part 248A and cam part 248B varies during actuation movement, the actuation movement is at least partly decoupled from the shape of cam lobe 258. The latter may in particular be the case when the contour or at least one of the contour sections is a plane tilted with respect to line 251 or provides a curved surface as it is the case for the illustrated decoupling section 263B, thereby enforcing a change in tilt angle α.

[0065] As further shown in Fig. 6 as an exemplary embodiment of tilt connection 249, a roller 265 forms tilt connection 249 for providing a roll-off movement between tilt connection 249 and intermediate guidance face 263. Specifically, lower end 248A' and upper end 248B" are mounted to an axis of roller 265. In Fig. 6, the position of roller 265 during cam driven operation is shown in solid lines (e.g. rolling along cam control section 263A).

[0066] In addition, the position of roller 265 is shown in dashed lines when being moved to the straight alignment (line 251) of split push rod 248 during decoupled operation mode, i.e. just before being decoupled from the cam interaction.

[0067] In the exemplary embodiment of Fig. 6, a brake unit 267 is further provided. Break unit 267 is configured to provide a delay force Fd onto tilt connection 249 in particular at tilt angles larger 180°, thereby delaying the lateral movement of tilt connection 249 during return movement R. For example, brake unit 267 may comprise a pressing member 267A pressing onto roller 265 during the return movement. For the pressing interaction, brake unit 267 may comprise a spring 267B and/or a damping device 267C. Moreover, brake unit 267 may be configured to allow for controlling delay force Fd during return movement R.

[0068] For decoupled operation mode, at tilt angles α larger 180°, cam lobe 258 does no longer result in a lifting force that controls the movement. Thus, biasing force Fb has essentially no counterforce such that valve 230 closes, rocker arm 246 pivots back, and push rod section 246B moves down, thereby further increasing tilt angle α. To at least provide some resistance, break unit 267 delays the closing be slowing down the change rate (increase rate) of tilt angle α.

[0069] At this stage, valve 230 is closed while lower end 248B' of cam part 248B is still displaced (lifted) by cam lobe 258. Driven by break unit 267, lower end 248B' will follow the decreasing slope of cam lobe 258 and roller 265 will return to interact with intermediate guidance face 263, thereby finalizing return movement R and bringing tilt connection 249 again into tilt angles smaller 180°. In other words, camshaft system 260 is brought back into the initial condition during which cam part 248B interacts with camshaft 256 next to cam lobe 258 and valve 230 maintains closed. The next actuation movement will be initiated again by cam lobe 58 at first by the lifting movement and then the cam decoupled return movement.

[0070] As further shown in Fig. 6 exemplarily for the interaction between cam part 248B and a hollow cylinder body 285 of a roller follower configuration 284, the interaction between cam part 248B and roller follower configuration 284 and/or the interaction between rocker part 248A and push rod section 246B of rocker arm 246 may be configured to allow for a change in tilt angle α. For example, hollow cylinder body 285 may comprise an opening 285A for interacting with cam part 248B. For example, opening 285A of hollow cylinder body 285 may be configured in size and/or shape such that the required angular range for cam part 248B of split push rod 248 can be accepted by roller follower configuration 284 during the interaction of wheel 286 with cam lobe 258.

[0071] Internal combustion engine 10 of Fig. 1 may in particular comprise a valve actuation assembly as disclosed in connection with Fig. 6, as well as cylinder head 24 with valve opening 28 fluidly connecting combustion chamber 26 with a charge air system, and engine valve

30. As schematically illustrated in Fig. 6, engine valve 230 may comprise valve stem 270 with valve head 270A for closing valve opening 228 (closed position C shown in solid lines, while open position shown in dashed lines in Fig. 6), valve stem guidance 271 for guiding a movement of valve stem 270, and valve spring 252. Specifically, valve spring 252 may be configured such that its spring force acts as biasing force Fb, in particular by acting via the top of valve stem 270 onto rocker arm 246.

[0072] As further shown in Fig. 6, intermediate guidance element 262 and/or break unit 267 may be connected to a control unit 280 via control lines 282 to control the movement of those elements for start operation mode B or for full load operation F.

[0073] Alternative configurations may be apparent to the skilled person, for example with respect to maintaining proper joint alignment between the various elements despite temporal introduction of a gap between the joint parts.

[0074] In further embodiments of camshaft systems providing cam decoupled operation modes, break unit 267 may be replaced by a further guiding surface for limiting and defining the return movement of the tilt connection. Furthermore, roller 265 may be replace by a sliding part.

[0075] With respect to the in connection with Fig. 6 described decoupled closing process, control unit 180 may use the information gained from the torque measurement to set control parameters such as the displacement of intermediate guidance element 262 by positioning unit 264 and/or the operation of break unit 267. Further control parameters will be apparent to the skilled person in view of specific implementations such as a tilt of intermediate guidance element 262 or the shape of the further guiding surface for limiting and defining the return movement of the tilt connection.

<u>Industrial Applicability</u>

[0076] The herein disclosed concepts, in particular based on cam decoupling units formed by the various components required to decouple the valve stem from the cam such as disclosed in connection with Figs. 5 and 6, may be used, for example, in gas engines manufactured by Caterpillar Energy Solutions GmbH as well as in engines manufactured by Caterpillar Motoren GmbH & Co. KG.

[0077] For multiple cylinder units/valve systems, one may further decouple - using the variable valve timing configurations - all valves (of all cylinder units/valve systems) except one valve actuation system. Thereby , the torque characteristic and, e.g. the valve spring force present in that selected valve actuation system may be derived. This may be, for example, performed at the engine start stepwise for each valve actuation system.

[0078] Although the preferred embodiments of this invention have been described herein, improvements and modifications may be incorporated without departing from the scope of the following claims.

Claims

1. Method for deriving a control parameter for a variable valve actuation assembly (40, 140, 240) using a valve spring driven /cam decoupled valve closing process, the method comprising:

   providing a camshaft driven valve actuation assembly (40, 140, 240) that is configured to provide a cam driven valve opening procedure and the valve spring driven / cam decoupled valve closing process;
   rotating the camshaft through a sequence of the cam driven valve opening process and the valve spring driven / cam decoupled valve closing process;
   during the rotation, measuring a torque to be provided for the rotation; and
   deriving the control parameter from the detected torque.

2. Method of claim 1, wherein the step of deriving the control parameter from the detected torque includes deriving a spring force parameter for each valve spring (52, 152, 252).

3. Method of claim 1 or claim 2, wherein the step of deriving the control parameter is made under consideration of the shape of the cam lobe (58, 158, 258) and/or the kinematics of the camshaft driven valve actuation assembly (40, 140, 240).

4. Method of any one of claim 1 to claim 3, wherein a plurality of camshaft driven valve actuation assemblies (40, 140, 240) is activated in line with the firing order by the camshaft (56, 156, 256), and the step of rotating the camshaft (56, 156, 256) includes rotating the camshaft (56, 156, 256) to cover the opening and closing process for the plurality of camshaft driven valve actuation assemblies (40, 140, 240), and the step of deriving the control parameter is made under consideration of the firing order.

5. Method of any one of claim 1 to claim 4, wherein the camshaft (56, 156, 256) is rotated continuously during operation of the underlying internal combustion engine (10); and
   the torque is measured continuously for revolutions, and the method further comprising:

   using the control parameter to adapt the valve closing process for one or a plurality of valve actuation assemblies (40, 140, 240).

6. A camshaft driven valve actuation assembly (40,

140, 240) configured to provide a cam driven valve opening process and a valve spring driven / cam decoupled valve closing process, the camshaft driven valve actuation assembly (40, 140, 240) comprising:

a camshaft system comprising a camshaft (56, 156, 256), a cam lobe (58, 158, 258), and a push rod (48, 148, 248);
an engine valve (30, 130, 230) comprising a valve stem (170, 270) with a valve head (170A, 270A), and a valve spring (52, 152, 252);
a rocker system comprising a rocker arm (46, 146, 246) with a valve actuation section and a push rod section, and a rocker shaft unit (162);
a cam decoupling unit configured for decoupling the valve stem (170, 270) from being driven by the cam lobe (58, 158, 258); and
a torque measurement device (60) for measuring a torque applied to the camshaft (56) for operating the engine valve (30, 130, 230).

7. The camshaft driven valve actuation assembly (40, 140, 240) of claim 6, wherein the camshaft system comprises a gear system, and the torque measurement unit measures the force applied to the gear system.

8. The camshaft driven valve actuation assembly (40, 140, 240) of claim 6 or claim 7, further comprising:

a control unit (180, 280) configured to receive a control parameter from the torque measurement device (60) and to control the cam decoupling unit to adapt the closing time of the engine valve (30, 130, 230).

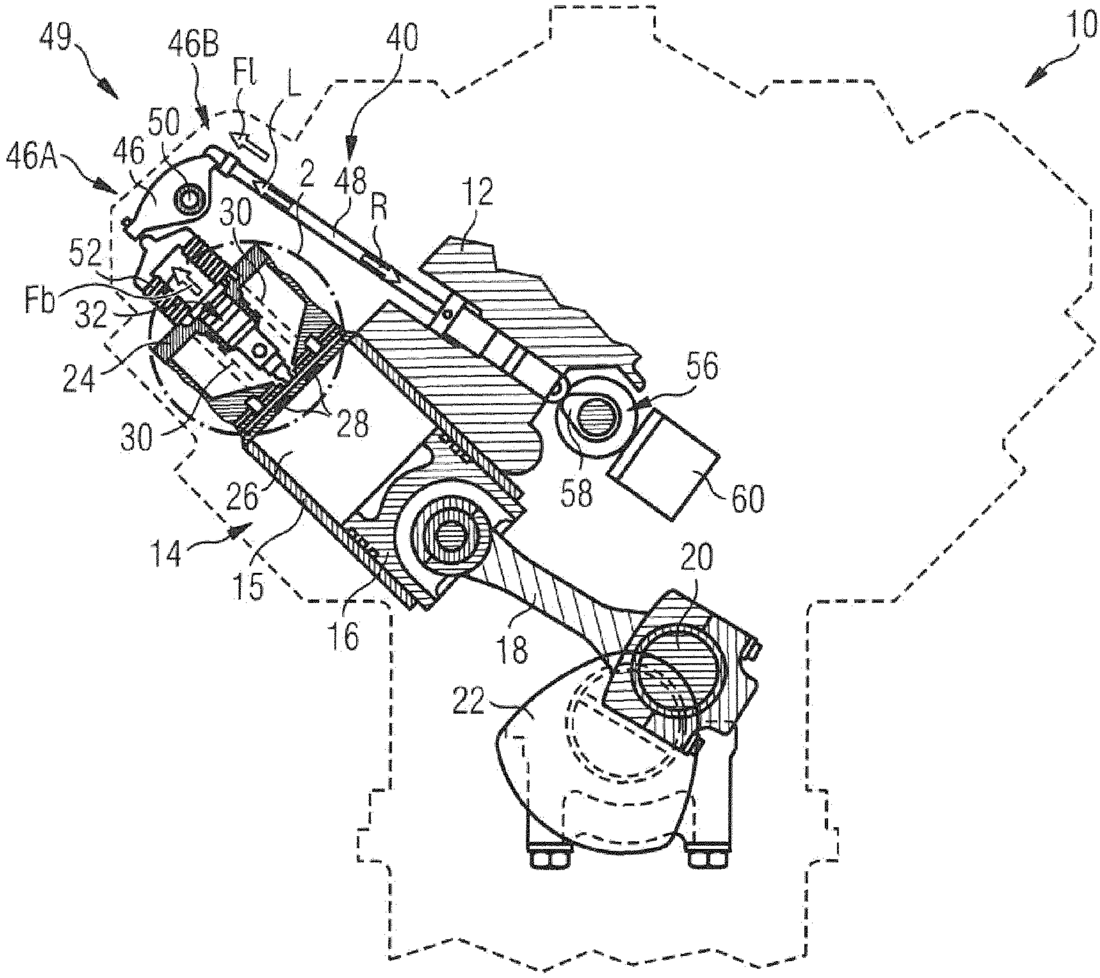
9. An internal combustion engine (10) comprising:

a plurality of cylinder units (14) with a plurality of engine valves (30) ;
a plurality of camshaft driven valve actuation assemblies (40, 140, 240) of any one claim 6 to claim 8 for respectively operating one or more engine valves (30) of the for the plurality of engine valves (30) of the plurality of cylinder units (14); and
a control unit (180, 280) configured to control the cam decoupling units to adapt the closing process of the engine valves for in particular synchronizing the valve closing times of the plurality of engine valves (30).

10. The internal combustion engine (10) of claim 9, wherein the cam decoupling unit comprises a rocker shaft unit (149) of at least one of the plurality of camshaft driven valve actuation assemblies (140), the rocker shaft unit (149) comprises a rocker shaft (150), and a rocker shaft mount (149A), wherein the rocker shaft (150) is configured to have a rocker arm (146) mounted thereto and to provide an axis (150A) of rotation for a pivot movement of the rocker arm (146) and the rocker shaft mount (149A) is configured to displaceably mount the rocker shaft (150) to allow for varying the position of the axis (150A) of rotation by displacing the rocker shaft (150) during the pivot movement, and
wherein the control unit (180) is configured to control the extent and/or the speed of the displacement of the rocker shaft during the pivot movement.

11. The internal combustion engine (10) of claim 9 or claim 10, wherein a camshaft driven valve actuation assemblies (240) of the plurality of camshaft driven valve actuation assemblies (40) is configured for driving a pivot movement of a rocker arm (246) for operating at least one of the plurality of engine valves (230) with adjustable closing times, and comprises
a camshaft system (260) with
a camshaft (256) with a cam lobe (258);
a split push rod (248) interacting with the cam lobe (258) to be displaced, during a rotation of the camshaft (256), in accordance with an actuation movement, the split push rod (248) comprising a rocker part (248A) and a cam part (248B), wherein a lower end (248A') of the rocker part (248A) and an upper end (248B") of the cam part (248B) are configured to form a tilt connection (249) allowing for changes in a tilt angle (α) between the rocker part (248A) and the cam part (248B), an upper end (248A") of the rocker part (248A) is configured for interacting with the push rod section (246B) of the rocker arm (246), and a lower end (248B') of the cam part (248B) is configured for being displaced by the cam lobe (258); and
an intermediate guidance element (262) with an intermediate guidance face (263) for guiding the tilt connection (249), wherein the intermediate guidance face (263) comprises a decoupling section (263B) for increasing the tilt angle (α) up to and beyond 180°, and
wherein the control unit (280) is configured to control the position of the intermediate guidance element (262).

FIG 1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46A
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Fb
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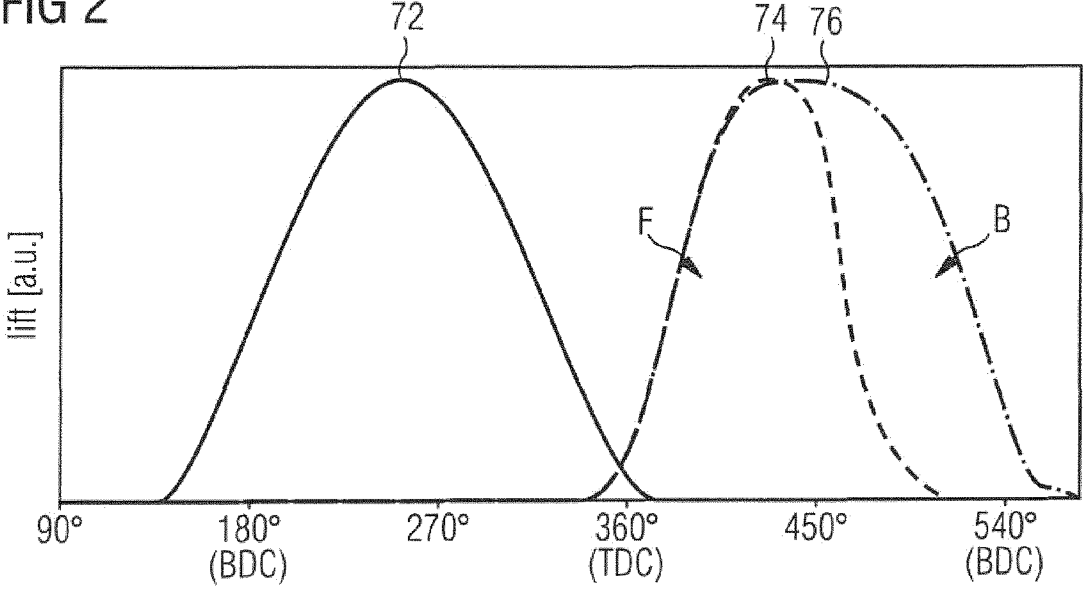
28
56
58
60
26
14
15
16
18
20
22

FIG 2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74
76
lift [a.u.]
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(BDC)
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360°
(TDC)
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(BDC)

FIG 3

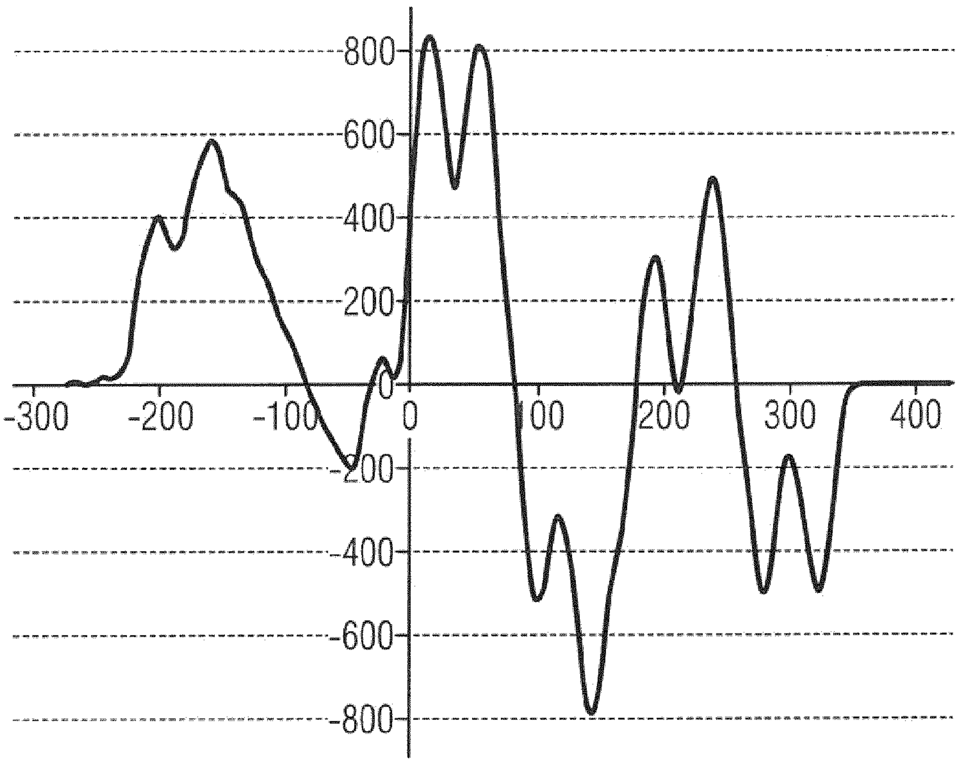
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FIG 4

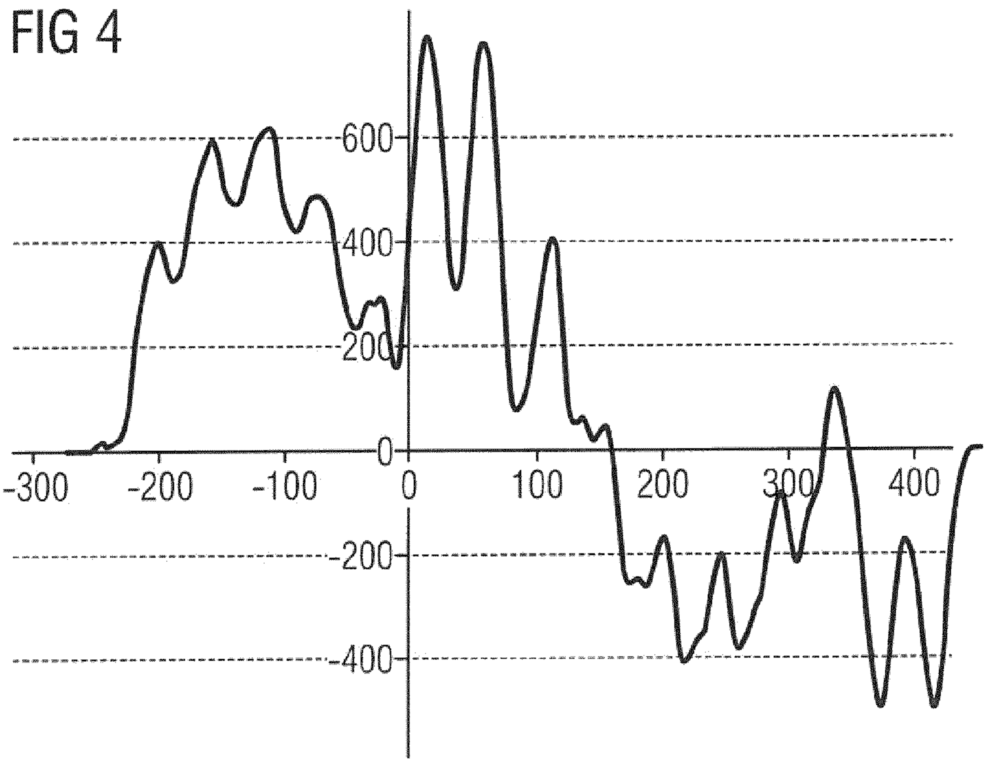
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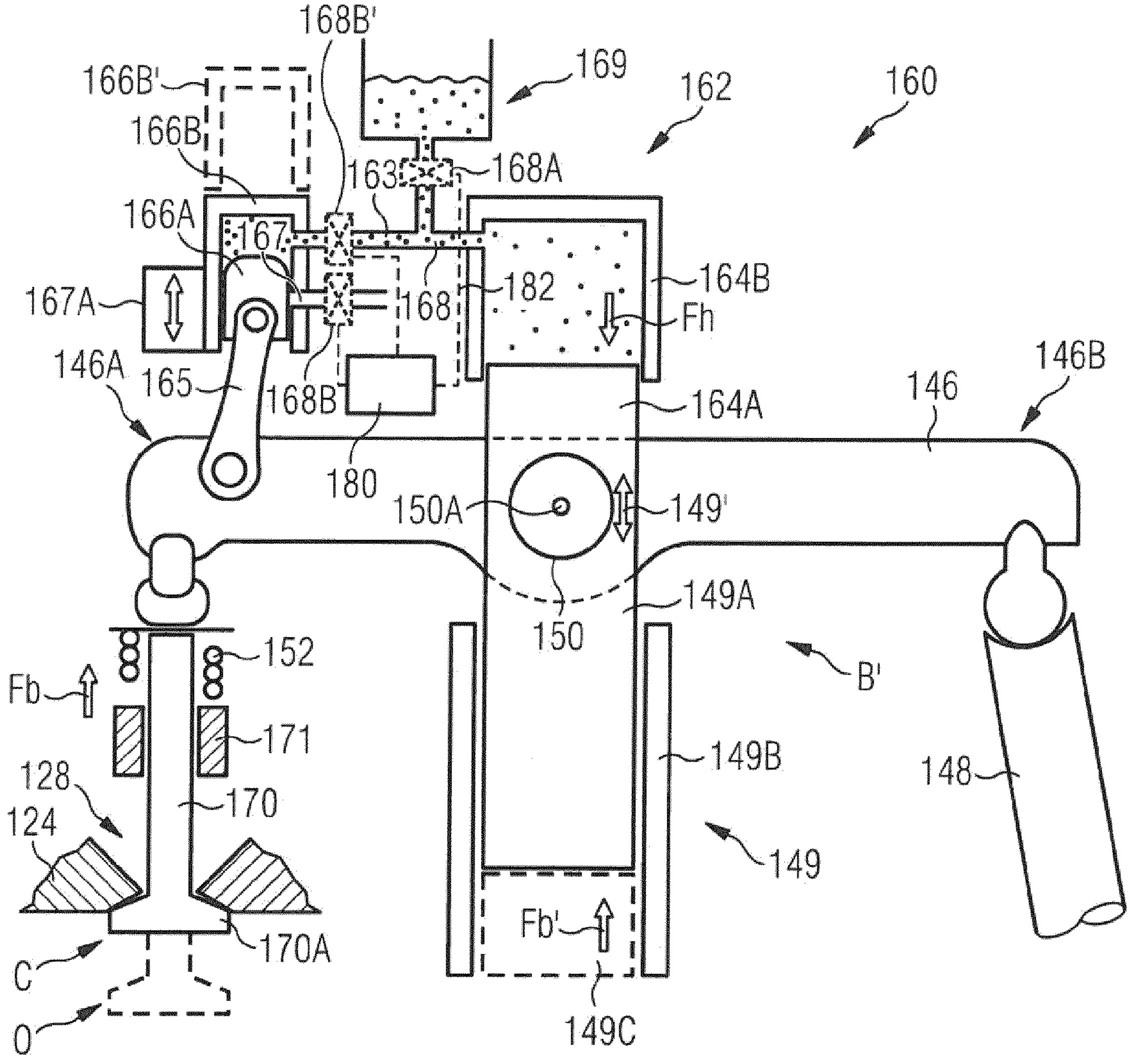
FIG 5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166B'
169
162
160
166B
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165
168B
164A
146
146B
180
150A
149'
149A
150
152
B'
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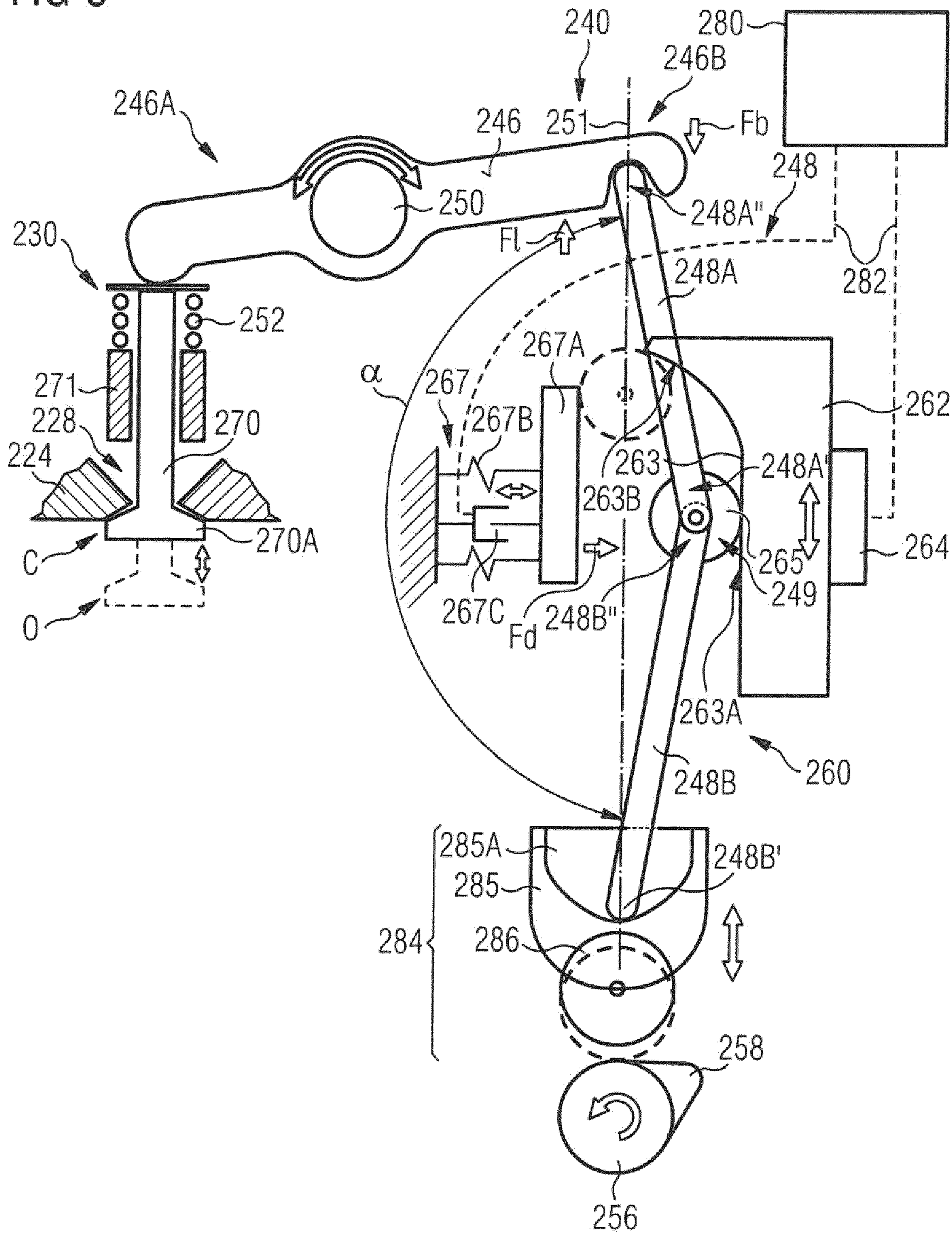
171
149B
128
148
170
124
149
170A
Fb'
C
149C
O

FIG 6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267B
228
270
263
248A'
224
263B
270A
C
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Fd
O
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284
286
258
256

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EUROPEAN SEARCH REPORT

Application Number
EP 15 16 0902

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	EP 1 816 456 A1 (CASTROL LTD [GB]) 8 August 2007 (2007-08-08) * the whole document * -----	1	INV. F01L13/00 F01L13/06
A	US 4 483 283 A (HAUSKNECHT LOUIS A [US]) 20 November 1984 (1984-11-20) * the whole document * -----	1	

TECHNICAL FIELDS SEARCHED (IPC)

F01L

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	30 September 2015	Klinger, Thierry

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 15 16 0902

30-09-2015

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