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(54) **METHOD AND ARRANGEMENT FOR CONTROLLING A COMBUSTION ENGINE**

(57) The invention relates to a method for optimizing an internal combustion engine with variable compression ratio for a direct start, the engine comprising a crankcase comprising a crankshaft connected to at least two pistons; and a cylinder block comprising at two cylinders. The method involves determining a crank angle adjustment required to achieve a crank angle suitable for ignition in a first cylinder and operating at least one actuator (223; 423) to displace the cylinder block relative to the

crankcase for adjustment of compression ratio and cylinder offset (O). This causes a simultaneous displacement of the cylinder block (217) in the direction of the cylinder axis (Y), and transverse to the cylinder axis (Y) and the crankshaft axis (X). The crank angle adjustment is performing using a mechanism (428; 528; 430) connecting the cylinder block and the crankshaft, which mechanism (428; 528; 430) is actuated by the cylinder block displacement.

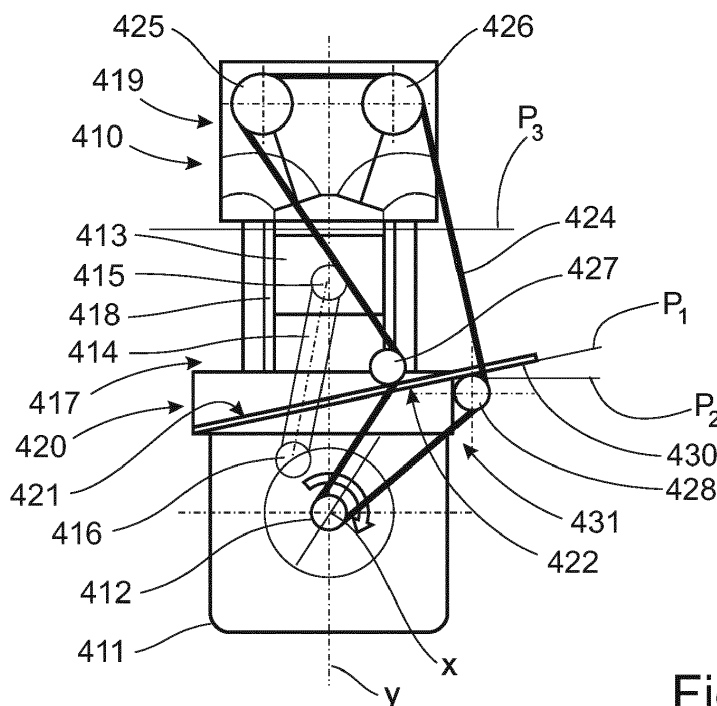


Fig.4A

## Description

### TECHNICAL FIELD

**[0001]** The invention relates to a method and an arrangement for controlling an internal combustion engine for direct start of the internal combustion engine, in particular for start-stop operation, using an arrangement for simultaneous adjustment of compression ratio and cylinder offset

### BACKGROUND OF THE INVENTION

**[0002]** Using start-stop operation for internal combustion engines is a common way of reducing fuel consumption, for instance by stopping the engine temporarily at traffic lights, during periods when the vehicle is sailing or coasting, or in response to a request for electric operation in a hybrid vehicle. When the engine is re-started it is advantageous to ensure that the crankshaft is positioned so that one of the pistons is in a suitable position for cranking.

**[0003]** A known device for starting an internal combustion engine is disclosed in WO 91/16538, in which an electric motor serving as generator and starter is coupled to a crankshaft. Prior to the internal combustion engine being started, the crankshaft is brought by means of the starter into a position in which the pistons are aligned in the most advantageous alignment for the next start. The rotational position of the crankshaft is determined via a sensor which is provided.

**[0004]** In the case of conventional ignition or injection systems of four-stroke engines, sensors for identifying the top dead center (TDC) of the pistons are provided on the flywheel of the starting motor. In addition, a sector identifying means for the sectors 0 - 360 degrees and 360 - 720 degrees of the crankshaft is provided. In order to allow a control unit connected to the ignition or injection system to determine the current position of the crankshaft from the sensor signals, the starter has to rotate the crankshaft through more than one revolution, and up to a maximum of 660 degrees in the case of a six-cylinder motor.

**[0005]** In the case of modern starting/stopping systems, it is now possible to reach the starting speed for the engine after a rotational angle of the crankshaft of just 90 degrees. It is therefore a disadvantage that despite reaching the starting speed, firing cannot be carried out until the control unit has determined the current position of the crankshaft, since the exact relative positions between the crankshaft and the pistons is demanded by the control unit before ignition takes place.

**[0006]** During positioning of the crankshaft, the piston arranged to perform the first firing must be displaced by the starter/generator towards and past the TDC during a compression cycle. Hence, the rotation of the crankshaft will require a relatively large torque from the starter/generator, especially for engines operated at relatively high

compression ratios.

**[0007]** The object of the invention is to provide an improved method and arrangement for controlling an internal combustion engine for direct start in order to overcome the above problems.

### INVENTION

**[0008]** The above problems have been solved by a method as claimed in the appended claims.

**[0009]** In the subsequent text, the term "engine" is used to denote an internal combustion engine, which engine can be either a spark ignited engine, a spark-assisted compression ignition engine, a flash-assisted compression ignition engine, or a conventional compression ignited engine. Further, when referring to the position of a crankshaft the terms "crankshaft rotational angle", "crank angle" or the abbreviation CAD may be used interchangeably in the text.

**[0010]** A preferred embodiment of the invention relates to a method for optimizing an internal combustion engine with variable compression ratio for a direct start. The engine comprises a crankcase comprising a crankshaft connected to at least two pistons; and a cylinder block comprising at least two cylinders, each provided with intake and exhaust valves. The method comprising the steps of:

- detecting that the internal combustion engine has stopped;
- detecting a current crank angle;
- determining which cylinder is next to fire in a predetermined cylinder firing order;
- determining a crank angle adjustment required to achieve a crank angle suitable for ignition in this first cylinder
- operating at least one actuator to displace the cylinder block relative to the crankcase for adjustment of compression ratio and cylinder offset;
- causing a simultaneous displacement of the cylinder block in the direction of the cylinder axis, and transverse to the cylinder axis and the crankshaft axis; and
- performing the crank angle adjustment using a mechanism connecting the cylinder block and the crankshaft, and which mechanism is actuated by the cylinder block displacement.

**[0011]** According to the invention, the method is carried out when the ignition is turned off, either manually by the driver or automatically by a control unit used for controlling a start-stop function, e.g. when stopping the engine temporarily at traffic lights. The method is completed prior

to engine re-start to ensure that the crankshaft is positioned so that one of the pistons is in a suitable position for direct start.

**[0012]** As indicated above, the method involves detecting the position of the crankshaft when the engine has stopped. This can be performed by means of known sensors connected to a control unit.

**[0013]** According to one example, a flywheel having an outer circumference provided with, for example, a toothing arrangement can be provided with a position marker for the crankshaft. The position marker reproduces the rotational position of the crankshaft and therefore the current position of each of the pistons of the internal combustion engine can be determined. The ignition in the combustion chambers of the internal combustion engine can be initiated at a suitable time by reference to the current position of the pistons. The position marker is realized by a relatively large tooth spacing in the toothing arrangement, so that a position sensor in the vicinity of the toothing arrangement identifies the rotational position of the crankshaft when the position marker rotates past the position sensor. The sensor can be a pulse counter or inductive pickup. If the signal of a camshaft position sensor of the internal combustion engine is added, then the position of the pistons can be determined exactly via the rotational position of the crankshaft. This makes it possible, for example, in the case of a spark-ignited internal combustion engine to identify whether a piston is at the beginning of ignition or at the beginning of induction. However, the invention is not restricted to spark-ignited internal combustion engines. In the same or modified manner, the invention is also suitable for self-igniting internal combustion engines (diesel). Instead of the toothing arrangement, a perforated disc may also be used.

**[0014]** During the switching-off process of the internal combustion engine, the crankshaft will come to a standstill in a rest position. When the engine is approaching its rest position the pressures of the previous, last cylinder in the firing order and the next cylinder in turn to fire will attempt to balance out. The previous, first cylinder will be in its expansion stroke while the next, second cylinder will be in its compression stroke. The momentum of the system as the engine revs down will cause the piston in the second cylinder to come to rest at least half way into the compression cycle, i.e. less than 90 crank angle degrees before top dead center.

**[0015]** The control unit is connected to one or more suitable sensors for detecting the exact position of the crankshaft and/or a camshaft when the rotation comes to a stop. Using the crankshaft position, camshaft position and/or other engine related data, the control unit can determine which cylinder is next to fire in the predetermined cylinder firing order for the engine in question. The control unit can then determine the crank angle adjustment required for rotating the crankshaft from the current, first crank angle to a desired, second crank angle suitable for performing ignition during a subsequent direct start.

**[0016]** In a spark ignition (SI) engine a direct start can be carried out by performing a fuel injection in the next cylinder is to fire in the predetermined cylinder firing order and igniting the air-fuel mixture using a spark plug. In a compression ignition engine a direct start can be carried out by performing a fuel injection in the next cylinder is to fire in the predetermined cylinder firing order, as well as into a pre-combustion chamber connected to the cylinder. An ignition is performed in the pre-combustion chamber in order to ignite the air-fuel mixture in the cylinder. Normal engine operation can then be resumed.

**[0017]** As indicated above the method involves operating at least one actuator to displace the cylinder block relative to the crankcase for adjustment of compression ratio and cylinder offset. This requires simultaneous displacement of the cylinder block in the direction of the cylinder axis and displacement of the cylinder block transverse to the cylinder axis and the crankshaft axis. Suitable guides are provided for controlling the relative displacement between the cylinder block and the crankcase.

**[0018]** As indicated above, a displacement of the cylinder block will act on a mechanism connecting the cylinder block and the crankshaft. This causes an adjustment of the crank angle from the current, first crank angle to the desired, second crank angle. Suitable mechanisms for this purpose can be connected directly to the crankshaft, which will then control the displacement of each camshaft via the transmission provided, or be connected to the transmission between crankshaft and camshaft. Such mechanisms will be discussed in further detail below.

**[0019]** According to one example, simultaneous adjustment of compression ratio and cylinder offset can be achieved by displacing the cylinder block along planar guide surfaces arranged at an angle to a first plane at right angles to the cylinder axis. The plane along which the cylinder block is displaced will intersect the first plane located at right angles to the cylinder axis in a line parallel to the crankshaft axis. The angle between the guide surfaces and the first plane is an acute angle within the range 0° to 60°. Further the size of the angle will have direct effect on the compression ratio and cylinder offset. For instance a relatively large angle, such as 50-60°, will cause a relatively larger and faster change in compression ratio and a relatively small change in cylinder offset during a displacement. Similarly, a relatively small angle, such as 5-10°, will cause a relatively smaller and slower change in compression ratio and a relatively large change in cylinder offset. In practice, a minimum useful angle corresponds to a slope of approximately 1/20, preferably within a range of 1/7 to 1/3.

**[0020]** The cylinder offset can vary from an initial negative offset or from zero offset, where the cylinder axis intersects the crankshaft axis, and up to a maximum value equal to the crank radius. In practical use, positive/negative offset up to +/- 2/3 of the crankshaft crank radius can be selected. For the purpose of this invention,

a positive offset is desired for performing a direct start.

**[0021]** Alternative examples for performing a simultaneous adjustment of compression ratio and cylinder offset can be achieved by displacing the cylinder block along cylindrical guide surfaces comprising generatrices parallel to the crankshaft axis, or by displacing the cylinder block at right angles to the crankshaft axis, along a fixed path having a predetermined curvature, e.g. by means of an excenter mechanism or guiding tracks (coulisse).

**[0022]** According to a second example, simultaneous adjustment of compression ratio and cylinder offset can be achieved by displacing the cylinder block along part-cylindrical guide surfaces comprising generatrices parallel to the crankshaft axis. In this example, operation of each actuator will cause the cylinder block to slide along the curved guide surfaces until the compression ratio and cylinder offset for the desired engine operating point is achieved. When the desired displacement has been performed each actuator is locked in position to prevent further displacement.

**[0023]** In the above examples, the guide surfaces can be located at either end of the cylinder block and/or between individual cylinders between the cylinder block and the crankcase. The guide surfaces comprise surfaces guiding the cylinder block along the plane of displacement, as well as additional angled, profiled or interlocking portions arranged to prevent movement of the cylinder block in the longitudinal direction of the crankshaft. The guide surfaces can also comprise two or more parallel rods, having a cylindrical or profiled cross-section, cooperating with guide surfaces arranged to at least partially enclose the rods.

**[0024]** Alternatively, the guide surfaces can be located along the front and rear sides of the cylinder block, extending parallel to the crankshaft. In this context, the terms "front" and "rear" are applicable to a transverse mounted engine. Such guide surfaces would also be provided with additional angled, profiled or interlocking portions arranged to prevent movement of the cylinder block in the longitudinal direction of the crankshaft.

**[0025]** According to a third example, simultaneous adjustment of compression ratio and cylinder offset can be achieved by displacing the cylinder block at right angles to the crankshaft axis, along a fixed path having a predetermined curvature. Suitable guide mechanisms for this purpose can be an excenter mechanism or guiding tracks (coulisse). For instance, an excenter mechanism can comprise two or more shafts located parallel to the crankshaft axis on opposite sides of the cylinder axis. The shafts are provided with cams or cranks and are rotated in the same direction to cause the cylinder block to be displaced relative to the crankcase along a curved path in the form of a quarter circle until the compression ratio and cylinder offset for the desired engine operating point is achieved. In the case of an excenter mechanism this can be rotated through up to 90° between two end positions. When the desired displacement has been performed each shaft is locked in position to prevent further

displacement.

**[0026]** For an excenter mechanism, the cranks or cams on the respective shafts are preferably, but not necessarily of the same size. It is also possible to provide cranks or cams having different sizes on each side of the cylinder axis. In the latter case, the shaft comprising the smaller cranks or cams is limited to a maximum rotation of 90° between two end positions. Alternatively, if a guide mechanism in the form of guiding tracks or a coulisse is used, then the path can be given any suitable constant or variable curvature. This allows the relative changes in compression ratio and offset to be adapted to achieve the desired properties.

**[0027]** According to a fourth example simultaneous adjustment of compression ratio and cylinder offset can be achieved by displacing the cylinder block using cooperating first planar guide surfaces arranged at a first angle to a plane at right angles to the cylinder axis and cooperating second planar guide surfaces arranged at a second angle to a plane parallel to the cylinder axis. A first actuator, such as an excenter mechanism is connected to and arranged to act on a first wedge that is displaced at right angles to the cylinder axis while in contact with a first planar guide surface on the cylinder block to displace the cylinder block parallel to the cylinder axis in order to adjust the compression ratio. The first wedge is preferably arranged substantially below the cylinder block. The first wedge can be arranged to travel in guides fixed to the crankcase and arranged at right angles to the cylinder axis, wherein displacement of the cylinder block is achieved by angled cooperating first planar guide surfaces between the wedge and the cylinder block. In this case the wedge will travel in a plane at right angles to the cylinder axis. Alternatively, the first wedge can be arranged to travel in guides fixed to the crankcase and arranged at an angle to the cylinder axis, wherein displacement of the cylinder block is achieved by angled cooperating first planar guide surfaces between the wedge and the crankcase. In this case the wedge will travel along the angled plane of the guide surfaces, being displaced simultaneously at right angles to, and parallel with the cylinder axis. A second actuator, such as an excenter mechanism is connected to and arranged to act on a second wedge that is displaced parallel to the cylinder axis while in contact with a second planar guide surface to displace the cylinder block parallel to the cylinder axis in order to adjust the offset. The first and second angles can be selected independently within the same range of angles in order to provide the desired displacement in the respective directions.

**[0028]** The arrangement according to the fourth example allows both simultaneous and independent adjustment of compression ratio and offset, depending on the operating conditions of the engine. For the purpose of the current invention, the crank angle adjustment is performed using a mechanism connecting the cylinder block and the crankshaft, which mechanism is preferably actuated by the first actuator controlling the compression

ratio. Advantages with this arrangement is, for instance, that the offset can be set to an optimum value for direct start under conditions where the optimum compression ratio cannot be achieved, and that the offset can be controlled under conditions when it is not desired to change the compression ratio.

**[0029]** In the above examples, the plane along which the cylinder block is displaced will intersect the first plane located at right angles to the cylinder axis in a line parallel to the crankshaft axis. The angle between the guide surfaces and the first plane is an acute angle within the range 0° to 60°.

**[0030]** The guiding means arranged to guide the cylinder block relative to the crankcase can comprise guide surfaces located in or on the respective cylinder block and crankcase. Alternatively, an intermediate component comprising guide surfaces or a guide mechanism can be located between the crankcase and the cylinder block, wherein the intermediate component is attached to the cylinder block and the crankcase respectively.

**[0031]** The guide surfaces described above can be used as described in each example, or as combinations of several examples. Where suitable, a combination of different guide surfaces can be used, such as planar guide surfaces extending parallel to the crankshaft and planar guide surfaces extending transverse to the crankshaft at each end of the cylinder block to create a continuous guide surface around the periphery of the cylinder block. The latter combination can be applied both to planar guide surfaces and part-cylindrical guide surfaces.

**[0032]** In addition to the cooperation guide surfaces described above, the cylinder block and the crankcase can be provided with clamping means. The clamping means will allow relative displacement of the cylinder block and the crankcase along the plane of desired displacement, while preventing separation of the cooperating guide surfaces in the direction of the cylinder axis.

**[0033]** In order to prevent crankcase gases and oil from leaking out of the engine, flexible and/or displaceable sealing means are provided between the cylinder block and the crankcase.

**[0034]** Examples of suitable sealing means includes a frame defining a sealing plane around the circumference of the crankcase, wherein the cylinder block is in contact with and is movable relative to this sealing plane. The sealing plane can be flat, in the case planar guide surfaces, or curved, in the case of part-cylindrical or curved guide surfaces. Linear seals located along the direction of displacement can be attached to or integrated in the guide surfaces and can be of the same type as used for crankshaft seals. Alternative or additional sealing means can be of a dual barrier type, a labyrinth seal, or a similar suitable sealing means allowing relative displacement between the cylinder block and the crankcase. Depending on the type of adjustment means used, a combination of different types of sealing means can be applied. An outer seal in the form of a bellows or a similar flexible arrangement can be used for sealing out dust and parti-

cles from the ambient environment, as well as sealing in oil mist from the crankcase. The sealing means must be sufficient for maintaining a lower than atmospheric pressure in the crankcase.

**[0035]** The one or more actuators used for effecting the relative displacement of the cylinder block and the crankcase is preferably mounted on the crankcase, but can also be mounted on the cylinder block. Although a single actuator is possible, two or more actuators are preferred in order to ensure that wedging does not occur between cooperating guide surfaces. Actuators can act directly on the respective component to be displaced, or via a force amplifying means such as a suitable gearing. A non-exhaustive list of examples of suitable actuators comprises double acting fluid actuators, lead or ball screws, electric motors and servo motors. Fluid actuators can be provided with a controllable valve allowing movement to be prevented between operations. Similarly, screw actuators, electric motors and servo motors can be provided with a controllable locking means. Alternatively, screw actuators can be self-locking to prevent movement. A sensor, such as a position or proximity sensor, is provided to detect and monitor the position of at least one actuator, preferably each actuator, in order to allow the current compression ratio and cylinder offset to be monitored.

**[0036]** In operation, an engine control unit can determine a current operating point for the engine based on available engine related parameters detected by suitable sensors. Examples of such parameters are engine speed, load, fuel type and composition, as well as ambient conditions. This solution allows the compression ratio and offset settings to be adjusted to adapt the engine for wide areas of operation. The engine can be adapted to operate at low engine speeds and loads using a relatively high compression ratio and small positive and/or negative cylinder offset. The engine can be adjusted gradually, in steps or continuously, to be operated at high engine speeds and loads using a relatively low compression ratio and larger cylinder offset. Also, the displacement of the cylinder block from a high load range to a low load range can be performed faster. For a spark ignition (SI) engine a common compression ratio can be in the range 14-15:1. Using an engine according to the invention the compression ratio can be lowered to 7-7,5:1 by means of a cylinder block displacement.

**[0037]** This operating condition can be used for compression ignition (CI) engines, such as diesel engines, homogenous charge compression ignition (HCCI) engines and partially pre-mixed compression ignition (PP-CI) engine. During a cold start or during part load operation it is advantageous to use high compression ratios to achieve ignition and stable operation without misfire. This is also the case when operating at high exhaust gas recirculation (EGR) volumes at light loads. Under these conditions an engine can be operated at compression ratios of approximately 17-20, in combination with a relatively small negative or positive offset. When moving

towards operating points where the engine load is higher, the engine can be adjusted towards reduced compression ratios of approximately 13-15, in combination with an increased offset.

**[0038]** By reducing the compression ratio the cylinder volume increases and the work required for turning the crankshaft from the first crank angle to the second crank angle can be significantly reduced. Also, when a direct start is initiated, the reduced compression ratio will reduce the compression work required for subsequently firing cylinders, making the engine easier to start. By increasing the offset it is possible to reduce tangential cylinder forces and friction forces, while at the same time achieving a more effective crank torque arm and crank location.

**[0039]** As described above the method involves determining the crank angle adjustment required to displace a piston in the first cylinder to fire into a position after top dead center, where the crank angle is suitable for direct start. The first crank angle is determined by the control unit as the engine revs down and comes to a stop. The second crank angle is selected between 10 crank angle degrees after top dead center and 10 crank angle degrees before exhaust valve opening. Due to the geometry of the piston and piston pin in relation to the crankshaft axis and crank pin when a positive offset is used, the second crank angle is preferably set at 10 crank angle degrees or more after top dead center. Also, as the starting speed for the engine can be reached after a rotational angle of the crankshaft of just 90 crank angle degrees it is possible to start the engine from a crank angle as late as 10 crank angle degrees before exhaust valve opening. Preferably the crank angle is selected between 30 and 60 crank angle degrees after top dead center.

**[0040]** The invention involves controlling the mechanism to connect the cylinder block and the crankshaft when the internal combustion engine is stopped. In this text the term "mechanism" is defined as including the component parts required for converting the linear displacement of the cylinder block into a rotary motion that can be applied to the crankshaft and/or the camshaft transmission. Alternatively the mechanism can further be controlled to disconnect the cylinder block and the crankshaft prior to an engine start. This can be achieved by, for instance a controllable arm or a rack located on the cylinder block and connectable to a control wheel or gear wheel located on the crankcase for rotating the crankshaft directly, via the flywheel or camshaft pulley, or indirectly, via a chain, belt or intermediate gear wheel. In this context a control wheel is defined as a part of the camshaft transmission that ensures correct tension in the belt or chain at all times, and which provides a belt geometry that provides sufficient friction for the driving and driven shafts. The camshaft transmission can comprise at least one control wheel. The controllable arm is pivoted or displaced to be in driving connection with the gear during periods when the ignition is off in order to rotate the crankshaft to a desired crank angle. If a fixed

rack is used, then the control wheel can be operatively disconnected from the rack by means of a free-wheeling device, a clutch or a similar controllable device.

**[0041]** Alternatively, a control wheel located on the cylinder block can be in driving connection with a rack on the crankcase and with the camshaft transmission, such as a belt or chain, normally driven by the crankshaft. During a displacement of the cylinder block the relative movement between cylinder block and crankcase causes a rotation of the control wheel. The control wheel will then rotate the crankshaft to a desired crank angle via the camshaft transmission. The control wheel can be provided with a free-wheeling device allowing it to be disconnected from the rack and be driven by the camshaft transmission during normal engine operation.

**[0042]** A variant of the above cases is to initiate a displacement of the cylinder block during the switching-off process of the internal combustion engine, while the crankshaft is coming to a standstill in a rest position. When the engine is approaching its rest position, the controllable device can be controlled to connect the cylinder block and the crankshaft in order to use the momentum of the engine to cause a displacement of the cylinder block. In this way controllable device can be timed to enable the crankshaft to drive the control wheel via the camshaft transmission to displace the cylinder block relative to the crankcase, in order to assist the actuator in performing a desired crank angle adjustment.

**[0043]** In both the above cases it is assumed that the available displacement range is sufficient for using a 1:1 ratio between the mechanism and the control wheel to achieve the desired crank angle. However, if this is not the case then a suitable gearing or similar device can be provided. According to one example a control wheel comprising two gear wheels side-by-side can be provided for the above control wheel in order to achieve a sufficient gear ratio. For instance, the control wheel can comprise a relatively smaller gear wheel connected to the cylinder block and a relatively larger gear wheel acting on the crankshaft, camshaft pulley or the camshaft transmission. The gear ratio between the smaller and larger gear wheels is selected depending on the available displacement range between cylinder block and the crankcase, and the rotational angle required to achieve the desired crank angle.

**[0044]** Under certain operating conditions, e.g. if the engine is operated at a relatively low compression ratio and high offset, the control unit may detect that the current relative position between the cylinder block and the crankcase is such that a desired crank angle rotation will not be possible. In such cases it can be necessary to perform a displacement of the cylinder block towards a higher compression ratio and lower offset when the engine is switched off and is revving down. This operation can also be used for stopping the engine more rapidly, as the increased compression ratio will assist in braking the engine.

**[0045]** The mechanism for adjusting the crank angle

can be designed to reflect the number of cylinders in the engine. Depending on the number of cylinders the distance, measured in crank angle degrees (CAD), between firing events will vary. In a four-cylinder, four-stroke engine the distance between two firing events is 180 CAD. In a four-stroke engine the four cycles are compression, expansion exhaust and intake, performed during two full revolutions of the crankshaft and making up a total of 720 CAD. When an engine of this type is running down with the ignition off, and stopped the pressures of the previous, last cylinder in the firing order and the next cylinder in turn to fire will attempt to balance out. The previous cylinder will be in its expansion stroke while the next cylinder will be in its compression stroke, whereby the momentum of the system will cause the piston in the next cylinder to come to rest at least half way into the compression cycle, i.e. less than 90 CAD before top dead center (TDC). Hence the distance required to rotate the crankshaft is at least 90 CAD plus the angle up to the desired firing position for direct start. According to the above examples, the minimum and maximum rotation required could be between 100 CAD ( $90^\circ+10^\circ$ ) and an angle up to 10 CAD before exhaust valve opening, respectively, depending on the exhaust valve opening timing. Preferably, the minimum and maximum rotation required could be between 120 CAD ( $90^\circ+30^\circ$ ) and 150 CAD ( $90^\circ+60^\circ$ ). Using the known possible displacement range required for achieving the desired crank angle it is possible to adapt the gear ratio of the mechanism to provide a sufficient range. When performing a displacement, the cylinder block is displaced towards the lowest compression ratio possible within the range of desired crank angles. Alternatively the cylinder block is displaced towards the compression ratio available at an optimum crank angle for start.

**[0046]** Similar adaptations are made for, for instance, three- or six-cylinder four-stroke engines where the distances between two firing events are 240 CAD and 120 CAD, respectively. Hence, in accordance with the above example the preferred the minimum and maximum crankshaft rotation required could be between 150 CAD ( $120^\circ+30^\circ$ ) and 180 CAD ( $120^\circ+60^\circ$ ) for a three cylinder engine, and between 90 CAD ( $60^\circ+30^\circ$ ) and 120 CAD ( $60^\circ+60^\circ$ ) for a six cylinder engine.

**[0047]** The invention also relates to an internal combustion engine comprising a crankcase with a crankshaft connected to at least two pistons and a cylinder block comprising at least two cylinders, each provided with intake and exhaust valves. The cylinder block is displaceable relative to the crankcase by at least one actuator connected between the cylinder block and the crankcase, wherein guiding means is arranged to guide the cylinder block relative to the crankcase for simultaneous adjustment of compression ratio and cylinder offset when the actuator is operated. The actuator causes a translator displacement of the cylinder block in a direction at right angles to the crankshaft axis. The engine further comprises a sensor arranged to detect a current, first crank

angle when the engine has stopped and a control unit arranged to determine which cylinder is next to fire in a predetermined cylinder firing order based on the detected crank angle and to determine a crank angle adjustment required to achieve a desired, second crank angle suitable for ignition in that cylinder. In order to perform the required crank angle adjustment a mechanism is arranged to connect the cylinder block and the crankshaft, so that a predetermined displacement the cylinder block by the actuator causes turning of the crankshaft to adjust the crank angle to the second crank angle.

**[0048]** The at least one actuator is arranged to displace the cylinder block and perform a simultaneous reduction of the compression ratio and increase of the offset during the crank angle adjustment. This requires simultaneous displacement of the cylinder block in the direction of the cylinder axis and displacement of the cylinder block transverse to the cylinder axis and the crankshaft axis. Suitable guides are provided for controlling the relative displacement between the cylinder block and the crankcase. A displacement of the cylinder block will act on a mechanism connecting the cylinder block and the crankshaft. This causes an adjustment of the crank angle from the current, first crank angle to the desired, second crank angle. Suitable mechanisms for this purpose can be connected directly to the crankshaft, which will then control the displacement of each camshaft via the transmission provided, or be connected to the transmission between crankshaft and camshaft. Such mechanisms will be discussed in further detail below.

**[0049]** In connection with a direct start, it is desirable to reduce the compression ratio and increase the offset simultaneously over at least a portion of a displacement range during the crank angle adjustment. The control unit is arranged to determine the crank angle adjustment required to displace the piston in the next cylinder to fire into a position after top dead center, where the crank angle is suitable for direct start. According to a first example, the second crank angle can be selected between 10 crank angle degrees after top dead center and 10 crank angle degrees before exhaust valve opening. According to a second example, the second crank angle can be selected between 30 and 50 crank angle degrees after top dead center.

**[0050]** The mechanism performing the crank angle adjustment is arranged to connect the cylinder block and the crankshaft when the internal combustion engine is stopped. The mechanism is operatively connected to the crankshaft during periods when the ignition is off in order to rotate the crankshaft to a desired crank angle. The mechanism can further be controlled to disconnect the cylinder block and the crankshaft prior to an engine start.

**[0051]** The mechanism can comprise a controllable arm located on the cylinder block and connectable to a control wheel, or gear wheel located on the crankcase for rotating the crankshaft directly, via the flywheel or camshaft pulley, or indirectly, via a gear wheel. The controllable arm is pivoted or displaced to be in driving con-

nection with the gear during periods when the ignition is off in order to rotate the crankshaft to a desired crank angle. Alternatively, a control wheel located on the cylinder block can be in driving connection with a rack on the crankcase and with the camshaft transmission, such as a belt or chain, normally driven by the crankshaft. During a displacement of the cylinder block the relative movement between cylinder block and crankcase causes a rotation of the control wheel. The control wheel will then rotate the crankshaft to a desired crank angle via the camshaft transmission. The control wheel can be provided with a free-wheeling device allowing it to be disconnected from the rack and be driven by the camshaft transmission during normal engine operation.

**[0052]** If the available displacement range between the cylinder block and the crankcase is not sufficient for using a 1:1 ratio between driving and driven wheels to achieve the desired crank angle then a suitable gearing or similar device can be provided to increase the gear ratio.

**[0053]** Simultaneous adjustment of compression ratio and cylinder offset can be achieved by displacing the cylinder block along planar guide surfaces arranged at an angle to a first plane at right angles to the cylinder axis. The plane along which the cylinder block is displaced will intersect the first plane located at right angles to the cylinder axis in a line parallel to the crankshaft axis. The angle between the guide surfaces and the first plane is an acute angle within the range  $0^{\circ}$  to  $60^{\circ}$ . The size of the angle can be selected to provide a desired range for compression ratio and cylinder offset. Alternative examples for performing a simultaneous adjustment of compression ratio and cylinder offset can be achieved by displacing the cylinder block along cylindrical guide surfaces comprising generatrices parallel to the crankshaft axis, or by displacing the cylinder block at right angles to the crankshaft axis, along a fixed path having a predetermined curvature, e.g. by means of an excenter mechanism or guiding tracks (coulisse).

**[0054]** The invention also relates to a vehicle comprising an internal combustion engine for optimizing an internal combustion engine with variable compression ratio for a direct start as described above.

**[0055]** It is particularly advantageous that a reliable direct starting of the internal combustion engine can be carried out with a conventional, and therefore cost-effective, determination of the rotational position of the crankshaft. The invention allows simultaneous adjustment of the crank angle, compression ratio and cylinder offset using a single actuator type. A reduced compression ratio will reduce the compression work required for subsequently firing cylinders, making the engine easier to start. By increasing the offset it is possible to reduce tangential cylinder forces and friction forces, while at the same time achieving a more effective crank torque arm and crank location. The same displacement used for these adjustments is used for performing the crank angle adjustment required to displace a piston in the first cylinder to fire into a piston after top dead center, where the crank an-

gle is suitable for direct start. By means of the rapid revving-up of the internal combustion engine in less than one complete revolution of the crankshaft, possibly at little as a quarter of a revolution, the crank case of the internal combustion engine can advantageously be prevented from slipping into a natural frequency of the engine assembly.

## FIGURES

**[0056]** In the following text, the invention will be described in detail with reference to the attached drawings. These schematic drawings are used for illustration only and do not in any way limit the scope of the invention. In the drawings:

Figure 1 shows a schematically indicated vehicle with an engine suitable for use with a method according to the invention;

Figure 2A-B show a side view of an internal combustion engine with variable compression and offset;

Figure 3 shows a schematic diagram of pressure vs. crank angle degrees;

Figure 4A-B show a side view of an internal combustion engine with a mechanism for adjusting the crank angle;

Figure 5 shows a side view of an alternative mechanism for the engine in Fig.4B.

## DETAILED DESCRIPTION

**[0057]** Figure 1 shows a schematically indicated vehicle 111 provided with an internal combustion engine 112 according to the invention. The vehicle 111 is further provided with a transmission arrangement 113 connected to the engine 112. The engine 112 and the transmission 113 is controlled by an electronic control unit (ECU) 114. The transmission 113 is controlled to select a gear ratio between the engine 112 and a pair of driven wheels 115, 116. Although the figure indicates a transmission for a rear wheel drive vehicle, the invention is not limited to any particular type of transmission.

**[0058]** The engine 112 is provided with a position sensor 121, in this example located adjacent a flywheel (not shown) having an outer circumference provided with a toothing arrangement to provide position markers for the engine crankshaft (not shown). The position markers reproduce the rotational position of the crankshaft and therefore the current position of each of the pistons of the engine 112 can be determined by the ECU 114. The ignition in the combustion chambers of the internal combustion engine can be initiated at a suitable time by reference to the current position of the pistons. The position sensor 121 is located in the vicinity of the toothing ar-



rangement that identifies the rotational position of the crankshaft when the position markers rotate past the position sensor 121. The sensor 121 can be a pulse counter or inductive pickup. An optional, second position sensor 122 connected to the ECU 114 can be provided for determining the position of at least one camshaft in the engine 112. If the signal of a camshaft position sensor 122 of the engine 112 is detected, then the position of the pistons can be determined exactly via the rotational position of the crankshaft.

**[0059]** Figure 2A shows a side view of an internal combustion engine 210 with variable compression and offset. The internal combustion engine 210 comprises a crankcase 211 having a crankshaft 212 connected to at least two pistons 213 (one shown), via a connecting rod 214. The connecting rod 214 is connected to the piston 213 by a piston pin 215 and to a crank 216 of the crankshaft 212. The crankshaft 212 has a central axis X in the longitudinal direction of the engine 210. The engine 210 further comprises a cylinder block 217 comprising at least one cylinder 218 (one shown) in which the piston 213 can perform a reciprocating motion. A cylinder block 219, comprising at least one intake valve and at least one exhaust valve controlled by a respective camshaft 225, 226, is mounted on the cylinder block 217. The position sensors 121, 122 described in Figure 1 are schematically indicated in Figure 2A.

**[0060]** The cylinder 218 has a central axis Y at right angles to the crankshaft axis X. In the example in Figure 2A, simultaneous adjustment of compression ratio CR and cylinder offset can be achieved by displacing the cylinder block 217 along opposed, contacting planar guide surfaces 221, 222 arranged in an angled first plane P1. A first guide surface 221 is located on the crankcase 211 and a second guide surface is located on the cylinder block 217. The first plane P1 is arranged at an angle  $\alpha$  relative to a second plane P2 at right angles to the cylinder axis Y, which angle can be selected between 0° and 60°. An actuator 223 for controlling the relative displacement of the crankcase 211 and the cylinder block 217 is located between the crankcase 211 and the cylinder block 217. In the example shown in Figure 2A, the actuator 223 is mounted onto the crankcase 211 in order to act on the cylinder block 217. The schematically indicated actuator can be operated by a suitable hydraulic, electric or mechanical means.

**[0061]** Figure 2B shows a side view of the engine in Figure 2A after actuation of the actuator 223. As in Figure 2A the internal combustion engine 210 comprises a crankcase 211 having a crankshaft 212 connected to a piston 213 via a connecting rod 214. The connecting rod 214 is connected to the piston 213 by a piston pin 215 and to a crank 216 of the crankshaft 212. The crankshaft 212 has a central axis X in the longitudinal direction of the engine 210. The engine 210 further comprises a cylinder block 217 comprising at least one cylinder 218 in which the piston 213 can perform a reciprocating motion. A cylinder block 219 comprising at least one intake valve

and at least one exhaust valve for each cylinder is mounted on the cylinder block 217. The cylinder 218 has a central axis Y at right angles to the crankshaft axis X.

**[0062]** As indicated in Figure 2B simultaneous adjustment of compression ratio CR and cylinder offset has been achieved by displacing the cylinder block 217 along opposed, contacting planar guide surfaces 221, 222 arranged in an angled first plane P1. The first plane P1 is arranged at an angle  $\alpha$  relative to a second plane P2 at right angles to the cylinder axis Y.

**[0063]** This displacement along the first plane P1 can be divided into two components. A first component causes an upward displacement of the cylinder block 217 in the direction of the cylinder axis Y in the direction of the arrow A1. The upper surface of the piston 213, which is located in the plane P3 in Figure 2A, will effectively be located further from the cylinder block 219, as indicated by the plane P4 in Figure 2B. The clearance volume will thereby be increased by the volume enclosed between the two planes P3 and P4, causing a lowered compression ratio. A second component causes a transverse displacement of the cylinder block transverse to the cylinder axis and the crankshaft axis, in the direction of the arrow A2. This causes a parallel displacement of the cylinder axis Y relative to the crankshaft axis X, resulting in a positive offset O, which is preferably up to 2/3 of the crank pin radius. The angle  $\alpha$  between the first and second planes P1, P2 and the crank pin radius determines the possible variation in compression ratio and the required displacement range of the guiding means between the cylinder block and the crankcase.

**[0064]** Figures 2A and 2B are used to illustrate the principle of a variable compression ratio engine providing simultaneous adjustment of compression ratio and cylinder offset. According to the invention the same displacement is used for simultaneously adjusting the crank angle of the crankshaft to a position suitable for direct start. The mechanism for achieving this function will be described in further detail below.

**[0065]** Figure 3 shows a schematic diagram of pressure vs. crank angle degrees (CAD) for the operating cycles of the three consecutive firing cylinders in a four-stroke four cylinder engine. In a four-stroke engine the four cycles are compression, expansion exhaust and intake, performed during two full revolutions of the crankshaft and making up a total of 720 CAD. When the engine is approaching its rest position the pressures of the previous, last cylinder C1 in the firing order and the next cylinder C2 in turn to fire will attempt to balance out. The previous, first cylinder C1 will be in its expansion stroke while the next, second cylinder C2 will be in its compression stroke. The momentum of the system as the engine revs down will cause the piston in the second cylinder C2 to come to rest at least half way into the compression cycle, i.e. less than 90 CAD before top dead center TDC2. In this example, the next cylinder to fire in a subsequent engine start will be the second cylinder C2.

**[0066]** Hence the distance required to rotate the crank-

shaft into a desired crank angle position for start is a first crank angle adjustment CA1 of at least 90 CAD plus an additional crank angle adjustment past top dead center TDC2 up to the desired firing position for direct start. According to the example in Figure 3, the additional crank angle adjustment is to be performed up to at least a second angle adjustment CA2 of 30 CAD, but no more than a third angle adjustment CA3 of 60 CAD. In the current example the minimum and maximum rotation required would be between 120 CAD ( $90^\circ+30^\circ$ ) and 150 CAD ( $90^\circ+60^\circ$ ). Knowing the available displacement range at the time of engine stop, a control unit (Figure 1) controls an actuator (Figure 2B) to displace the cylinder block towards the lowest compression ratio possible within the range of desired crank angles. As indicated in Figure 3, the crankshaft would be rotated from its rest position at a first crank angle 301 to its starting position at a second crank angle 302 prior to start.

**[0067]** Figure 4A shows a side view of an internal combustion engine 410 with variable compression and offset. The internal combustion engine 410 comprises a crankcase 411 having a crankshaft 412 connected to at least two pistons 413 (one shown), via a connecting rod 414. The connecting rod 414 is connected to the piston 413 by a piston pin 415 and to a crank 416 of the crankshaft 412. The crankshaft 412 has a central axis X in the longitudinal direction of the engine 410. The engine 410 further comprises a cylinder block 417 comprising at least one cylinder 418 (one shown) in which the piston 413 can perform a reciprocating motion. A cylinder block 419, comprising at least one intake valve and at least one exhaust valve controlled by a respective camshaft 425, 426, is mounted on the cylinder block 417. The position sensors 121, 122 described in Figure 1 are schematically indicated in Figure 4A.

**[0068]** The cylinder 418 has a central axis Y at right angles to the crankshaft axis X. In the example in Figure 4A, simultaneous adjustment of compression ratio CR and cylinder offset can be achieved by displacing the cylinder block 417 along opposed, contacting planar guide surfaces 421, 422 arranged in an angled first plane P1. A first guide surface 421 is located on the crankcase 411 and a second guide surface is located on the cylinder block 417. The first plane P1 is arranged at an angle  $\alpha$  relative to a second plane P2 at right angles to the cylinder axis Y, which angle can be selected between  $0^\circ$  and  $60^\circ$ . An actuator 423 (see Figure 4B) for controlling the relative displacement of the crankcase 411 and the cylinder block 417 is located between the crankcase 411 and the cylinder block 417. In this example the actuator is to be mounted onto the crankcase 411 in order to act on the cylinder block 417. The actuator can be operated by a suitable hydraulic, electric or mechanical means.

**[0069]** The engine in Figure 4A is further provided with a first and a second camshaft 425, 426 for controlling their respective intake and exhaust valves. The camshafts 425, 426 are driven by the crankshaft 412 via a camshaft transmission, which in this case comprises a

belt 424 and a first and a second control wheel 427, 428. The usual function of a control wheel is to ensure correct tension in the belt or chain at all times, and to provide a belt geometry that provides sufficient friction for the driving and driven shafts.

**[0070]** In Figure 4A, the first control wheel 427 is arranged to ensure that tension is maintained in the belt 424. The second control wheel 428 is located fixed relative to the crankcase 411 and is in driving connection with a rack 430 on the cylinder block 417. In this example the rack 430 is arranged in the plane P1, at right angles to the crankshaft axis X. During a displacement of the cylinder block, as shown by the arrow B in Figure 4B, the relative movement between the cylinder block 417 and the crankcase 411 causes a rotation of the second control wheel 428. The second control wheel 428 will then act on the belt to rotate the crankshaft 412 to a desired crank angle. At the same time the camshafts 425, 426 will be repositioned via the camshaft transmission. The second control wheel 428 is provided with a free-wheeling device 431 allowing it to be disconnected from the rack 430 to be driven by the camshaft transmission during normal engine operation. The free-wheeling device can be replaced by a controllable clutch or a similar device for disconnecting the second control wheel from the rack. In the case of a clutch, the clutch should be biased to a non-actuated position under normal engine operation. During normal operation of the engine the control wheel 428 is driven by the belt 424 and is disconnected from the above-mentioned mechanism. Consequently, after start the compression ratio and the offset can be controlled depending on the current operating conditions of the engine, without interfering with the mechanism for performing the crank angle adjustment prior to start.

**[0071]** In the above case it is assumed that the available displacement range for the cylinder block 417 along the plane P1 is sufficient for using a 1:1 ratio between the rack 430 and the second wheel 428 to achieve the desired crank angle adjustment. However, if this is not the case then a suitable gearing or similar device can be provided. According to an alternative example shown in Figure 5, a control wheel 528 comprising two gear wheels 528a, 528b arranged side-by-side on the same axis can be provided in order to achieve a sufficient gear ratio. For instance, the control wheel 528 can comprise a relatively smaller gear wheel 528a connected to the crankcase and a relatively larger gear wheel 528b acting on the crankshaft 512 via the camshaft transmission belt 524. The gear ratio between the smaller and larger gear wheels is selected depending on the available displacement range between cylinder block and the crankcase, and the rotational angle required to achieve the desired crank angle. Figure 5 schematically indicates a pair of opposed, contacting planar guide surfaces 521, 522 and a rack 530 in contact with displaced with the displacement of the cylinder block (not shown) to act on the smaller gearwheel 528a.

**[0072]** The invention is not limited to the embodiments

described above but may be varied freely within the scope of the claims.

## Claims

1. Method for optimizing an internal combustion engine with variable compression ratio for a direct start, the engine comprising a crankcase (211; 411) comprising a crankshaft (212; 412) connected to at least two pistons; and a cylinder block (217; 417) comprising at least two cylinders (218; 418), **characterized by** the method comprising the steps of:
  - detecting that the internal combustion engine has stopped;
  - detecting a current crank angle;
  - determining which cylinder is next to fire in a predetermined cylinder firing order;
  - determining a crank angle adjustment required to achieve a crank angle suitable for ignition in this first cylinder
  - operating at least one actuator (223; 423) to displace the cylinder block (217; 417) relative to the crankcase (211; 411) for adjustment of compression ratio and cylinder offset (O);
  - causing a simultaneous displacement of the cylinder block (217; 417) in the direction of the cylinder axis (Y), and transverse to the cylinder axis (Y) and the crankshaft axis (X); and
  - performing the crank angle adjustment using a mechanism (428; 428'; 430) connecting the cylinder block and the crankshaft, and which mechanism (428; 428'; 430) is actuated by the cylinder block displacement.
2. Method according to claim 1, **characterized by** reducing the compression ratio and increasing the offset simultaneously over at least a portion of a displacement range during the crank angle adjustment.
3. Method according to claim 1 or 2, **characterized by** determining a crank angle adjustment required to displace the piston in the first cylinder to fire into a position after top dead center, where the crank angle is suitable for direct start.
4. Method according to claim 3, **characterized in that** the crank angle is selected between 10 crank angle degrees after top dead center and 10 crank angle degrees before exhaust valve opening.
5. Method according to claim 4, **characterized in that** the crank angle is selected between 30 and 50 crank angle degrees after top dead center.
6. Method according to any one of claims 1-5, **characterized by** controlling the mechanism (428; 428'; 430) to connect the cylinder block and the crankshaft when the internal combustion engine is stopped.
7. Method according to claim 6, **characterized by** controlling the mechanism (428; 428'; 430) to disconnect the cylinder block and the crankshaft prior to an engine start.
8. Method according to any one of claims 1-5, **characterized by** mechanism (428; 428'; 430) is connected to the crankshaft via a free-wheeling device.
9. Method according to any one of claims 1-8, **characterized by** displacing the cylinder block (217; 417) along guide surfaces (221, 222; 421, 422) arranged at an angle ( $\alpha$ ) to a plane (P2) at right angles to the cylinder axis (Y).
10. Method according to claim 9, **characterized in that** the angle between the guide surfaces and the first plane is an acute angle ( $\alpha$ ) within the range 0° to 60°
11. An internal combustion engine, comprising a crankcase (211; 411) with a crankshaft (212; 412; 212; 412'; 92; 212) connected to at least two pistons; a cylinder block (217; 417) comprising at least two cylinders, which cylinder block is displaceable relative to the crankcase; and at least one actuator (123) connected between the cylinder block and the crankcase, wherein guiding means (221, 222; 421, 422) is arranged to guide the cylinder block (217; 417) relative to the crankcase (211; 411) for simultaneous adjustment of compression ratio and cylinder offset when the actuator is operated, **characterized in that** the engine further comprises:
  - a sensor arranged to detect a current, first crank angle when the engine has stopped;
  - a control unit arranged to determine which cylinder is next to fire in a predetermined cylinder firing order based on the detected crank angle and to determine a crank angle adjustment required to achieve a desired, second crank angle suitable for ignition **in that** cylinder; and
  - a mechanism (428; 428'; 430) arranged to connect the cylinder block and the crankshaft, so that a predetermined displacement the cylinder block by the actuator causes turning of the crankshaft to adjust the crank angle to the second crank angle.
12. An internal combustion engine according to claim 11, **characterized in that** the actuator (223; 423) is arranged to displace the cylinder block and perform a simultaneous reduction of the compression ratio and increase of the offset during the crank angle adjustment.

13. An internal combustion engine according to claim 11 or 12, **characterized in that** the control unit is arranged to determine the crank angle adjustment required to displace the piston in the next cylinder to fire into a position after top dead center, where the crank angle is suitable for direct start. 5
14. An internal combustion engine according to claim 13, **characterized in that** the second crank angle is selected between 10 crank angle degrees after top dead center and 10 crank angle degrees before exhaust valve opening.. 10
15. An internal combustion engine according to claim 14, **characterized in that** the second crank angle is selected between 30 and 50 crank angle degrees after top dead center. 15
16. An internal combustion engine according to any one of claims 11-15, **characterized in that** the mechanism (428; 428'; 430) is arranged to connect the cylinder block and the crankshaft when the internal combustion engine is stopped. 20
17. An internal combustion engine according to any one of claims 11-15, **characterized in that** the mechanism (428; 428'; 430) is arranged to disconnect the cylinder block and the crankshaft prior to an engine start. 25  
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18. An internal combustion engine according to any one of claims 11-15, **characterized in that** the mechanism (428; 428'; 430) is arranged to turn the crankshaft via a free-wheeling device. 35
19. An internal combustion engine according to any one of claims 11-18, **characterized in that** the guiding means comprises planar guide surfaces (221, 222; 421, 422) arranged at a predetermined angle to a first plane at right angles to the cylinder axis. 40
20. An internal combustion engine according to claim 19, **characterized in that** the angle between the guide surfaces and the first plane is an acute angle ( $\alpha$ ) within the range  $0^\circ$  to  $60^\circ$ . 45
21. Vehicle **characterized in that** the vehicle comprises an internal combustion engine according to any one of claims 11-20. 50  
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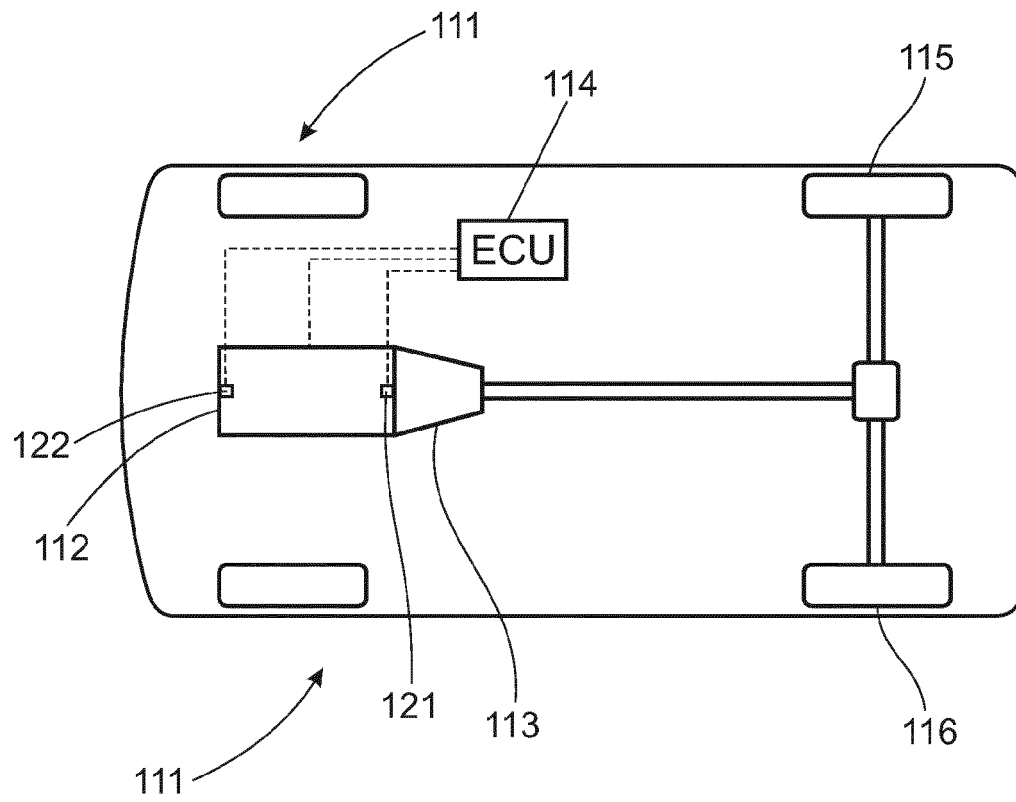


Fig.1

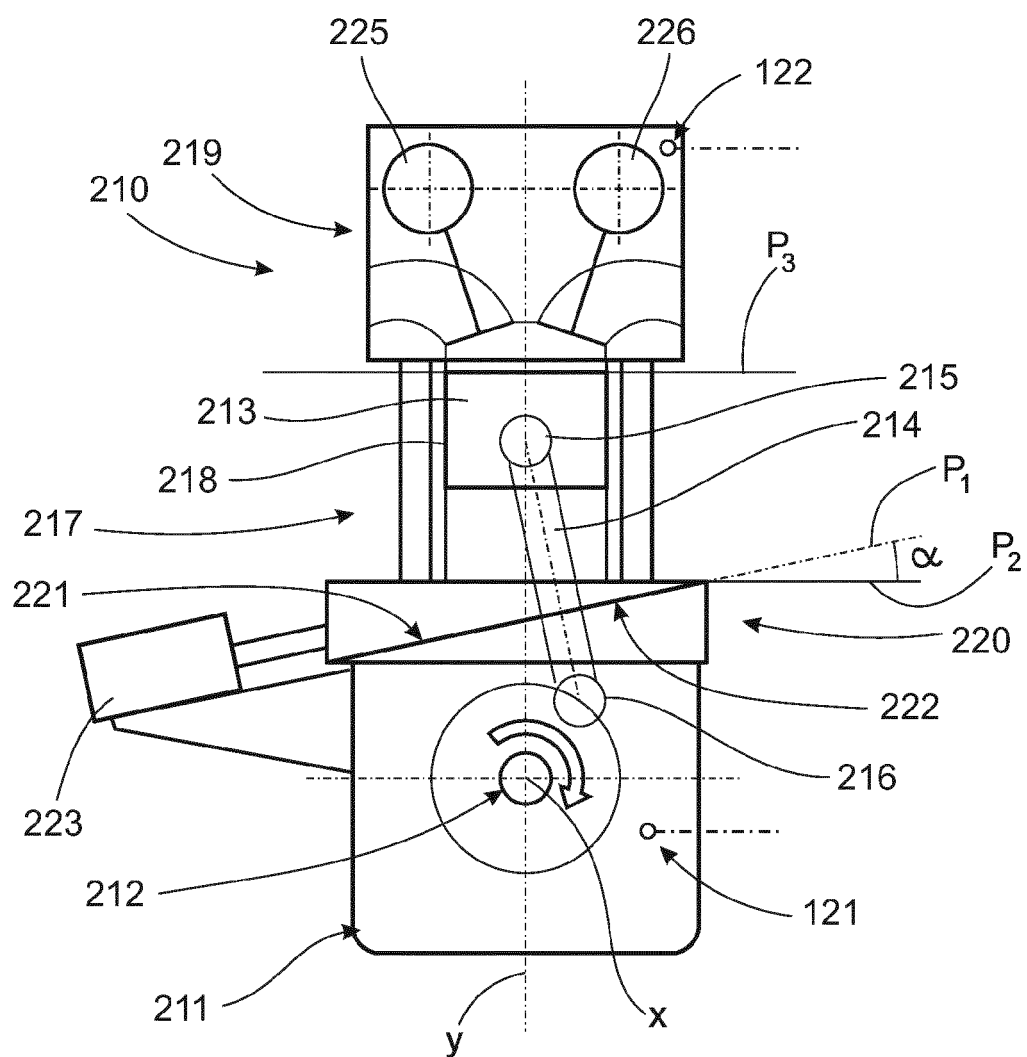


Fig.2A

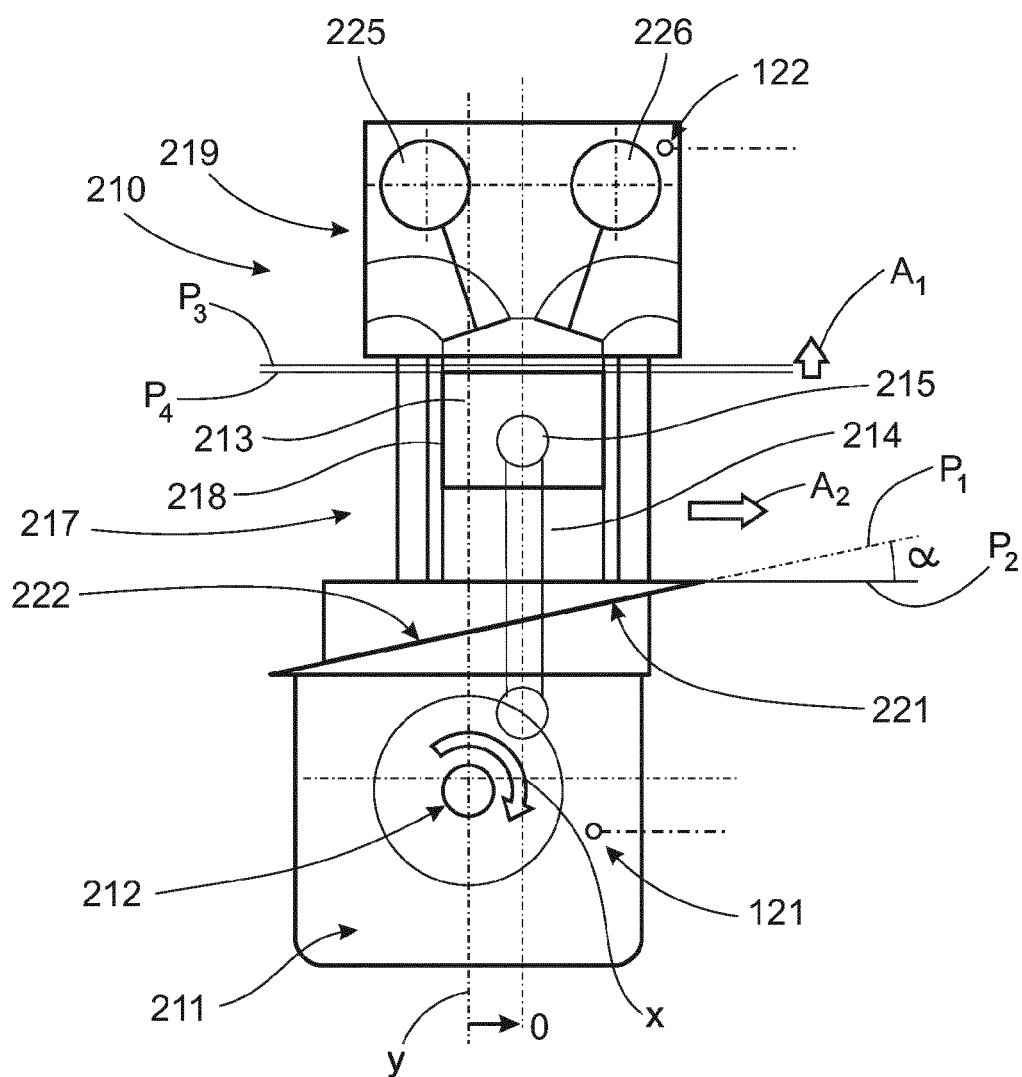


Fig.2B

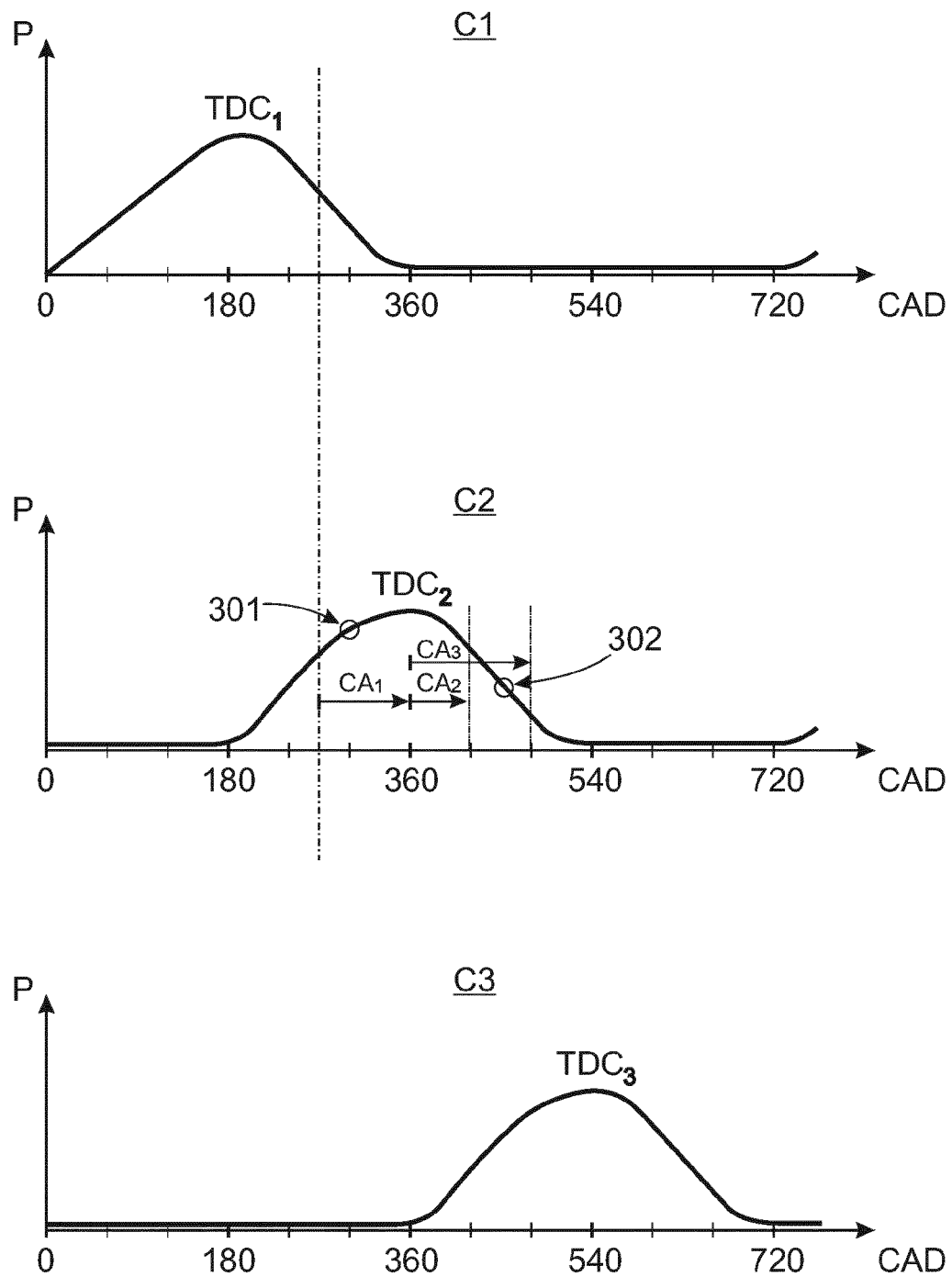
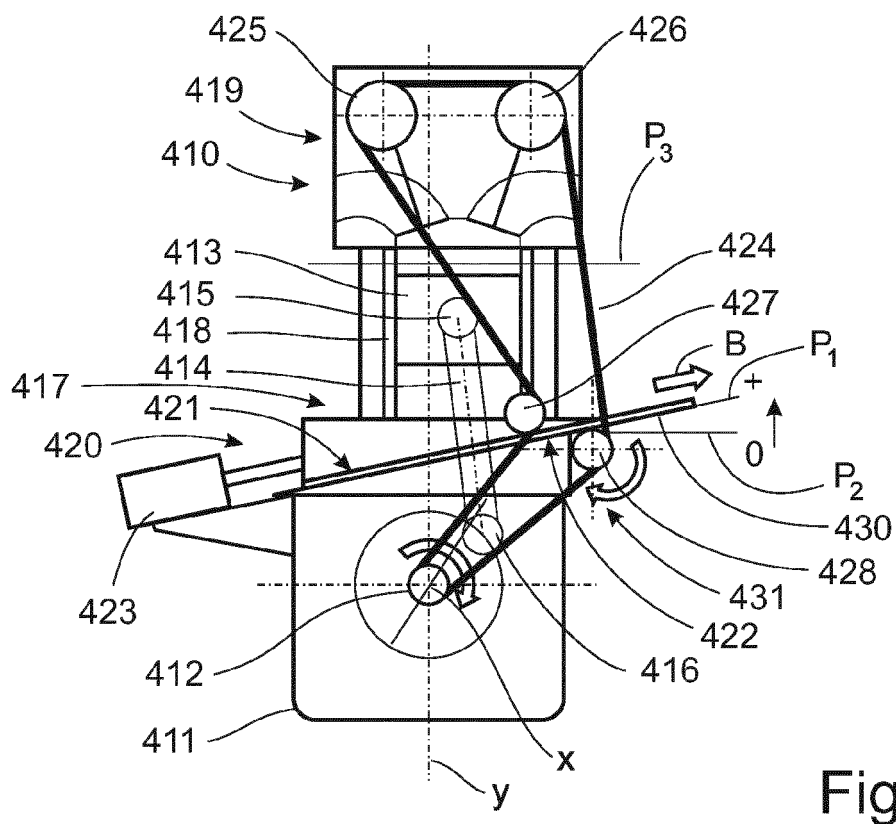
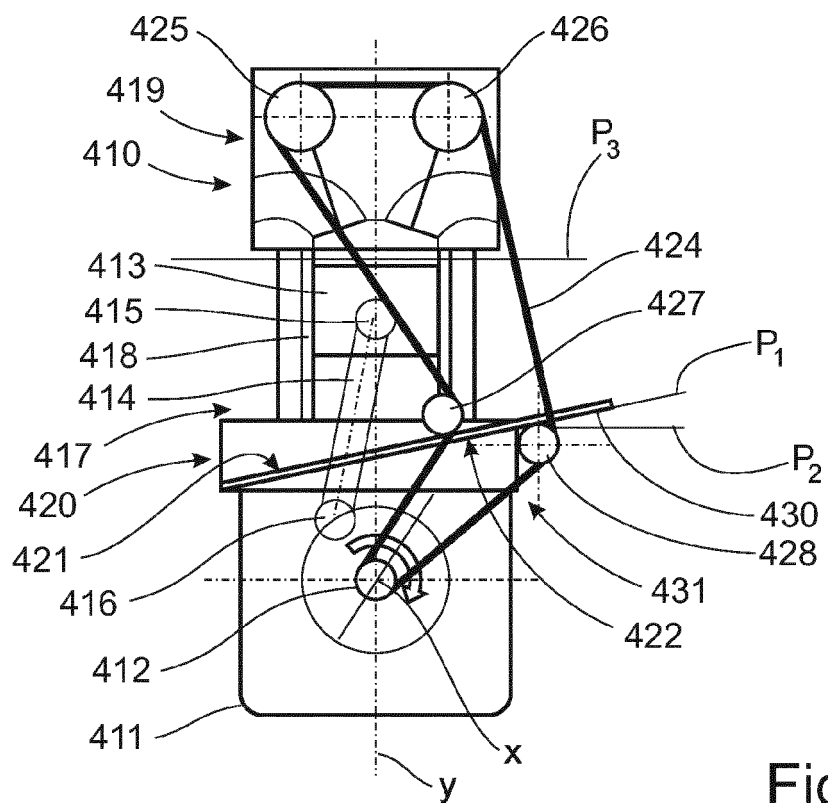


Fig.3





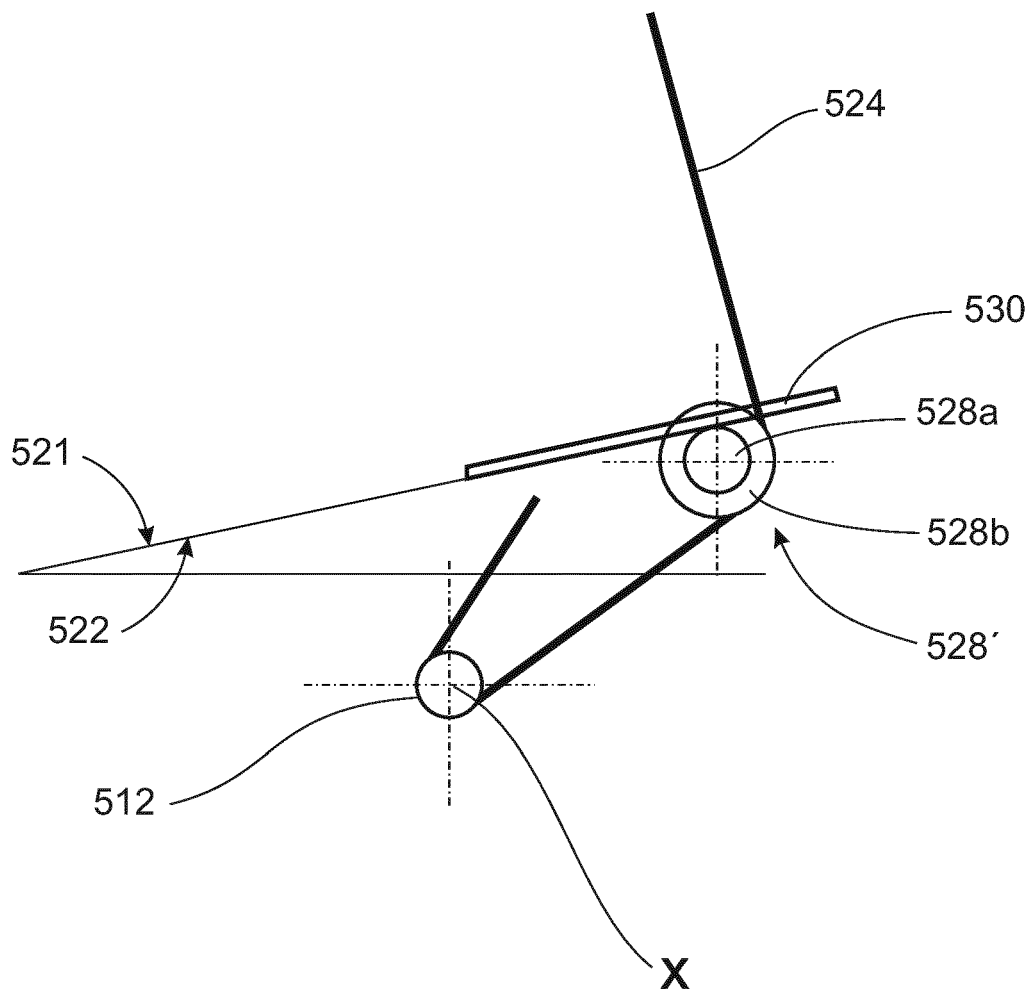


Fig.5



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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                    |                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                              |                                                                       |
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| Place of search<br>Munich                                                                                                                                                                                                                              |                                                                                                                                                                                                                        | Date of completion of the search<br>21 October 2016                                                                                                                                                                                                                          | Examiner<br>Wettemann, Mark                                           |
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