(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 073 069 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
28.09.2016 Bulletin 2016/39

(51) Int Cl.:
F01L 13/00 *(2006.01)* ***F01L 1/14*** *(2006.01)*

(21) Application number: **15160887.4**

(22) Date of filing: **25.03.2015**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA

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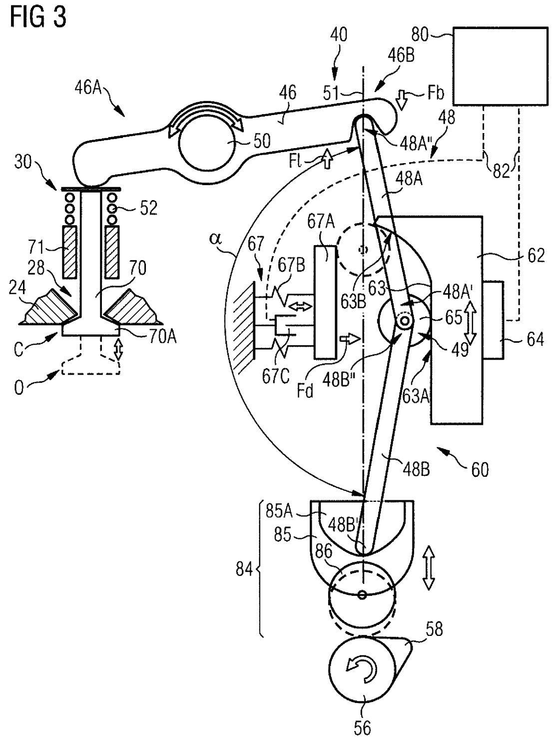
(54) PUSH ROD BASED VARIABLE VALVE TIMING SYSTEMS

(57) A camshaft system (60) for driving a pivot movement of a rocker arm (46) of a valve actuation assembly (40) for operating a valve (30) of an internal combustion engine (10) with adjustable closing times is disclosed. The camshaft system (60) comprises a camshaft (56) with a cam lobe (58) and a split push rod (48) interacting with the cam lobe (58) to be displaced, during a rotation of the camshaft (56), in accordance with an actuation movement. The split push rod (48) comprises a rocker part (48A) and a cam part (48B), wherein a lower end (48A') of the rocker part (48A) and an upper end (48B") of the cam part (48B) are configured to form a tilt connection (49) allowing for changes in a tilt angle (α) between the rocker part (48A) and the cam part (48B). An upper end (48A") of the rocker part (48A) is configured for interacting with the push rod section (46B) of the rocker arm (46), and a lower end (48B') of the cam part (48B) is configured for being displaced by the cam lobe (58). Moreover, the camshaft system (60) comprises an intermediate guidance element (62) with an intermediate guidance face (63) for guiding the tilt connection (49), wherein the intermediate guidance face (63) comprises a decoupling section (63B) for increasing the tilt angle (α) up to and beyond 180°. The herein disclosed configurations allow for a at least partly cam-decoupled valve actuation.

FIG 3



Printed by Jouve, 75001 PARIS (FR)

Description

Technical Field

[0001] The present disclosure generally relates to valve operation systems for an internal combustion engine and, more particularly, to adapting valve timings.

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 camshaft system for driving a pivot movement of a rocker arm of a valve actuation assembly for operating a valve of an internal combustion engine with adjustable closing times comprises a camshaft with a cam lobe and a split push rod interacting with the cam lobe to be displaced, during a rotation of the camshaft, in accordance with an actuation movement. The split push rod comprises a rocker part and a cam part, wherein a lower end of the rocker part and an upper end of the cam part are configured to form a tilt connection allowing for changes in a tilt anglebetween the rocker part and the cam part. An upper end of the rocker part is configured for interacting with the push rod section of the rocker arm, and a lower end of the cam part is configured for being displaced by the cam lobe. Moreover, the camshaft system comprises an intermediate guidance element with an intermediate guidance face for guiding the tilt connection, wherein the intermediate guidance face comprises a decoupling section for increasing the tilt angle up to and beyond 180°.

[0007] In another aspect, a valve actuation assembly for operating a valve of an internal combustion engine with adjustable closing times comprises a rocker arm rotatably mounted to a rocker shaft to perform a pivot movement for operating the valve, wherein the rocker arm comprises a valve actuation section and a push rod section. The valve actuation assembly comprises further a camshaft system as summarized above wherein the upper end of the rocker part is configured for interacting with the push rod section of the rocker arm for providing a lifting force onto the rocker arm during a lifting movement of the actuation movement. The valve actuation assembly comprises further a biasing force providing unit providing a biasing force acting onto the rocker arm and counteracting the lifting force for enforcing a return movement of the actuation movement.

[0008] In another aspect, an internal combustion engine comprises a valve actuation assembly such as the one summarized above, a cylinder head with a valve opening fluidly connecting a combustion chamber with a charge air system, and a valve. The valve comprises a valve stemwith a valve head for closing the valve opening, a valve stem guidance for guiding a movement of the valve stem, and a valve spring configured such that its spring force acts as a biasing force, in particular by acting via the valve stem onto the rocker arm. Thereby, during the first valve actuation mode, it may be ensured that the rocker arm follows the return movement of the push rod and, during the second valve actuation mode, closing the valve may be decoupled from the cam lobe interaction.

[0009] In another aspect, a method for operating a valve of an engine with adjustable closing times, wherein the engine omprising a split push rod based valve actuation system such as the above summarized valve actuation assembly comprises the steps of selectively modifying a tilt angle between a rocker part and a cam part of the split push rod to at least partly decouple the actuation movement of the push rod from the shape of the cam lobe.

[0010] Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

Brief Description of the Drawings

[0011] 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;

Fig. 3 shows a schematic illustration of a first exemplary valve timing adjustment system; and

Fig. 4 shows a schematic illustration of an exemplary second valve timing adjustment system.

Detailed Description

[0012] 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.

[0013] The present disclosure may be based in part on the realization that dividing a push rod in more than one part allows adapting the "active" length, in particular by changing a tilt angle between the two parts of such a split push rod. Moreover, a split push rod may allow to decouple the cam lobe from the rocker arm, in particular for the closing of the valve.

[0014] In addition, the present disclosure may be based in part on the realization that a delay forth may be provided that acts in particular onto a tilt connection between two parts of a split push rod, thereby further controlling the closing movement of the valve stem.

[0015] Referring to the drawings, exemplary embodiments are disclosed that illustrate the herein disclosed adjustable valve timing concepts that can be employed, for example, in the internal combustion engine of Fig. 1.

[0016] Specifically, 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. 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 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.

[0017] 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.

[0018] 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 (not shown in Fig. 1). Each cylinder unit 14 may include multiple intake and exhaust openings 28 and respectively multiple intake and exhaust valves 30.

[0019] 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.

[0020] 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).

[0021] Valve actuation assembly 40 includes a rocker arm 46. Rocker arm 46 is pivotably mounted on cylinder head 24 by a rocker shaft 50 and interacts with engine valves 30 at a valve actuation section 46A and with a split push rod 48 at a push rod section 46B.

[0022] 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) split push rod 48 when camshaft 56 is rotated. Exemplarily, split push rod 48 comprises two parts: a rocker part 48A and a cam part 48B. As shown in more detail for the exemplary embodiments illustrated in Figs. 3 and 4, a lower end 48A' of rocker part 48A and an upper end 48B" of cam part 48B are configured to form a tilt connection 49. Tilt connection 49 allows for changes in a tilt angle α between rocker part 48A and cam part 48B. Moreover, an upper end 48A" of rocker part 48A is configured for interacting with push rod section 46B, while a lower end 48B' of cam part 48B is configured for interacting with cam lobe 58.

[0023] 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).

[0024] In a cam lobe driven operation of valve 30, the displacement of split push rod 48 corresponds to an actuation movement of push rod 48 in consequence resulting in a conventional actuation of valve 30. 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 - lifting lower end 48B' of cam part 48B - and results in a lifting force Fl onto rocker arm 46 (assuming an essentially fixed relation/tilt angle between rocker part 48A and cam part 48B) 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 Fig. 3). This corresponds essentially to a conventional push rod/cam based valve actuation (herein referred to as a first or cam driven operation mode of the valve actuation). As described in connection with Fig. 3, in addition to cam lobe 58, also the tilt angle between the parts of push rod 48 may be modified which results in a cam decoupled operation mode (herein referred to as a second or decoupled operation mode of the valve actuation).

[0025] In the first operation mode, 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 i.e. following of cam lobe 58. In consequence, opening 28 is closed via a respective valve head.

[0026] Thus, the cam driven operation mode results in an oscillation of rocker arm 46 about its pivot point in dependence of the shape of cam lobe 58 (including essentially neglectable minor changes in the tilt angle) and determines the respective opening duration of valve 30.

[0027] 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.

[0028] 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. Such a full load operation is indicated with reference numeral F in Fig. 2.

[0029] However, 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. Such a filling optimized operation is indicated with reference numeral S 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, thereby, for example, reducing 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. The filling optimized operation may be implemented by a specific shape of cam lobe 58 extending over an angular range that results in the long opening of the valve.

[0031] Although the exemplary configurations explained in the following may allow adaptation of valve timings, for example, for the full load operation of engine 10 in Miller-like manner and for the part load operation of engine 10 in a filling optimized manner, the skilled person will acknowledge that the underlying valve adaptation may be applied to varies types of valve timing modifications, in particular valve closing movements.

[0032] With reference to Fig. 3, a schematic illustration of a valve actuation assembly 40 is exemplarily illustrated. Valve actuation assembly 40 includes inter alia a camshaft system 60 with components such as camshaft 56, cam lobe 58, and split push rod 48. Moreover, valve actuation assembly 40 includes rocker arm 46 mounted to rocker shaft 50, and a biasing force generating unit. The biasing force generating unit is configured, for example, as valve spring 52, 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.

[0033] As shown in Fig. 3, valve actuation assembly 40 is based on split push rod 48 that interacts with cam lobe 58 to be displaced, during a rotation of camshaft 56, in accordance with a desired actuation movement during cam driven operation mode. As mentioned above, split push rod 48 comprises rocker part 48A and cam part 48B connected at tilt connection 49. Tilt connection 49 is configured to allow for an adjustment of tilt angle α between rocker part 48A and cam part 48B.

[0034] Moreover, upper end 48A" of rocker part 48A interacts with push rod section 46B, in particular for providing lifting force Fl onto rocker arm 46 during lifting movement L. Similarly, a lower end 48B' of cam part 48B interacts with cam lobe 58, in particular via a roller follower configuration 84 described below.

[0035] Camshaft system 60 comprises further an intermediate guidance element 62 providing an intermediate guidance face 63 for guiding tilt connection 49. In general, the contour of intermediate guidance face 63 may be plane (for example extending essentially along the direction between push rod section 46B and camshaft 56 or at a desired angle). The contour may alternatively be shaped in a curved manner in same section as described below.

[0036] In particular, the shape of cam lobe 58 and the contour of intermediate guidance face 63 may define the movement of rocker arm 46 during cam driven operation. During cam driven operation tilt connection moves back and forth along a cam control section 63A of intermediate guidance face 63, wherein tilt angle α is maintained below 180°.

[0037] Moreover, intermediate guidance face 63 comprises a decoupling section 63B being shaped to provide in combination with the shape of cam lobe 58 a desired lifting movement L in the decoupled operation mode. The desired lifting movement L may extend up to the maximal valve opening based on the cam lobe 58 or lifting movement L may be reduced, in dependence of the position of intermediate guidance face 63. In any case, 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 49 to loose contact with intermediate guidance face 63 and further increase tilt angle α. In other words, tilt connection 49 bends over a straight alinement - indicated as dashed line 51 - of rocker part 48A and cam part 48B.

[0038] In Fig. 3, cam section 63A is configured to be plane, while decoupling section 63B is curved to move tilt connection 49 towards (and in some embodiments slightly beyond) the straight alignment. For positioning a respective section 63A, 63B to interact with tilt connection 49 in a guiding manner, a positioning unit 64 allows displacement of intermediate guidance element 62.

[0039] In general, the contour of cam control section 63A can also be configured to affect the actuation movement. In some embodiment, the contour may be shaped such that a displacement of cam part 48B of push rod 48 will result in a corresponding displacement of push rod section 46B of rocker arm 46, thereby essentially maintaining the actuation movement as defined by cam lobe 58. Specifically, when tilt connection 49 is guided by intermediate guidance face 63 along a path such that tilt angle α between rocker part 48A and cam part 48B is essentially constant during the actuation movement, the actuation movement is defined by cam lobe 58.

[0040] In the decoupled operation mode, the shape of the contour will define in combination with a shape of cam lobe 58 the displacement of push rod section 46B during the lifting movement. For example, when tilt connection 49 is guided by intermediate guidance face 63 along a path such that tilt angle α between rocker part 48A and cam part 48B varies during actuation movement, the actuation movement is at least partly decoupled from the shape of cam lobe 58. 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 51 or provides a curved surface as it is the case for the illustrated decoupling section 63B, thereby enforcing a change in tilt angle α.

[0041] As further shown in Fig. 3 as a first exemplary embodiment of tilt connection 49, a roller 65 forms tilt connection 49 for providing a roll-off movement between tilt connection 49 and intermediate guidance face 63. Specifically, lower end 48A' and upper end 48B" are mounted to an axis of roller 65. In Fig. 3, the position of roller 65 during cam driven operation is shown in solid lines (e.g. rolling along cam control section 63A.

[0042] In addition, the position of roller 65 is shown in dashed lines when being moved to the straight alignment (line 51) of split push rod 48 during decoupled operation mode, i.e. just before being decoupled from the cam interaction.

[0043] In the embodiment of Fig. 3, a brake unit 67 is further provided. Break unit 67 is configured to provide a delay force Fd onto tilt connection 49 in particular at tilt angles larger 180°, thereby delaying the lateral movement of tilt connection 49 during return movement R. For example, brake unit 67 may comprise a pressing member 67A pressing onto roller 65 during the return movement. For the pressing interaction, brake unit 67 may comprise a spring 67B and/or a damping device 67C. Moreover, brake unit 67 may be configured to allow for controlling delay force Fd during return movement R.

[0044] For decoupled operation mode, at tilt angles α larger 180°, cam lobe 58 does no longer result in a lifting force that controls the movement. Thus, biasing force Fb has essentially no counterforce such that valve 30 closes, rocker arm 46 pivots back, and push rod section 46B moves down, thereby further increasing tilt angle α. To at least provide some resistance, break unit 67 delays the closing be slowing down the change rate (increase rate) of tilt angle α.

[0045] At this stage, valve 30 is closed while lower end 48B' of cam part 48B is still displaced (lifted) by cam lobe 58. Driven by break unit 67, lower end 48B' will follow the decreasing slope of cam lobe 58 and roller 65 will return to interact with intermediate guidance face 63, thereby finalizing return movement R and bringing tilt connection 49 again into tilt angles smaller 180°. In other words, camshaft system 60 is brought back into the initial condition during which cam part 48B interacts with camshaft 56 next to cam lobe 58 and valve 30 maintains closed. During the initial condition with tilt angle α smaller 180°, break unit 67 ensures that roller 65 contacts intermediate guidance face 63, such that cam part 48B follows the cam lobe when the same is rotated again to interact with cam part 48B. Cam lobe 58 initiates the next actuation movement including at will be initiated again by at first the lifting movement and then the cam decoupled return movement.

[0046] As further shown in Fig. 3 exemplarily for the interaction between cam part 48B and a hollow cylinder body 85 of a roller follower configuration 84, the interaction between cam part 48B and roller follower configuration 84 and/or the interaction between rocker part 48A and push rod section 46B of rocker arm 46 may be configured to allow for a change in tilt angle α. For example, hollow cylinder body 85 may comprise an opening 85A for interacting with cam part 48B. For example, opening 85A of hollow cylinder body 85 may be configured in size and/or shape such that the required angular range for cam part 48B of split push rod 48 can be accepted by roller follower configuration 84 during the interaction of wheel 86 with cam lobe 58.

[0047] Internal combustion engine 10 of Fig. 1 may in particular comprise a valve actuation assembly as disclosed in connection with Fig. 3, 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. 3, engine valve 30 may comprise valve stem 70 with valve head 70A for closing valve opening 28 (closed position C shown in solid lines, while open position shown in dashed lines in Fig. 3), valve stem guidance 71 for guiding a movement of valve stem 70, and valve spring 52. Specifically, valve spring 52 may be configured such that its spring force acts as biasing force Fb, in particular by acting via the top of valve stem 70 onto rocker arm 46.

[0048] As further shown in Fig. 3, intermediate guidance element 62 and/or break unit 67 may be connected to a control unit 80 via control lines 82 to control the movement of those elements for start operation mode S or for full load operation F.

[0049] 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.

[0050] While Fig. 3 illustrates an embodiment subject to a tilt angle within the plan of the rocker arm's pivot movement, Fig. 4 illustrates a further embodiment of a camshaft system 60' for use in internal combustion engine 10 that uses a split push rod 48' with a tilt angle α within a plane orthogonal to the rocker arm's pivot movement.

[0051] Fig. 4 shows a rocker arm configuration for activating exhaust valves. Specifically, two valve stems 70' are biased by valve springs 52' and displaced via a common rocker arm 46' operatively connected to a camshaft 56' with a cam lobe 58'. For comparison, also a rocker arm 46" for inlet valves is schematically shown.

[0052] Moreover, Fig. 4 illustrates an essentially almost linear alignment of a rocker part 48A and a cam part 48B of a split push rod 48. Rocker part 48A and cam part 48B are tiltably connected at a sliding body 68. As shown in Fig. 4, the displacement d1 of sliding body 68 from a line 51' (corresponding to the linear alignment) for the cam driven operation mode is about 5 mm corresponding to a maintained tilt angle of about 178°. Ingeneral, tilt angles in the range from 170° to 179.8°, for example 175° to 179.5° may be used. The almost linear alignment may be maintained throughout the cam driven actuation motion as well as during the initial phase of the lifting motion in the decoupled operation mode. A respective potential position of an intermediate guidance element 62' is shown that provides an essentially planar section of an intermediate guidance face 63' for guiding sliding body 68.

[0053] Intermediate guidance element 62' further comprises a curved section of intermediate guidance face 63' for guiding sliding body 68 towards line 51', thereby increasing tilt angle α beyond 180°.

[0054] Valve spring 52 will force - in light of the removed resistance from the cam lobe 58' - push rod section 46B' downward resulting in increasing tilt angle α further beyond 180°. However, the camshaft system comprises a return guidance element 69 that provides a return guiding face 69A and is positioned - with respect to return guidance element 69 - opposite to intermediate guidance element 62'. Due to the presence of that return guiding face 69A, sliding body 68 is limited in its lateral displacement and, therefore, the rate of increase of tilt angle α is limited, and a too fast closing of the engine valve is avoided. For illustration of the return movement, a maximum displacement d2 of e.g. 70 mm is shown in Fig. 4 corresponding to a tilt angle of about 200° to 205°. In general, tilt angles during the return movement may be in the range from 190° to 250°.

[0055] The final return to a tilt angle smaller than 180°, which is possible once cam lobe 58' has passed, may be achieved by gravity or a restoring force generated by a spring (not shown). In general, the final return may require a valve clearance allowing, for example, the mechanical flexibility for the non-cam controlled movement.

Industrial Applicability

[0056] In the following, operating an internal combustion engine under variable valve timing conditions using the split push rod configuration is described, exemplarily referring to the embodiment and reference numerals illustrated in Fig. 3. At first, a cam driven operation is described followed by a decoupled operation mode.

[0057] Assuming a rotation of camshaft 56, cam lobe 58 will interact with roller 86 of roller follower configuration 84, thereby displacing roller follower configuration 84 in dependence of the shape of cam lobe 58. Accordingly, a displacement of roller follower configuration 84 will be transferred to cam part 48B of split push rod 48. In consequence, tilt connection 49 will move along intermediate guidance face 63 and may transfer the movement onto rocker part 48A, which then provides lifting force Fl onto rocker arm 46 during the upward movement. Lifting force Fl overcomes biasing force Fb generated, for example, by valve spring 52. During the downward movement, biasing force Fb may force rocker arm 46 and split push rod 48 to follow the shape of cam lobe 58, thereby tilt connection 49 is again guided by intermediate guidance face 63.

[0058] Assuming a shape of intermediate guidance face 63 that ensures essentially tilt angle α during the actuation movement, the operation of valve 30 is essentially defined by the shape of cam lobe 58. This may apply to the cam driven operation as well as to the lifting motion in the decoupled operation mode.

[0059] To switch between the operation modes, one may position intermediate guidance element 62 such that different sections of intermediate guidance face 63 - thus different shapes - may guide tilt connection 49 during the actuation movement and in particular during the lifting movement.

[0060] In general, providing a shape of intermediate guidance face 63 that modifies tilt angle α between cam part 48B and rocker part 48A (assuming that essentially upper end 48A" and lower end 48B' are essentially fixed in space with respect to rocker arm 46 and roller follower configuration 84, respectively) modifying angle α will result in a change in distance between upper end 48A" and lower end 48B'. Specifically, changing tilt angle α towards 180° will increase the respective distance, while changing tilt angle α away from 180° will decrease the respective distance. Accordingly, any shape of intermediate guidance face 63 modifying tilt angle α will - similar to cam lobe 58 - effect the movement of upper end 48A", and thus the movement of push rod section 46B of rocker arm 46. In other words, the shape of intermediate guidance face 63 can influence the actuation movement.

[0061] Moreover, selectively modifying tilt angle α between rocker part 48A and cam part 48B of split push rod 48 may at least partly decouple the actuation movement of the push rod 48 from the shape of the cam lobe 58.

[0062] This is used in the decoupled operation mode. Specifically, allowing tilt angle α to increase essentially freely beyond 180° decouples the valve operation/rocker arm 46 from cam lobe 58. Thus, the valve closing can take place independently from cam lobe 58. To decouple completely, tilt angles beyond 180° and, thus, no interaction with intermediate guidance face 63 are used for the return movement. Specifically, a section of intermediate guidance face 63 is moved to interact with tilt connection 69 and move the same to and over the straight connection. Thereafter, the mechanics is decoupled from cam lobe 58.

[0063] Return movement R of split push rod 48 may then be influenced by brake unit 67.

[0064] When starting engine 10, a filling optimized lift curve such as valve lift curve 76 shown in Fig. 2 may be desired for the exhaust valve operation. Accordingly, cam lobe 58 of camshaft 56 may be configured to provide such a broad opening duration. As long as the valve operation should be controlled by that specific cam lobe 58, the tilt angle may be maintained by a specifically selected shape of intermediate guidance face 63. However, if operation of the engine should be performed based on a valve actuation that is not consistent with the shape of cam lobe 58 (e.g. Miller operation), a shape of intermediate guidance face 63 may be selected that decouples rocker arm from the cam lobe and, thereby, earlier valve closing times.

[0065] In the above disclosure of exemplary embodiments, it is referred to a split push rod that in particular comprises a rocker part and a cam part. However, a person skilled in the art will understood that the rocker part and/or the cam part may themselves comprise further parts (in other words being themselves split in multiple parts). Accordingly, there herein disclosed concept may be understood to be used in connection with push rods comprising three or four parts, wherein at least between two parts a tilt connection is provided that is used as described herein to provide for a decoupling of the actuation movement from the cam.

[0066] In a further exemplary embodiment, the herein disclosed concepts may be used for idle operation using the decoupling together with a small valve lift, the latter, for example, provided by a lowered position of intermediate guidance element 62.

[0067] In general, the herein disclosed concepts may be used, for example, in gas engines manufactured by Caterpillar Energy Solutions GmbH and/or internal combustion engines manufactured by Caterpillar Motoren GmbH & Co. KG.

[0068] 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. A camshaft system (60) for driving a pivot movement of a rocker arm (46) of a valve actuation assembly (40) for operating a valve (30) of an internal combustion engine (10) with adjustable closing times, the camshaft system (60) comprising:

    a camshaft (56) with a cam lobe (58);
    a split push rod (48) interacting with the cam lobe (58) to be displaced, during a rotation of the camshaft (56), in accordance with an actuation movement, the split push rod (48) comprising a rocker part (48A) and a cam part (48B), wherein a lower end (48A') of the rocker part (48A) and an upper end (48B") of the cam part (48B) are configured to form a tilt connection (49) allowing for changes in a tilt angle (α) between the rocker part (48A) and the cam part (48B), an upper end (48A") of the rocker part (48A) is configured for interacting with the push rod section (46B) of the rocker arm (46), and a lower end (48B') of the cam part (48B) is configured for being displaced by the cam lobe (58); and
    an intermediate guidance element (62) with an intermediate guidance face (63) for guiding the tilt connection (49), wherein the intermediate

guidance face (63) comprises a decoupling section (63B) for increasing the tilt angle (α) up to and beyond 180°.

2. The camshaft system (60) of claim 1, wherein the camshaft system (60) is configured such that a change of the tilt angle (α), and in particular a change rate in the tilt angle (α), is decoupled from the cam lobe (58) at tilt angles beyond 180°.

3. The camshaft system (60) of claim 1 or claim 2, wherein the intermediate guidance face (63) comprises a cam control section (63A), which results at guiding the tilt connection (49) while maintaining a tilt angle smaller 180°.

4. The camshaft system (60) of any one of the preceding claims, the valve actuation assembly (40) further comprising:

a break unit (67) configured to provide a delay force (Fd) to delay a movement of the tilt connection (49) during an increase in tilt angle (α) during a return movement (R) of the actuation movement, and wherein in particular the break unit (67) comprises a pressing member (67A), a spring (67B), and/or a damping device (67C), which are configured to allow for controlling the delay force.

5. The camshaft system (60) of claim 4, further comprising a positioning unit (64) for positioning a respective section (63A, 63B) of the intermediate guidance face (63) to interact with the tilt connection (49).

6. The camshaft system (60) of any of the preceding claims, further comprising a control unit (80) configured to control the position of the intermediate guidance element (62) and/or of the delay force provided by a break unit (67).

7. The camshaft system (60) of any of the preceding claims, wherein the interaction between the cam part (48B) and a roller follower configuration (84) interacting with the cam lobe (58) and/or the interaction between the rocker part (48A) and the push rod section (46B) are configured to allow for a change in the tilt angle (α).

8. The camshaft system (60) of any of the preceding claims, wherein the intermediate guidance element (62) comprises a return guidance element with a first return guidance face (69A), which results in providing a defined increase rate of the tilt angle beyond 180°, and/or
a second return section, which results in decreasing the tilt angle from beyond 180° to below 180°.

9. The camshaft system (60) of any of the preceding claims, further comprising:

a roller (65) or sliding body (68) mounted at the tilt connection (49) for providing a roll-off or sliding movement between the tilt connection (49) and the intermediate guidance face (63) and/or the return guidance face (69A).

10. A valve actuation assembly (40) for operating a valve (30) of an internal combustion engine (10) with adjustable closing times, the valve actuation assembly (40) comprising:

a rocker arm (46) rotatably mounted to a rocker shaft (50) to perform a pivot movement for operating the valve (30), the rocker arm (46) comprising a valve actuation section (46A) and a push rod section (46B);
a camshaft system (60) of any one of the preceding claims, wherein the upper end (48A") of the rocker part (48A) is configured for interacting with the push rod section (46B) of the rocker arm (46) for providing a lifting force (Fl) onto the rocker arm (46) during a lifting movement (L) of the actuation movement; and
a biasing force providing unit (52) providing a biasing force (Fb) acting onto the rocker arm (46) and counteracting the lifting force (Fl) for enforcing a return movement (R) of the actuation movement.

11. The valve actuation assembly (40) of claim 10, wherein a contour of the cam control section of the intermediate guidance face (63) and the shape of the cam lobe (58) define a first valve actuation mode, and/or
a contour of the cam control section and/or the decoupling section of the intermediate guidance face (63) define the lifting movement of a second valve actuation mode and the change of the tilt angle (α) at angles larger 180° defines the return movement of the valve actuation movement of the second valve actuation mode.

12. An internal combustion engine (10) comprising:

the valve actuation assembly (40) of claim 10 or claim 11;
a cylinder head (24) with a valve opening (28) fluidly connecting a combustion chamber (26) with a charge air system; and
a valve (30),
wherein the valve (30) comprises a valve stem (70) with a valve head (70A) for closing the valve opening (28), a valve stem guidance (71) for guiding a movement of the valve stem (70), and a valve spring (52) configured such that its

spring force acts as a biasing force (Fb), in particular by acting via the valve stem (70) onto the rocker arm (46), thereby, during the first valve actuation mode, ensuring that the rocker arm (46) follows the return movement (R) of the push rod (48) and, during the second valve actuation mode, closing the valve decoupled from the cam lobe interaction.

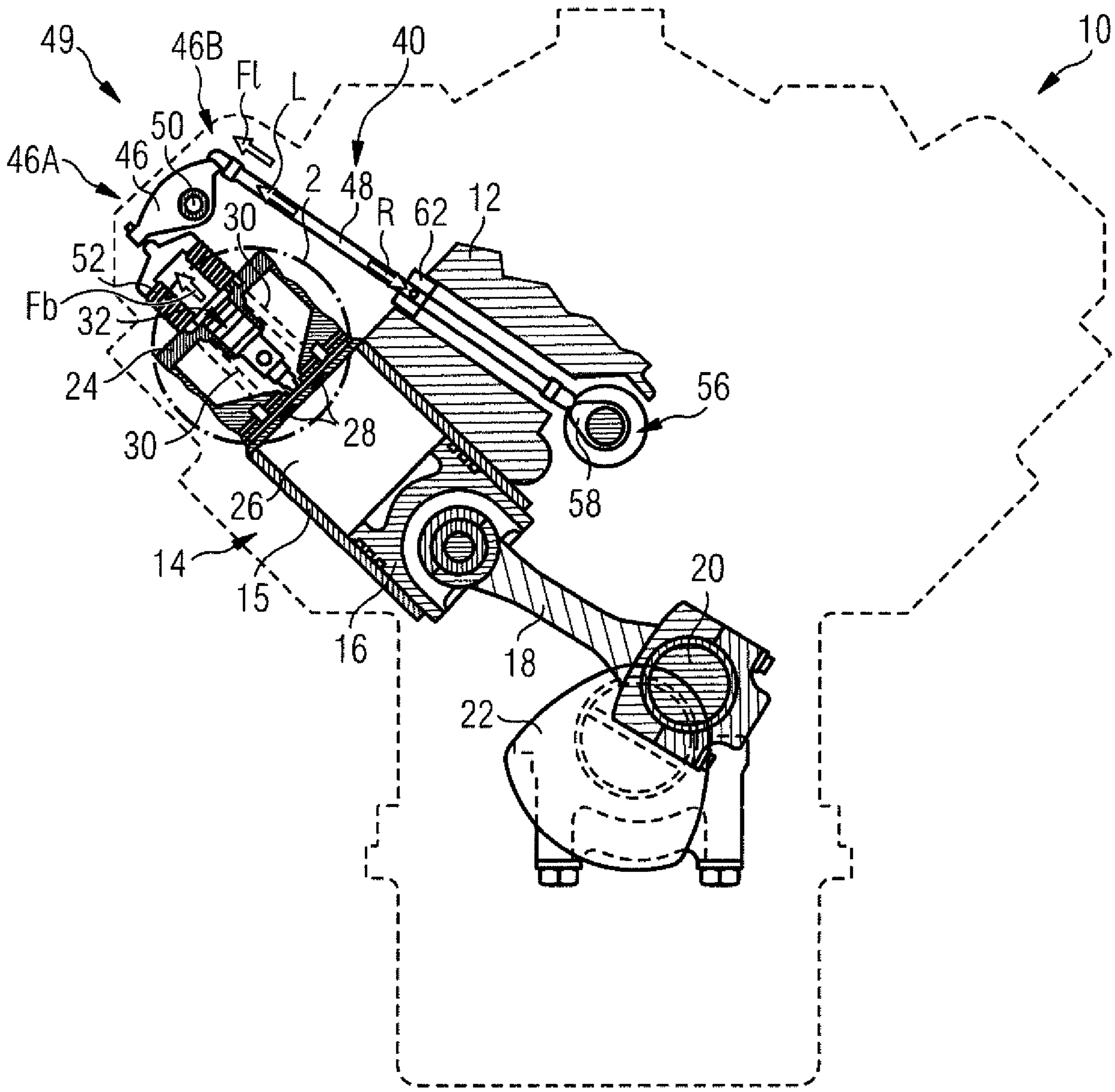
13. A method for operating a valve (30) of an engine (10) with adjustable closing times, the engine (10) comprising a split push rod based valve actuation system such as a valve actuation assembly (40) according to any one of claim 1 to claim 11, the method comprising:

selectively modifying a tilt angle (α) between a rocker part (48A) and a cam part (48B) of the split push rod to at least partly decouple the actuation movement of the push rod (48) from the shape of the cam lobe (58).

14. The method of claim 14, wherein modifying a tilt angle (α) comprises increasing the tilt angle (α) up to beyond 180°, wherein a change and in particular a change rate at tilt angles (α) beyond 180° is decoupled from the cam lobe (58).

15. The method of claim 13 or claim 14, wherein modifying a tilt angle (α) comprises essentially maintaining the tilt angle (α) below 180° during the lifting movement (L) of the push rod (48), in particular when opening the valve (30), and above 180° during the return movement (R), which is decoupled from the cam lobe (58), in particular when closing the valve (30).

FIG 1



49
46B
Fl
L
40
10
50
46A
46
2
48
R
62
12
30
52
Fb
32
24
30
28
56
58
26
14
15
16
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20
22

FIG 2

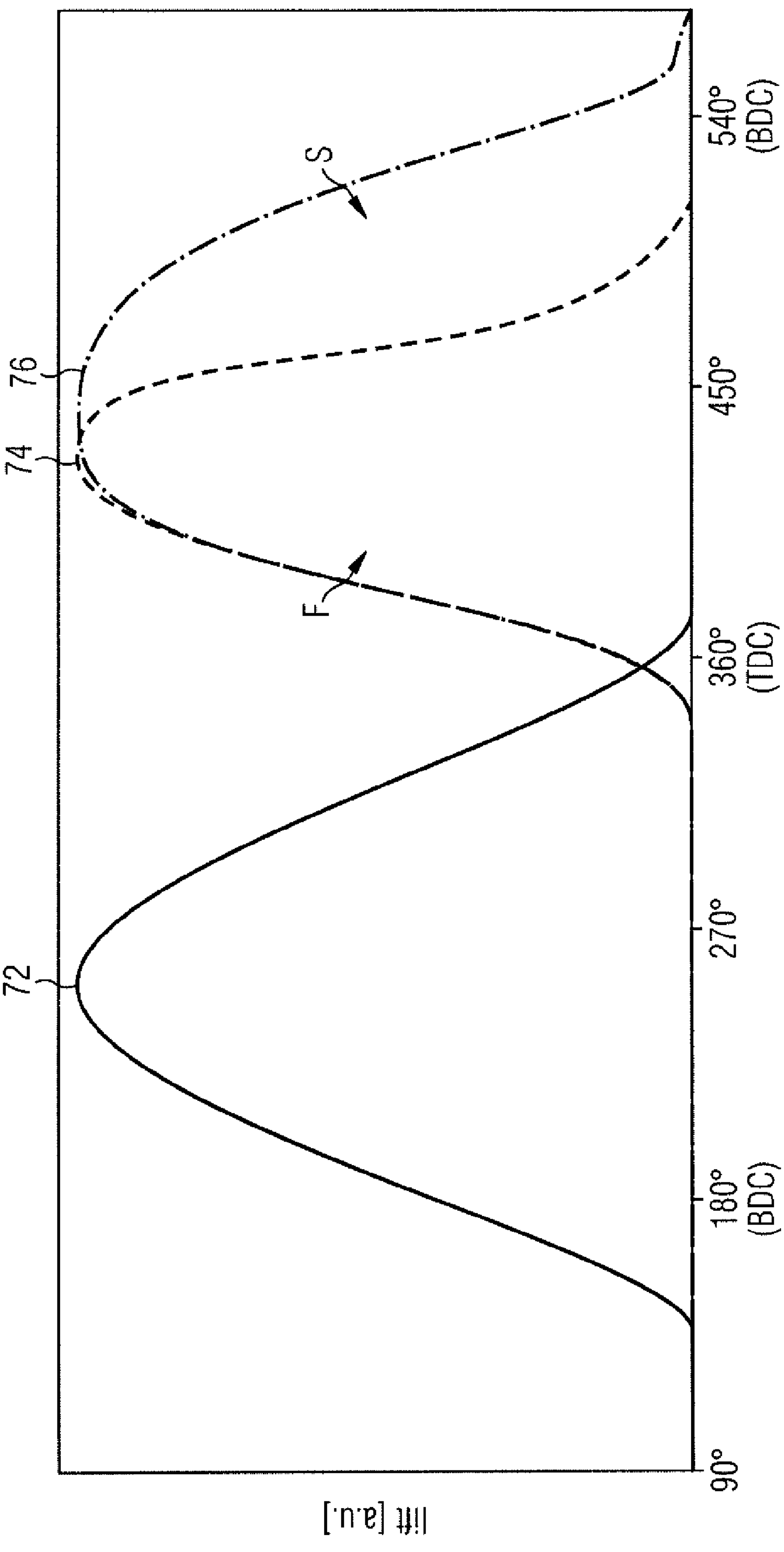
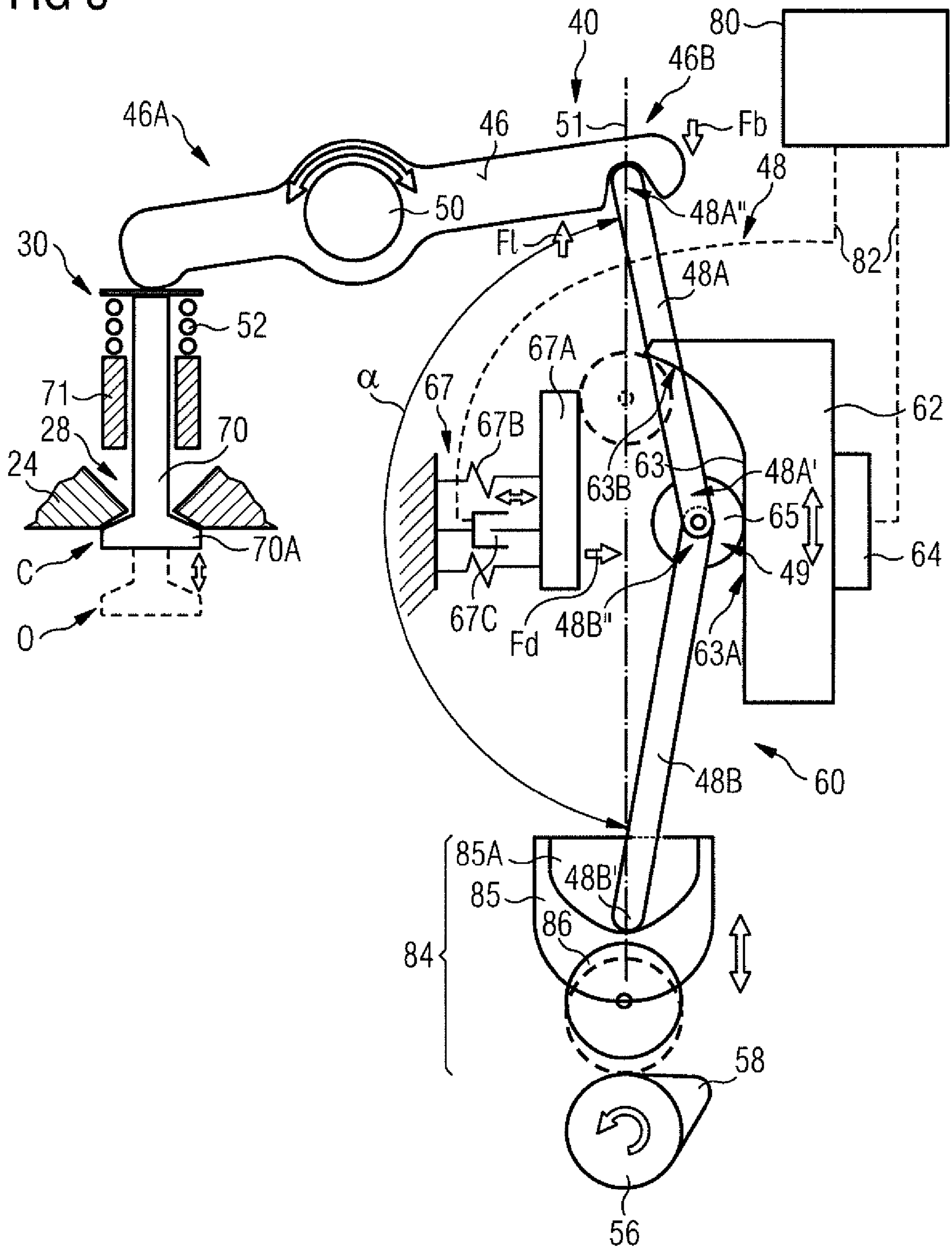


FIG 3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Fb
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71
67B
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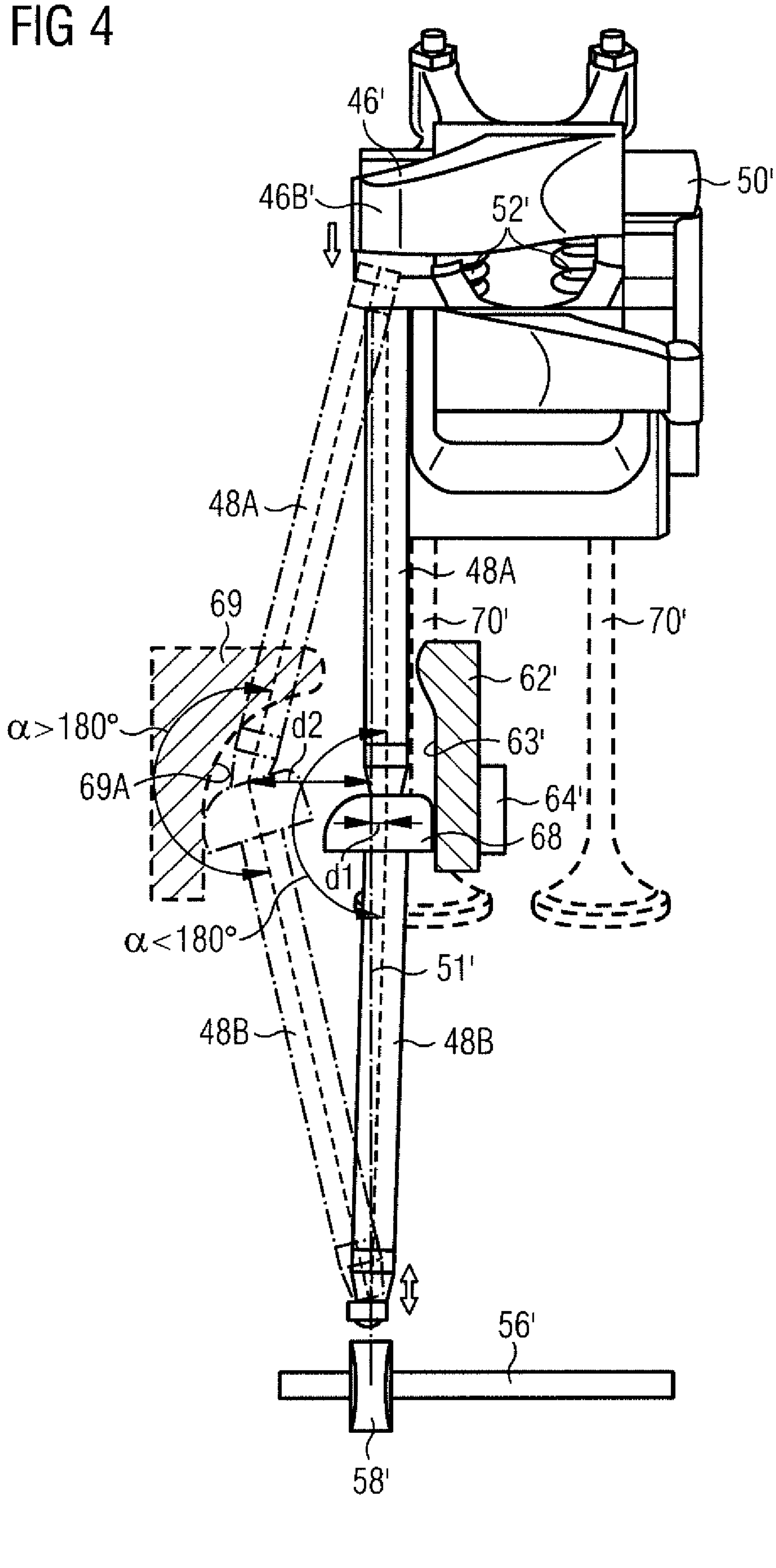
70
63
48A'
24
63B
65
64
C
70A
49
67C
Fd
48B''
O
63A
48B
60
85A
48B'
85
86
84
58
56

FIG 4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52'
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48A
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70'
69
62'
α>180°
d2
63'
69A
64'
68
d1
α<180°
51'
48B
48B
56'
58'

Europäisches Patentamt
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EUROPEAN SEARCH REPORT

Application Number
EP 15 16 0887

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 94/21897 A1 (WRIDE DONALD CHARLES [AU]) 29 September 1994 (1994-09-29) * the whole document * -----	1,10	INV. F01L13/00 F01L1/14
X	DE 43 30 913 A1 (MAK MASCHINENBAU KRUPP [DE]) 16 March 1995 (1995-03-16) * the whole document * -----	1,10	

TECHNICAL FIELDS SEARCHED (IPC)
F01L

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	10 September 2015	Klinger, Thierry

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10-09-2015

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82