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(54) **An internal combustion engine including variable compression ratio**

(57) An internal combustion engine (1) including variable compression ratio comprises a crankcase (3) and a crankshaft (4) including a crankshaft axis (5) and at least a central main portion (6), a crankpin (7) and a crankshaft web (8) located between the central main portion (6) and the crankpin (7). The crankshaft (4) is supported by the crankcase (3) and rotatable with respect thereto about the crankshaft axis (5). The engine has at least a connecting rod including a big end and a small end, a piston which is rotatably connected to the small end and a crank member (9) which is rotatably mounted on the crankpin (7). The crank member comprises at least a bearing portion which is eccentrically disposed with respect to the crankpin (7) and has an outer circumferential wall which bears the big end of the connecting rod such that the connecting rod is rotatably mounted on the bearing portion of the crank member (9) via the big end. The engine also comprises a driving mechanism (2) for rotat-

ing the crank member (9) at a rotation frequency with respect to the crankcase (3) which is substantially half of that of the crankshaft (4) as seen from the crankcase (3). The driving mechanism (2) comprises a drive shaft (10) that extends concentrically through the central main portion (6). The drive shaft (10) is drivably coupled to the crank member (9) via a transmission (11) at a side of the crankshaft web (8) where the crankpin (7) is located. At the opposite side of the crankshaft web (8) the drive shaft (10) is drivably coupled to the crankshaft (4) via a lockable coupling (22) for adjusting the mutual rotational position of the crank member (9) and the crankshaft (4) at any rotational position of the crank member (9) with respect to the crankcase (3). The engine includes a controller for controlling the coupling (22) such that in unlocked condition of the coupling (22) said mutual rotational position is adjustable.

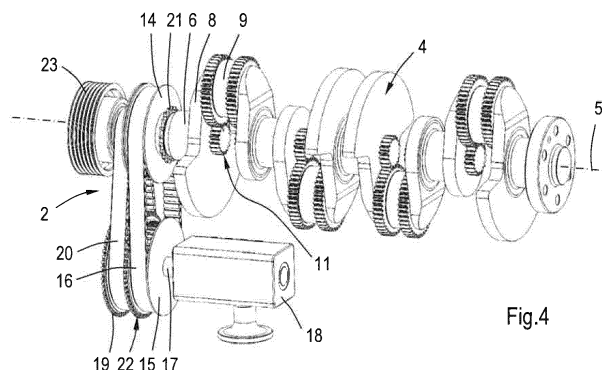


Fig.4

EP 2 902 603 A1

Description

[0001] The present invention pertains to an internal combustion engine including variable compression ratio.

[0002] An engine with variable compression ratio is well-known in the field of spark-ignition engines. It provides the opportunity to operate the engine at high efficiency, particularly under part-load conditions. Increasing the compression ratio leads to decreasing fuel consumption. At high-load or full-load the compression ratio must be lowered in order to avoid knocking. Several earlier applications of the applicant disclose internal combustion engines with variable compression ratio, for example WO 2009/018863.

[0003] An object of the invention is to provide an improved engine.

[0004] This is achieved by the internal combustion engine according to claim 1.

[0005] In locked condition of the coupling the crank member is driven by the crankshaft under operating conditions. In unlocked condition of the coupling the crank member can be rotated with respect to the crankpin at a virtual standstill of the crankshaft. In locked condition each rotational position of the crank member with respect to the crankcase corresponds to a repetitive rotational position of the crankshaft, since the crankshaft rotates at double speed of the crank member as seen from the crankcase. In unlocked condition this mutual position can be adjusted, resulting in a change of top dead centre and bottom dead centre of the piston, hence adjusting the compression ratio.

[0006] The advantage of the internal combustion engine according to the invention is that it provides the opportunity to adjust the mentioned mutual position automatically by means of using combustion forces. Combustion forces are exerted via the big end onto the bearing portion of the crank member. Due to the eccentric position of the bearing portion with respect to the crankpin, a natural torque is created on the crank member within certain ranges of rotational positions of the crankshaft angle with respect to the crankcase such that the crank member tends to rotate about the crankpin. For example, within a range during the combustion stroke of the piston when it travels from top dead centre to bottom dead centre. When the coupling is unlocked and subsequently locked within such a range the compression ratio can be changed without additional adjusting means. Therefore, an aspect of the invention is related to a method of changing the compression ratio of the engine according to claim 1 by means of unlocking and subsequently locking and the coupling during a selected time period and adjusting the mutual rotational position of the crank member and the crankshaft by means of combustion forces.

[0007] It is noted that the drive shaft is rotatable with respect to the crankcase as well as to the central main portion of the crankshaft. The crankshaft axis forms a common axis of the crankshaft and the drive shaft.

[0008] The mutual rotational position of the drive shaft and the crankshaft at any repetitive rotational position of the crank member with respect to the crankcase depends on the dimensions of the transmission. Although the crank member rotates at half crankshaft speed with respect to the crankcase, the speed ratio of the drive shaft and the crankshaft may be different. For example, the transmission may be configured such that after each revolution of the crank member with respect to the crankcase the drive shaft has rotated more or less than two revolutions with respect to the crankcase.

[0009] Preferably, the driving mechanism is adapted such that the crank member rotates in the same rotational direction as that of the crankshaft as seen from the crankcase, since this appears to minimize friction losses. This means that the crank member rotates in opposite direction as seen from the crankpin, i.e. the crankpin rotates at crankshaft speed in one direction, whereas the crank member rotates in opposite direction at half crankshaft speed with respect to the crankpin.

[0010] In a practical embodiment the transmission comprises an external crank member gear which is fixed to the crank member and an external drive shaft gear which is fixed to the drive shaft and which meshes with the crank member gear in order to rotate the crank member in the same direction as the crankshaft as seen from the crankcase.

[0011] The external crank member gear may be a separate part or integral with the crank member. Similarly, the external drive shaft gear may be a separate part or made of one piece with the drive shaft. The diameter of the crank member gear may be twice the diameter of the drive shaft gear, but alternative ratios are conceivable. In case of a ratio of two, the drive shaft must be driven at a speed which is twice the crankshaft speed and in the same direction thereof, as seen from the crankcase.

[0012] The drive shaft at the opposite side of the crankshaft web may also be drivably coupled to a braking system for braking the drive shaft in unlocked condition of the coupling. This provides the opportunity to change the compression ratio rapidly by decelerating the drive shaft in unlocked condition of the coupling. For example, a fast change to reduced compression ratio is typically desired in case of switching from low to high engine load in order to avoid the risk of knocking. For this reason, the driving mechanism is preferably configured such that the crank member is turned about the crankpin at a virtual standstill of the crankshaft towards a lower compression ratio position upon decelerating the crank member temporarily with respect to the crankshaft, and thus decelerating the drive shaft. It is noted that braking of the rotating drive shaft can be done fast and relatively simple. The braking system may be used in addition or instead of changing compression ratio by means of combustion forces as mentioned above.

[0013] Under practical conditions the rotational position of the crank member with respect to the crankpin may be such that at maximum compression ratio at the end of the compression stroke, when the piston is in top dead centre, a centre line of the bearing portion lies beyond a centre line of the crank pin as seen from the crankshaft axis, whereas the centre

line of the bearing portion, the centre line of the crankpin and the crankshaft axis lie in a common plane. The compression ratio can be reduced by turning the crank member from this position about its centre line relative to the crankpin in its rotational direction under normal operating conditions at a virtual standstill of the crankshaft over a certain turning angle. The minimum compression ratio at the end of the compression stroke, when the piston is in top dead centre, may lie at a turning angle of the crank member of 90° to 140° from the above-mentioned position at maximum compression ratio with respect to the crankcase, for example.

[0014] In other words, if the crankshaft under stable operating conditions rotates clockwise with respect to the crankcase, the crank member also rotates clockwise with respect to the crankcase but at half speed of the crankshaft speed; in this case the crank member is rotated clockwise with respect to the crankpin at a virtual standstill of the crankshaft in order to decrease the compression ratio. This means that under operating conditions in unlocked condition of the coupling the crank member must be accelerated temporarily with respect to the crankcase if the engine should be switched to a lower compression ratio. This also means that the crank member decelerates temporarily in opposite rotational direction with respect to the crankpin. Similarly, if the engine should be switched to a higher compression ratio the crank member must be decelerated temporarily with respect to the crankcase and thus accelerated temporarily in opposite rotational direction with respect to the crankpin.

[0015] It is noted that temporarily acceleration and deceleration of the crank member with respect to the crankcase in order to switch to lower and higher compression ratio, respectively, may be performed inversely if the control range between minimum and maximum compression ratio is different. In that case, the maximum compression ratio at the end of the compression stroke, when the piston is in top dead centre, may also be if the rotational position of the crank member with respect to the crankpin is such that the centre line of the bearing portion lies beyond the centre line of the crankpin as seen from the crankshaft axis, whereas the centre line of the bearing portion, the centre line of the crankpin and the crankshaft axis lie in a common plane. However, the compression ratio is reduced by turning the crank member about its centre line relative to the crankpin opposite to its rotational direction under normal operating conditions at a virtual standstill of the crankshaft. The minimum compression ratio at the end of the compression stroke, when the piston is in top dead centre, may lie at a turning angle of the crank member of -90° to -140° from the position at maximum compression ratio with respect to the crankcase, for example.

[0016] Alternative control processes are conceivable. For example, in case that the crankshaft and crank member both rotate clockwise with respect to the crankcase and the crank member is rotated clockwise with respect to the crankpin at a virtual standstill of the crankshaft in order to decrease the compression ratio and anti-clockwise in order to increase the compression ratio, it is also possible to switch from lower to higher compression ratio by turning the crank member with respect to the crankcase clockwise by less than one revolution. For example, a rotational shift of the crank member of 1° anti-clockwise equals a shift of 359° clockwise as seen from the crankcase. Hence, in this case the crank member is always turned clockwise at virtual standstill of the crankshaft in order to change the compression ratio, but the turning angle of the crank member is relatively large when switching to a higher compression ratio.

[0017] The lockable coupling may comprise a locking member that is activated by the controller, for example by means of a hydraulically actuated lock.

[0018] The drive shaft may be located at a front side of the engine, opposite to the rear side thereof where the flywheel is located. This means that the central main portion, the crankshaft web and the crankpin lie behind each other in the mentioned sequence as seen from the front side to the rear side of the engine. In a multi-cylinder engine the crankshaft web and the crankpin are the first crankshaft web and the first crankpin as seen from the front side to the rear side of the engine in this case.

[0019] In a preferred embodiment the braking system comprises a power take-off member of the engine which is drivably coupled to the drive shaft, since this provides the opportunity to unlock the coupling by means of the controller, whereas the power take-off member automatically brakes the drive shaft due to its power absorption. If the power take-off member provides sufficient resistance the controller does not need to activate a separate braking mechanism.

[0020] Several power take-off members of the engine are conceivable in practice. In a practical embodiment the power take-off member comprises an alternator. If the alternator provides insufficient resistance to adjust the mutual position of the crank member and the crankshaft, it is conceivable that the alternator output load is increased temporarily during the unlocked condition of the coupling.

[0021] The crankshaft may be drivably coupled to a rotatable input member of the coupling and the drive shaft may be drivably coupled a rotatable output member of the coupling.

[0022] Preferably, at least one of the rotatable input and output member is provided with sensing means for detecting the mutual position as mentioned hereinbefore. In fact the actual mutual position between the rotatable input and output members is detected, but this is directly related to the mutual rotational position of the crank member and the crankpin at any rotational position of the crank member with respect to the crankcase because of the drivable connection between the crankshaft and the rotatable input member and the drivable connection between the crank member and the rotatable output member.

[0023] The rotatable input member may comprise a first driving wheel that is drivably coupled to the crankshaft via a

first endless member whereas the rotatable output member may comprise a second driving wheel that is drivably coupled to the drive shaft via a second endless member. Alternatively, the rotatable input member may comprise an external first driving gear that meshes with an external crankshaft driving gear of the crankshaft whereas the rotatable output member comprises an external second driving gear that meshes with an external drive shaft gear of the drive shaft.

[0024] The first driving wheel may be drivably coupled to the central main portion of the crankshaft and the second driving wheel may be drivably coupled to the drive shaft at a portion that projects from the central main portion as seen from the crankshaft web, or the external crankshaft driving gear may be located at the central main portion of the crankshaft and the external drive shaft gear may be located at a portion of the drive shaft that projects from the central main portion as seen from the crankshaft web. This provides the opportunity to dispose the locations where the first driving wheel is coupled to the central main portion and the second driving wheel is coupled to the drive shaft, or the locations of the crankshaft driving gear and the drive shaft gear, close to each other in longitudinal direction of the crankshaft. When the drive shaft is located at the front side of the engine the locations where the second driving wheel is coupled to the drive shaft and the first driving wheel is coupled to the central main portion, or the locations of the drive shaft gear and the crankshaft driving gear, are located behind each other in the mentioned sequences as seen from the front side to the rear side of the engine.

[0025] The first driving wheel can be coupled to a crankshaft driving wheel, which may be fixed to the central main portion by means of a hollow nut through which the drive shaft extends. Similarly, the external crankshaft driving gear may be fixed to the central main portion by means of such a hollow nut. The hollow nut can be incorporated in a space within the crankshaft driving wheel or the crankshaft driving gear.

[0026] It is advantageous when the rotatable input member and the rotatable output member are rotatable about a common centre line which extends parallel to the crankshaft axis, since this provides the opportunity to build the engine in a compact way. Besides, the coupling can be located between the input and output member.

[0027] The drive shaft may be drivably coupled to the braking system of the engine via a third wheel that is fixed to the drive shaft at the opposite side of the crankshaft web.

[0028] In an advantageous embodiment the third wheel is drivably coupled to the alternator via a third endless member. This means that the drive shaft extends through the crankcase and the third wheel is located at the outside of the crankcase. The third wheel can be a pulley such as used in conventional engines without variable compression ratio.

[0029] The crankcase may comprise a drive shaft bearing on which the drive shaft rotates. This is also advantageous in case the third wheel is fixed to the drive shaft. In the latter case the third wheel may be located outside the crankcase and the drive shaft bearing is preferably combined with an oil seal ring.

[0030] As described hereinbefore, if under operation conditions the engine should be switched to a higher compression ratio the crank member can be decelerated with respect to the crankcase temporarily. In case of a transmission which comprises an external crank member gear which is fixed to the crank member and an external drive shaft gear which is fixed to the drive shaft and meshes with the crank member gear, the drive shaft must be accelerated temporarily. This can be achieved by means of a return actuator for exerting a return force on the drive shaft in the unlocked condition of the coupling. The controller may be adapted such that it is able to unlock the coupling and activate the return actuator, for example in case of decreasing engine load.

[0031] The return actuator may comprise a spring, a hydraulic member or an alternator which is provided with an electric motor function. In the latter case, the controller may be adapted such that it is able to unlock the coupling and drive the alternator.

[0032] It is noted that in practice a switch to a lower compression ratio must be performed rapidly which is possible with the braking system and/or by using combustion forces. Switching to a higher compression ratio may be performed less rapidly, but may also be performed by using a braking system and/or combustion forces.

[0033] The invention will hereafter be elucidated with reference to the schematic drawings showing embodiments of the invention by way of example.

Fig. 1 is a perspective view of a part of an embodiment of an internal combustion engine according to the invention.

Fig. 2 is a similar view as Fig. 1, showing the engine without a cover at a front side thereof.

Fig. 3 is a similar view as Fig. 1, showing the engine without a large part of an upper section of the crank case.

Fig. 4 is a similar view as Fig. 3 as seen from a different side and without the crankcase.

Fig. 5 is a similar view as Fig. 4, but without the crankshaft.

Figs. 6-8 are similar views as Fig. 3, but showing parts thereof on a larger scale in order to illustrate assembled and disassembled conditions.

Fig. 9 is a similar view as Fig. 8, showing a part thereof on enlarged scale.

Fig. 10 is a similar view as Fig. 8, showing a part thereof in disassembled condition on enlarged scale

Figs. 11-12 are perspective partly broken-away views of a part of an alternative embodiment of an internal combustion engine according to the invention.

Fig. 13 is a perspective view of the crankshaft of the engine according to Figs. 11-12 on a larger scale.

Fig. 14 is a partly broken-away side view of the crankshaft as shown in Fig. 13.

[0034] Fig. 1 shows a part of an embodiment of an internal combustion 1 according to the invention. The engine 1 has a variable compression ratio which provides the opportunity to operate the engine at high compression ratio under part-load conditions resulting in improved efficiency. Under high-load conditions the compression ratio can be lowered in order to avoid knocking. Figs. 2-10 show more details of a mechanism for varying the compression ratio. The embodiment of the engine 1 as shown in Figs. 1-10 is provided with a driving mechanism 2 which is used for varying the compression ratio which is located at a front side of the engine 1. An opposite rear side of the engine 1 is provided with a flywheel (not shown). In Figs. 1-9 the front side of the engine is located at the left side in the drawings.

[0035] The internal combustion engine 1 comprises a crankcase 3 which supports a crankshaft 4 via bearings. The crankshaft 4 is rotatable with respect to the crankcase 3 about a crankshaft axis 5. At the front side of the engine 1 where the driving mechanism 2 is located, the crankshaft 4 has a central main portion 6, a crankpin 7 and a crankshaft web 8. The crankshaft web 8 is located between the central main portion 6 and the crankpin 7 as seen in longitudinal direction of the crankshaft axis 5.

[0036] The embodiment of the engine 1 as shown in Figs. 1-10 is a four-cylinder engine 1 and has four crankpins 7 and four pairs of crankshaft webs 8 each at opposite ends of each crankpin 7, whereas similar central main portions 6 are located between crankshaft webs 8 at sides thereof opposite to the sides where the respective crankpins 7 are located. The driving mechanism 2 is also applicable for engines having a different number of cylinders. For explanatory reasons herein the central main portion 6, crankpin 7 and crankshaft web 8 closest to the front side of the engine 1 are referred to as the central main portion 6, the crankpin 7 and the crankshaft web 8, respectively. The engine 1 is also provided with connecting rods, each including a big end and a small end, and pistons which are rotatably connected to the respective small ends. These parts are not shown for clarity reasons.

[0037] The engine 1 comprises a crank member 9 which is rotatably mounted on the crankpin 7. The crank member 9 comprises a bearing portion which is eccentrically disposed with respect to the crankpin 7. The bearing portion has an outer circumferential wall which bears the big end of a connecting rod such that the connecting rod is rotatably mounted on the bearing portion of the crank member 9 via the big end. In the embodiment as shown in Figs. 1-10 the bearing portion of the crank member 9 is located between two external gears.

[0038] The driving mechanism 2 is configured such that under operating conditions the crank member 9 is rotated at a rotation frequency with respect to the crankcase 3 which is half of that of the crankshaft 4 and in the same rotational direction as that of the crankshaft 4 as seen from the crankcase 3. Hence, a single revolution of the crank member 9 with respect to the crankcase 3 corresponds to two revolutions of the crankshaft 4 with respect to the crankcase 3.

[0039] The driving mechanism 2 comprises a drive shaft 10, see Fig. 5, which extends concentrically through the central main portion 6. The drive shaft 10 is mechanically coupled to the crank member 9 via a transmission 11 located at a side of the crankshaft web 8 where the crankpin 7 is located. In this case the transmission 11 comprises an external crank member gear 12 of the crank member 9 and an external drive shaft gear 13 which is fixed to the drive shaft 10. The drive shaft gear 13 meshes with the crank member gear 12. In this embodiment the dimensions of the crank member gear 12 and the drive shaft gear 13 are selected such that the drive shaft 10 runs at double crankshaft speed with respect to the crankcase 3. It is noted, that this is only the case if the gear ratio between the crank member gear 12 and the drive shaft gear 13 is exactly two. For example, if the gear ratio is larger than two the rotation frequency of the drive shaft will be larger than two under operating conditions.

[0040] The relationship between the rotational speed of the drive shaft 10 and the dimensions of the crank member gear 12 and the drive shaft gear 13 is as follows:

$$n_{ds} = (0.5 \times (N_{cmg}/N_{ds}) + 1) \times n_{cs},$$

wherein

n_{ds} = speed of drive shaft with respect to crankcase

n_{cs} = speed of crankshaft with respect to crankcase

N_{cmg} = number of teeth of crank member gear

N_{ds} = number of teeth of drive shaft gear.

[0041] In case of an engine 1 having a plurality of cylinders including a plurality of crank members 9, such as in the embodiment as shown in Figs. 1-10, the crank members 9 are mechanically coupled to each other such that all crank members 9 are rotated in a similar manner. In this case the crank members 9 are coupled to each other through external gears which mesh with external gears of the respective crank members 9 and which are fixed to common shafts extending

concentrically through the respective central main portions 6 and corresponding crankshaft webs 8 at both sides of the respective central main portions 6 of the crankshaft 4. This is illustrated in Figs. 3-5. It is advantageous when the transmission 11 is configured such that the crank member gear 12 and the drive shaft gear 13 have similar dimensions as the respective other crank member gears and the drive shaft gears of the engine, since this minimizes the number of different parts in the engine 1.

[0042] The drive shaft 10 extends concentrically through the central main portion 6 at a side of the crankshaft 8 web opposite to the side where the crankpin 7 is located and is drivably coupled to the crankshaft 4. Figs. 3 and 4 show that in this case a crankshaft driving wheel 14 is mounted to the central main portion 6 of the crankshaft 4 and drivably coupled to a first driving wheel 15 via a first endless belt 16. In this case the first driving wheel 15 is mounted to an oil pump shaft 17 for driving an oil pump 18 of the engine 1, but the first driving wheel 15 may be mounted to a separate shaft in an alternative embodiment. The drive shaft 10 is drivably coupled to a second driving wheel 19 via a second endless belt 20. The portion of the drive shaft 10 where the second endless belt 20 engages projects from the central main portion 6 at the front side of the engine 1. Thus, the crankshaft driving wheel 14 is disposed between the crankshaft web 8 and the mentioned portion of the drive shaft 10. The crankshaft 4 is also provided with a sprocket 21 for driving other auxiliary parts of the engine 1, see Fig. 4, for example for driving a camshaft.

[0043] For changing the compression ratio under operating conditions it is required to be able to adjust the mutual position of the crank member 9 and the crankshaft 4 at a certain rotational position of the crank member 9 with respect to the crankcase 3. When the engine 1 runs at a fixed engine speed the crankshaft 4 and the drive shaft 10 have the same mutual rotational position after each revolution of the crank member 9 and after two revolutions of the crankshaft 4 with respect to the crankcase 3, if the gear ratio of the crank member gear 12 and the drive shaft gear 13 equals two. This is not the case, if the mentioned ratio is different. Changing to a different mutual rotational position means that due to the eccentric crank member 9 top dead centre and bottom dead centre of the respective pistons of the engine 1 will change. For this reason the engine 1 is provided with a lockable coupling 22, which is located at the first and second driving wheels 15, 19 in the embodiment as shown in Figs. 1-10. The first and second driving wheels 15, 19 form a rotatable input member and a rotatable output member of the coupling 22, respectively. The first and second driving wheels 15, 19 are rotatable about a common centre line which extends parallel to the crankshaft axis 5 and can be locked with respect to each other, for example hydraulically or electrically.

[0044] In a locked condition of the coupling 22 the first and second driving wheels 15, 19 rotate at the same speed and the crankshaft 4 drives the drive shaft 10 under operating conditions. In an unlocked condition the mutual position of the first and second driving wheels 15, 19 at any rotational position of the crankshaft 4 can be adjusted, resulting in a change of compression ratio. If the engine should be operated at a lower compression ratio the coupling 22 can be unlocked and the drive shaft 10 can be decelerated with respect to the crankshaft 4, for example by a braking system. Decelerating the drive shaft 10 in this embodiment means that the crank member 9 will be accelerated with respect to the crankcase 3 in its rotational direction. In the embodiment as shown in Figs. 1-10 a pulley 23 is mounted on the drive shaft 10 and drivably coupled to an alternator via an endless belt (both not shown). In this case the alternator functions as the braking system.

[0045] Furthermore, when switching from a low-load to a high-load condition the engine speed normally increases, whereas the compression ratio should be reduced at the same time. This means that upon increasing speed and load of the engine 1 there is a natural force to change the mutual position of the drive shaft 10 and the crankshaft 4 towards a lower compression ratio. The relative angle can be determined by a controller for controlling a locking mechanism of the coupling 22. In an alternative embodiment the drive shaft 10 may be coupled to a different power take-off member.

[0046] As mentioned above, the dimensions of the parts of the driving mechanism 2 are selected such that the drive shaft 10 runs at double crankshaft speed with respect to the crankcase 3. This means that when the pulley 23 drives auxiliary members of the engine 1 as in a conventional engine, for example a water pump, the diameter of the pulley 23 should be reduced to about a half of the pulley of a conventional engine.

[0047] Fig. 9 shows that both the first and second driving wheels 15, 19 are provided with toothed flanges. One or more sensors (not shown) can scan the toothed flanges in order to determine the rotational shift between the first and second driving wheels 15, 19. The rotational shift is directly related to the mutual rotational position of the crank member 9 and the crankshaft 4 at any rotational position of the crank member 9 with respect to the crankcase 3. It can be seen that both toothed flanges have one wide reference tooth. It is noted that measurement on the drive shaft 10 is more difficult since it is difficult to find an appropriate location for mounting sensing means. Furthermore, it is noted that if the first driving wheel 15 always runs at crankshaft speed because of its dimensions, it is only necessary to apply sensing means to the second driving wheel 19.

[0048] Figs. 6-8 illustrate how the driving mechanism 2 of this embodiment is assembled. Figs. 6 and 7 show that the crankshaft driving wheel 14 is fixed to the crankshaft by means of a nut 24, which is accommodated in an internal space of the crankshaft driving wheel 14. The nut has a central through-hole 25 through which the drive shaft 10 is passed. Fig. 8 shows that the drive shaft 10 is supported by a drive shaft bearing or ball bearing 26 which is mounted in the crankcase 3, whereas a sealing ring is applied, as well. The opposite side of the drive shaft 10 is supported by the

crankshaft 4 through a sleeve bearing in the central main portion 6 close to the drive shaft gear 13.

[0049] In the embodiment as shown in Figs. 1-10, the pulley 23, the central main portion 6, the crankshaft web 8 and the crankpin 9 lie behind each other in the mentioned sequence as seen from the front side to the rear side of the engine 1. It is noted that the pulley 23 may also be mounted to a shaft of the second driving wheel 19 instead of the drive shaft 10. In that case the drive shaft 10 may also be supported by the ball bearing 26 which is mounted in the crankcase 3, but a sealing ring may be omitted.

[0050] If the engine 1 should be operated at a higher compression ratio the coupling 22 can be unlocked and the drive shaft 10 can be accelerated with respect to the crankshaft 4 by a return actuator for exerting a return force on the drive shaft 10. During such an action the crank member 9 is rotated in opposite direction (of its normal rotational direction with respect to the crankcase) at a virtual standstill of the crankshaft 4. The return actuator may comprise a spring or a hydraulic member. Alternatively, the alternator is provided with an electric motor function, such that the drive shaft 10 can be accelerated by means of the alternator.

[0051] Fig. 1 shows that the driving mechanism 2 at the front side of the engine is partly covered by a cover 27 located behind the pulley 23. The drive shaft bearing 26 can be mounted in the cover 27.

[0052] Fig. 10 shows the drive shaft 10 including a toothed portion 28 for receiving the second endless belt 20, a flange 29 and a bearing receiving portion 30 on which the drive shaft bearing 26 fits. The drive shaft 10 is provided with splines 35 for fixing the drive shaft gear 13 to the drive shaft 10 in rotational direction thereof. The pulley 23 is fixed against an axial end of the drive shaft 10 by means of a bolt in a hole 36 of the drive shaft 10. The pulley 23 is locked with respect to the drive shaft 10 in rotational direction thereof by means of a locking element 37. For appropriate centering the pulley 23 on the drive shaft 10, the end of the drive shaft 10 is provided with a circumferential recess for receiving the pulley 23.

[0053] The crankshaft driving wheel 14 and the first driving wheel 15 have the same diameters such that the first driving wheel 15 also rotates at crankshaft speed and in the same direction. The second driving wheel 19 rotates at the same speed and in the same direction as the first driving wheel 15 in locked condition of the coupling 22. The ratio between the diameter of the second driving wheel 19 and the portion of the drive shaft 10 where the second endless belt 20 engages is such that the drive shaft 10 rotates at substantially double speed with respect to the crankshaft 4 and in the same direction thereof. The ratio between the crank member gear 12 and the drive shaft gear 13 is two in this case such that the crank member 9 is rotated at half crankshaft speed in opposite direction of the drive shaft 10 as seen from the crankpin 7. Consequently, as seen from the crankcase 3 the crank member 9 rotates at half crankshaft speed and in the same direction thereof.

[0054] In the embodiment as shown in Figs. 1-10 the maximum compression ratio at the end of the compression stroke, when the piston is in top dead centre, is achieved when the maximum eccentricity of the bearing portion of the crank member 9 is directed upwardly and substantially aligned with the connecting rod. This is the case when the centre line of the bearing portion, the centre line of the crankpin 7 and the crankshaft axis 5 lie in a common plane, and when the centre line of the crank pin 7 lies between the centre line of the bearing portion and the crankshaft axis 5. Under stable operating conditions at maximum compression ratio the crankshaft 4 rotates clockwise as seen in a direction from the front side to the rear side of the engine 1. As explained hereinbefore, the crank member 9 also rotates clockwise, but at half crankshaft speed with respect to the crankcase 3. In the embodiment as shown in Figs. 1-10 the compression ratio is reduced by turning the crank member 9 clockwise at a virtual standstill of the crankshaft 4 over a certain turning angle. This means that in the new condition of lower compression ratio at the end of the compression stroke, when the piston is in top dead centre, the maximum eccentricity is turned outside the common plane in which the centre line of the crankpin 7 and the crankshaft axis 5 extend. The compression ratio can be further reduced by turning the crank member 9 clockwise at a virtual standstill of the crankshaft 4 over a larger turning angle. The minimum compression ratio at the end of the compression stroke, when the piston is in top dead centre, may lie at a turning angle of 90° to 140° from the position at maximum compression ratio with respect to the crankcase, for example. As explained hereinbefore, the clockwise rotation of the crank member 9 at a virtual standstill of the crankshaft can be achieved by braking the drive shaft 10 in unlocked condition of the coupling 22.

[0055] Alternatively, the crank member 9 may be rotated anti-clockwise at a virtual standstill of the crankshaft 4 from the position of maximum compression ratio at the end of the compression stroke when the piston is in top dead centre. In this case the crank member 9 and the crankshaft 4 may both still rotate clockwise at fixed compression ratio. Furthermore, the engine 1 may be configured such that at maximum compression ratio at the end of the compression stroke, when the piston is in top dead centre, the centre line of the bearing portion is not exactly in the common plane in which the centre line of the crankpin 7 and the crankshaft axis 5 extend.

[0056] Figs. 11-14 show an alternative embodiment of the engine 1 according to the invention. The parts that are similar to the embodiment as shown in Figs. 1-10 are indicated by the same reference signs. In Figs. 11-14 the front side of the engine 1 is located at the right side in the drawings. This embodiment also represents a four-cylinder engine 1 including a crankcase (not shown) which supports the crankshaft 4 via bearings. Fig. 11 shows the central main portion 6, the crankpin 7 and the crankshaft web 8 of the crankshaft 4. The crank member 9 is rotatably mounted on the crankpin 7 and comprises a bearing portion which is eccentrically disposed with respect to the crankpin 7. The driving mechanism

2 comprises the drive shaft 10, which extends concentrically through the central main portion 6. The drive shaft 10 is mechanically coupled to the crank member 9 via the transmission 11 at a side of the crankshaft web 8 where the crankpin 7 is located. The transmission 11 comprises the external crank member gear 12 of the crank member 9 and the external drive shaft gear 13 which is fixed to the drive shaft 10.

[0057] The driving mechanism 2 of the embodiment as shown in Figs. 11-14 is different with respect to the embodiment as shown in Fig. 1-10. The drive shaft 10 also extends concentrically through the central main portion 6 and is also drivably coupled to the crankshaft 4, but in a different way. Figs. 11-14 show that an external crankshaft driving gear 31 is mounted on the central main portion 6 of the crankshaft 4. The crankshaft driving gear 31 meshes with an external first driving gear 32. The first driving gear 32 may be mounted to an oil pump shaft for driving an oil pump, but this is not necessary. An external drive shaft gear 33 is mounted to the drive shaft 10 at a portion which extends beyond the central main portion 6 as seen from the first crankshaft web 8 to the front side of the engine 1. The external drive shaft gear 33 meshes with an external second driving gear 34. In this case the pulley 23 is also fixed to the drive shaft 10.

[0058] The embodiment of the engine 1 as shown in Figs. 11-14 is also provided with the lockable coupling 22, which is located at the first and second driving gears 32, 34. The first and second driving gears 32, 34 are rotatable about a common centre line which extends parallel to the crankshaft axis 5 and can be locked with respect to each other. In a locked condition the crankshaft 4 drives the drive shaft 10 under operating conditions through the crankshaft driving gear 31, the first driving gear 32, the second driving gear 34 and the drive shaft gear 33. In unlocked condition the mutual position of the first and second driving gears 32, 34 can be adjusted, resulting in a change of compression ratio.

[0059] If the engine should be operated at a lower compression ratio the coupling 22 can be unlocked and the drive shaft 10 can be decelerated with respect to the crankshaft 4 temporarily by the braking system, in this case by the alternator (not shown) of the engine 1 which is drivably coupled to the pulley 23 via an endless belt (not shown). When the engine speed increases upon switching from a low-load to a high-load condition the compression ratio is reduced at the same time if the coupling 22 is unlocked temporarily. The relative angle can be determined by a controller for controlling the locking mechanism of the coupling 22. The first and second driving gears 32, 34 may be provided with sensing means for supplying actual rotational positions of the first and second driving gears 32, 34, which information can be transferred to the controller.

[0060] It is noted that mounting the pulley 23 on the drive shaft 10 is independent from the presence of the coupling 22. In other words, another aspect of the invention is related to:

An internal combustion engine, comprising
a crankcase;

a crankshaft including a crankshaft axis, said crankshaft having at least a central main portion, a crankpin and a crankshaft web located between the central main portion and the crankpin, said crankshaft being supported by the crankcase and rotatable with respect thereto about the crankshaft axis;

at least a connecting rod including a big end and a small end;

a piston being rotatably connected to the small end;

a crank member being rotatably mounted on the crankpin, and comprising at least a bearing portion which is eccentrically disposed with respect to the crankpin, and having an outer circumferential wall which bears the big end of the connecting rod such that the connecting rod is rotatably mounted on the bearing portion of the crank member via the big end;

a driving mechanism for rotating the crank member at a rotation frequency with respect to the crankcase which is substantially half of that of the crankshaft as seen from the crankcase,

wherein the driving mechanism comprises a drive shaft that extends concentrically through the central main portion, wherein the drive shaft is drivably coupled to the crank member via a transmission at a side of the crankshaft web where the crankpin is located, wherein the drive shaft at the opposite side of the crankshaft web is drivably coupled to driving means and provided with a rotating member, such as a pulley.

[0061] The pulley may be coupled via an endless belt to driving means for driving the drive shaft or to a power take-off member for driving the power take-off member. The engine according to this aspect of the invention may be combined with features that are described in relation to the embodiments hereinbefore.

[0062] It is also noted that a bearing in the crankcase for supporting the drive shaft is independent from the presence of the coupling. In other words, another aspect of the invention is related to:

An internal combustion engine, comprising
a crankcase;

a crankshaft including a crankshaft axis, said crankshaft having at least a central main portion, a crankpin and a crankshaft web located between the central main portion and the crankpin, said crankshaft being supported by the crankcase and rotatable with respect thereto about the crankshaft axis;

at least a connecting rod including a big end and a small end;
 a piston being rotatably connected to the small end;
 a crank member being rotatably mounted on the crankpin, and comprising at least a bearing portion which is
 eccentrically disposed with respect to the crankpin, and having an outer circumferential wall which bears the big
 end of the connecting rod such that the connecting rod is rotatably mounted on the bearing portion of the crank
 member via the big end;
 a driving mechanism for rotating the crank member at a rotation frequency with respect to the crankcase which is
 substantially half of that of the crankshaft as seen from the crankcase,
 wherein the driving mechanism comprises a drive shaft that extends concentrically through the central main portion,
 wherein the drive shaft is drivably coupled to the crank member via a transmission at a side of the crankshaft web
 where the crankpin is located, wherein the drive shaft at the opposite side of the crankshaft web is drivably coupled
 to driving means and supported by a bearing in the crankcase.

[0063] The advantage of this embodiment is that the drive shaft can be disposed accurately in the engine. The engine
 according to this aspect of the invention may be combined with features that are described in relation to the embodiments
 hereinbefore.

[0064] It is also noted that mounting the driving wheel on the crankshaft by means of a nut including a central through-
 hole is independent from the presence of the coupling. In other words, another aspect of the invention is related to:

An internal combustion engine, comprising
 a crankcase;
 a crankshaft including a crankshaft axis, said crankshaft having at least a central main portion, a crankpin and a
 crankshaft web located between the central main portion and the crankpin, said crankshaft being supported by the
 crankcase and rotatable with respect thereto about the crankshaft axis;
 at least a connecting rod including a big end and a small end;
 a piston being rotatably connected to the small end;
 a crank member being rotatably mounted on the crankpin, and comprising at least a bearing portion which is
 eccentrically disposed with respect to the crankpin, and having an outer circumferential wall which bears the big
 end of the connecting rod such that the connecting rod is rotatably mounted on the bearing portion of the crank
 member via the big end;
 a driving mechanism for rotating the crank member at a rotation frequency with respect to the crankcase which is
 substantially half of that of the crankshaft as seen from the crankcase,
 wherein the driving mechanism comprises a drive shaft that extends concentrically through the central main portion,
 wherein the drive shaft is drivably coupled to the crank member via a transmission at a side of the crankshaft web
 where the crankpin is located, wherein the drive shaft at the opposite side of the crankshaft web is drivably coupled
 to driving means, wherein a crankshaft driving wheel is fixed to the central main portion by means of a hollow nut
 through which the drive shaft extends.

[0065] The engine according to this aspect of the invention may be combined with features that are described in
 relation to the embodiments hereinbefore.

[0066] From the foregoing, it will be clear that the invention provides an improved internal combustion engine including
 variable compression ratio.

[0067] The invention is not limited to the embodiments shown in the drawings and described hereinbefore, which may
 be varied in different manners within the scope of the claims and their technical equivalents. For example, the crankshaft
 driving wheel 14, the first driving wheel 15, the second driving wheel 19, the first endless member 16 and the second
 endless member 20 may be replaced by sprockets and chains. The transmission may be different than two meshing
 external gears. It is also conceivable to use combustion forces of the engine in addition or instead of the braking system
 for adjusting the mutual position of the crank member and the crankshaft at a virtual standstill of the crankshaft. Fur-
 thermore, it is possible to adapt the driving mechanism such that at fixed compression ratio the crank member rotates
 in opposite rotational direction as that of the crankshaft as seen from the crankcase.

Claims

1. An internal combustion engine (1) including variable compression ratio, comprising
 a crankcase (3);
 a crankshaft (4) including a crankshaft axis (5), said crankshaft (4) having at least a central main portion (6), a
 crankpin (7) and a crankshaft web (8) located between the central main portion (6) and the crankpin (7), said

crankshaft (4) being supported by the crankcase (3) and rotatable with respect thereto about the crankshaft axis (5);
 at least a connecting rod including a big end and a small end;
 a piston being rotatably connected to the small end;

a crank member (9) being rotatably mounted on the crankpin (7), and comprising at least a bearing portion which is eccentrically disposed with respect to the crankpin (7), and having an outer circumferential wall which bears the big end of the connecting rod such that the connecting rod is rotatably mounted on the bearing portion of the crank member (9) via the big end;

a driving mechanism (2) for rotating the crank member (9) at a rotation frequency with respect to the crankcase (3) which is substantially half of that of the crankshaft (4) as seen from the crankcase (3),

wherein the driving mechanism (2) comprises a drive shaft (10) that extends concentrically through the central main portion (6), wherein the drive shaft (10) is drivably coupled to the crank member (9) via a transmission (11) at a side of the crankshaft web (8) where the crankpin (7) is located, wherein the drive shaft (10) at the opposite side of the crankshaft web (8) is drivably coupled to the crankshaft (4) via a lockable coupling (22) for adjusting the mutual rotational position of the crank member (9) and the crankshaft (4) at any rotational position of the crank member (9) with respect to the crankcase (3), and a controller for controlling the coupling (22) such that in unlocked condition of the coupling (22) said mutual rotational position is adjustable.

2. An internal combustion engine (1) according to claim 1, wherein the driving mechanism (2) is adapted such that the crank member (9) rotates in the same rotational direction as that of the crankshaft (4) as seen from the crankcase (3).

3. An internal combustion engine (1) according to claim 1 or 2, wherein the transmission (11) comprises an external crank member gear (12) which is fixed to the crank member (9) and an external drive shaft gear (13) which is fixed to the drive shaft (10) and meshes with the crank member gear (12).

4. An internal combustion engine (1) according to one of the preceding claims, wherein the drive shaft (10) at the opposite side of the crankshaft web (8) is also drivably coupled to a braking system for braking the drive shaft (10) in unlocked condition of the coupling (22).

5. An internal combustion engine (1) according to claim 4, wherein the braking system comprises a power take-off member of the engine (1), which is drivably coupled to the drive shaft (10).

6. An internal combustion engine (1) according to claim 5, wherein the power take-off member comprises an alternator.

7. An internal combustion engine (1) according to one of the preceding claims, wherein the crankshaft (4) is drivably coupled to a rotatable input member (15, 32) of the coupling (22) and the drive shaft (10) is drivably coupled a rotatable output member (19, 34) of the coupling (22).

8. An internal combustion engine (1) according to claim 7, wherein at least one of the rotatable input (15, 32) and output member (19, 34) is provided with sensing means for detecting said mutual position.

9. An internal combustion engine (1) according to claim 7 or 8, wherein the rotatable input member comprises a first driving wheel (15) that is drivably coupled to the crankshaft (4) via a first endless member (16) and the rotatable output member comprises a second driving wheel (19) that is drivably coupled to the drive shaft (10) via a second endless member (20), or wherein the rotatable input member comprises an external first driving gear (32) that meshes with an external crankshaft driving gear (31) of the crankshaft (4) and the rotatable output member comprises an external second driving gear (34) that meshes with an external drive shaft gear (33) of the drive shaft (10).

10. An internal combustion engine (1) according to claim 9, wherein the first driving wheel (15) is drivably coupled to the central main portion (6) of the crankshaft (4) and the second driving wheel (19) is drivably coupled to the drive shaft (10) at a portion that projects from the central main portion (6) as seen from the crankshaft web (8), or wherein the external crankshaft driving gear (31) is located at the central main portion (6) of the crankshaft (4) and the external drive shaft gear (33) is located at a portion of the drive shaft (10) that projects from the central main portion (6) as seen from the crankshaft web (8).

11. An internal combustion engine (1) according to claim 10, wherein a crankshaft driving wheel (14) which is drivably coupled to the first driving wheel (15), or the external crankshaft driving gear (31), is fixed to the central main portion (6) by means of a hollow nut (24) through which the drive shaft (10) extends.

EP 2 902 603 A1

12. An internal combustion engine (1) according to one of the claims 7-11, wherein the rotatable input member (15, 32) and the rotatable output member (19, 34) are rotatable about a common centre line extending parallel to the crankshaft axis (5).

5 **13.** An internal combustion engine (1) according to one of the preceding claims and claim 4, wherein the drive shaft (10) is drivably coupled to the braking system of the engine via a third wheel (23) that is fixed to the drive shaft (10) at the opposite side of the crankshaft web (8), wherein the third wheel (23) is preferably drivably coupled to the alternator via a third endless member.

10 **14.** An internal combustion engine (1) according to one of the preceding claims, wherein the driving mechanism (2) comprises a return actuator for exerting a return force on the drive shaft (10) in the unlocked condition of the coupling (22).

15 **15.** An internal combustion engine (1) according to claim 14, wherein the return actuator comprises a spring, a hydraulic member, an electric motor or an alternator which is provided with an electric motor function.

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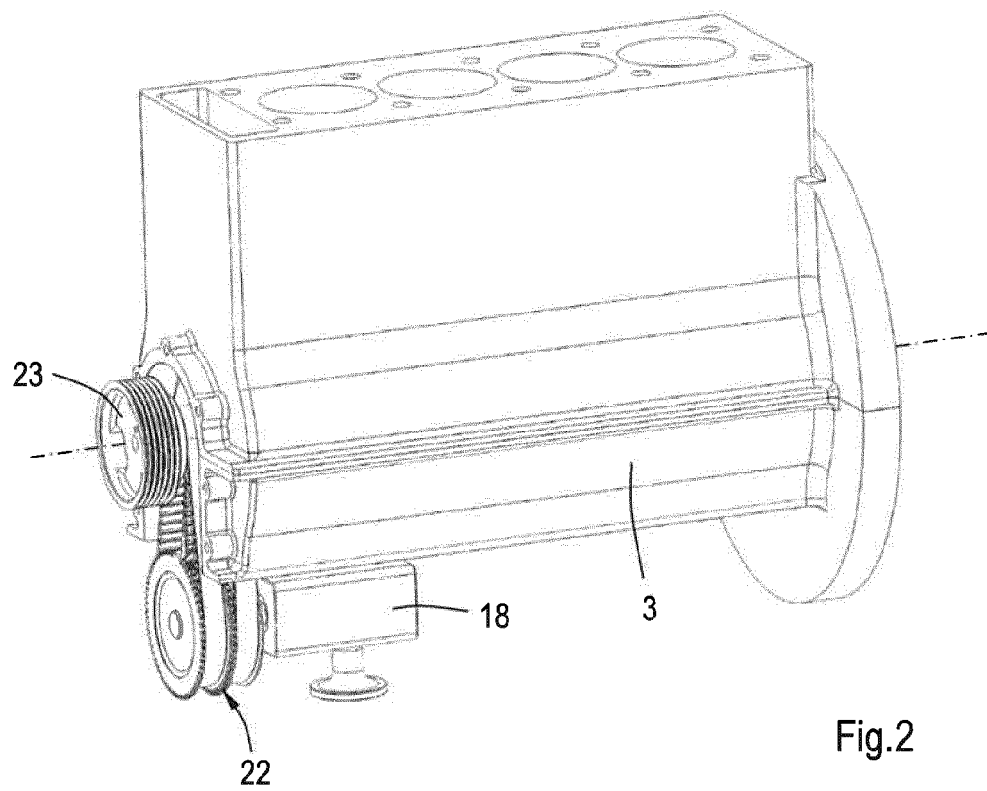
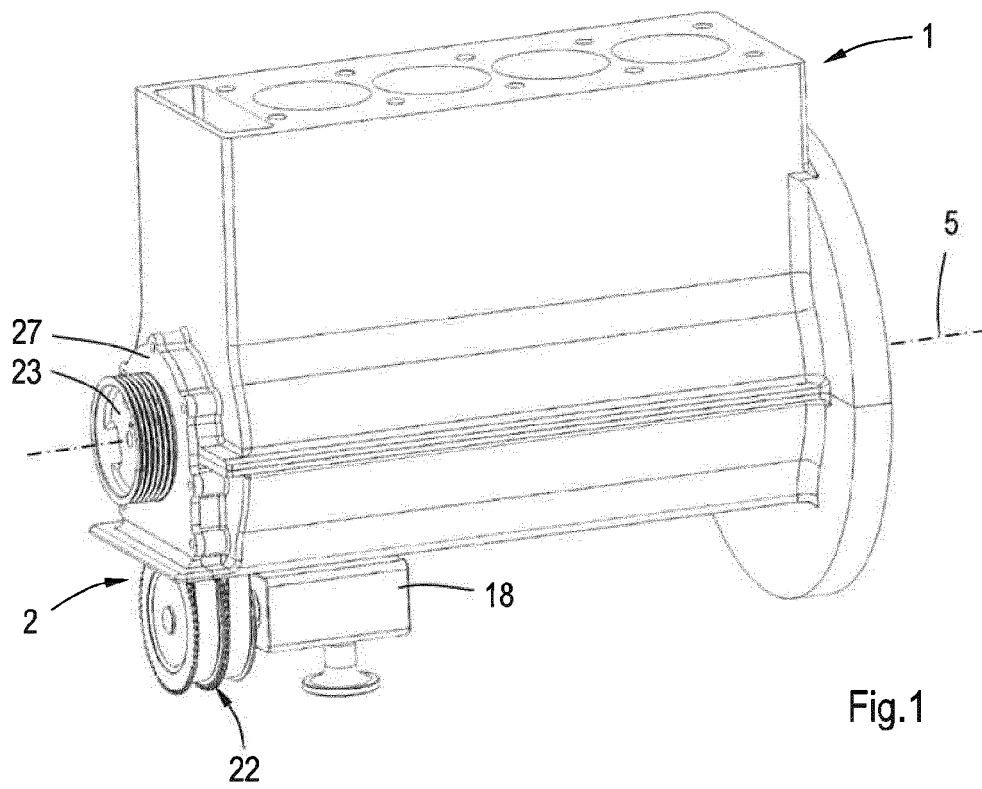
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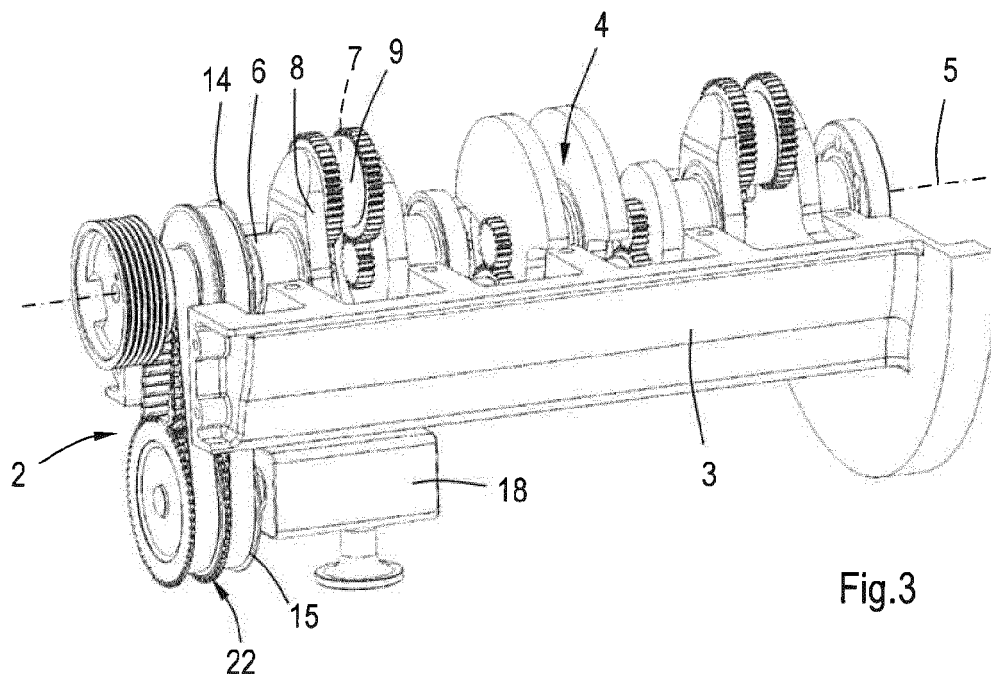


Fig.3

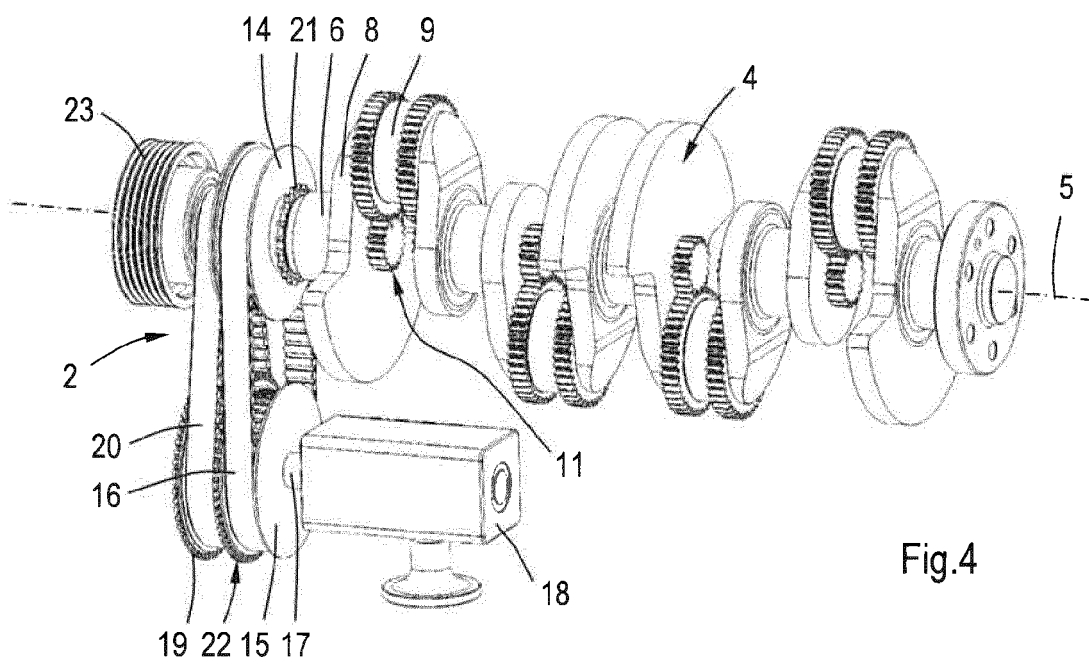


Fig.4

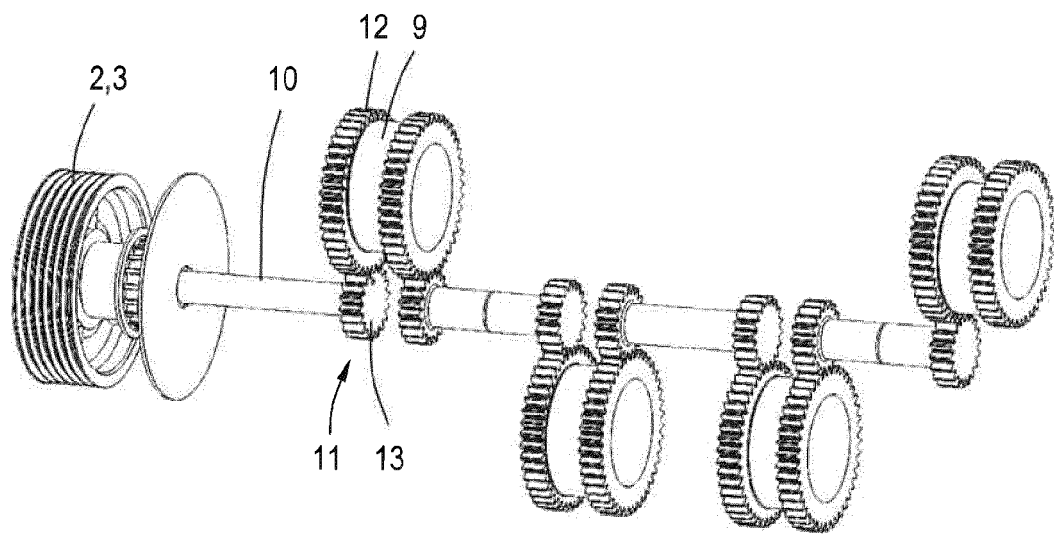


Fig.5

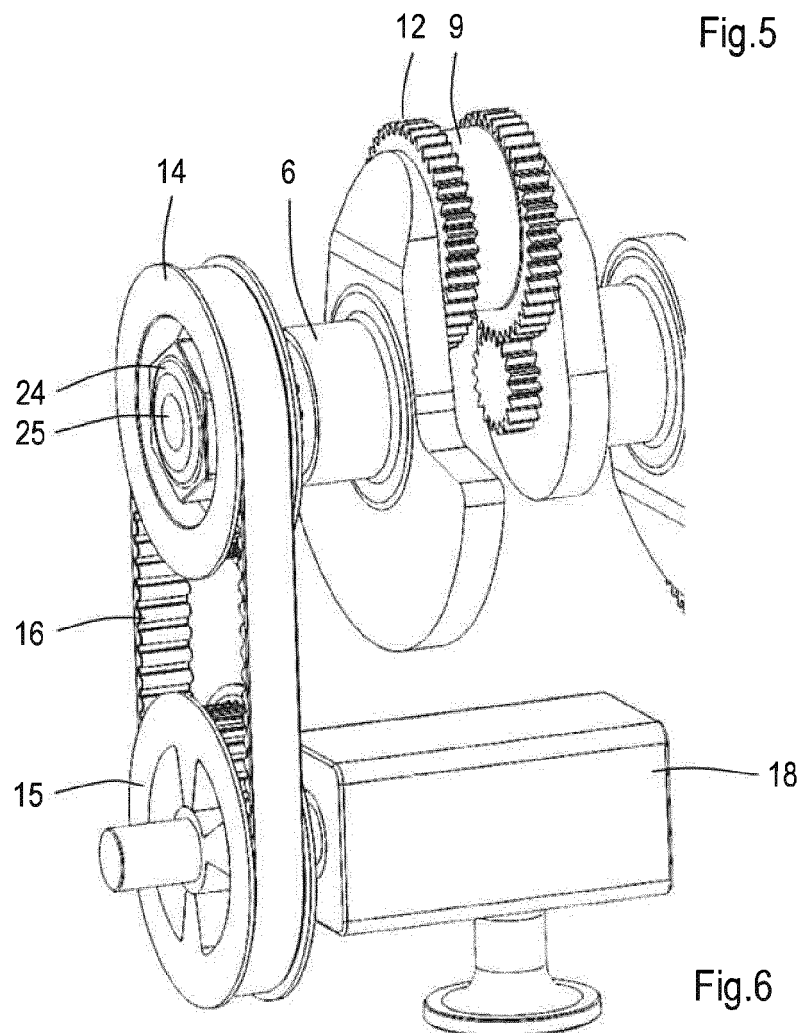
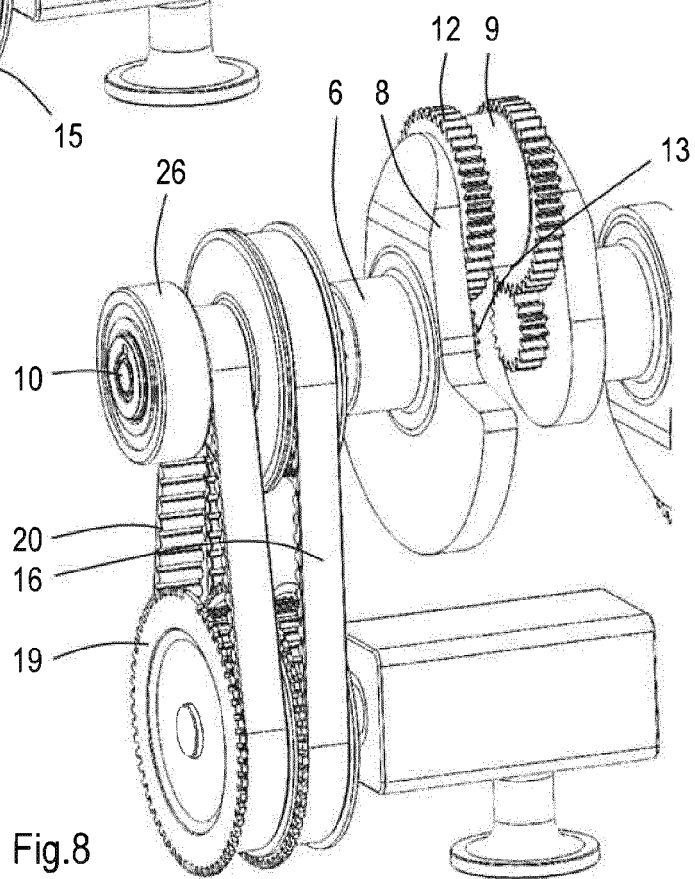
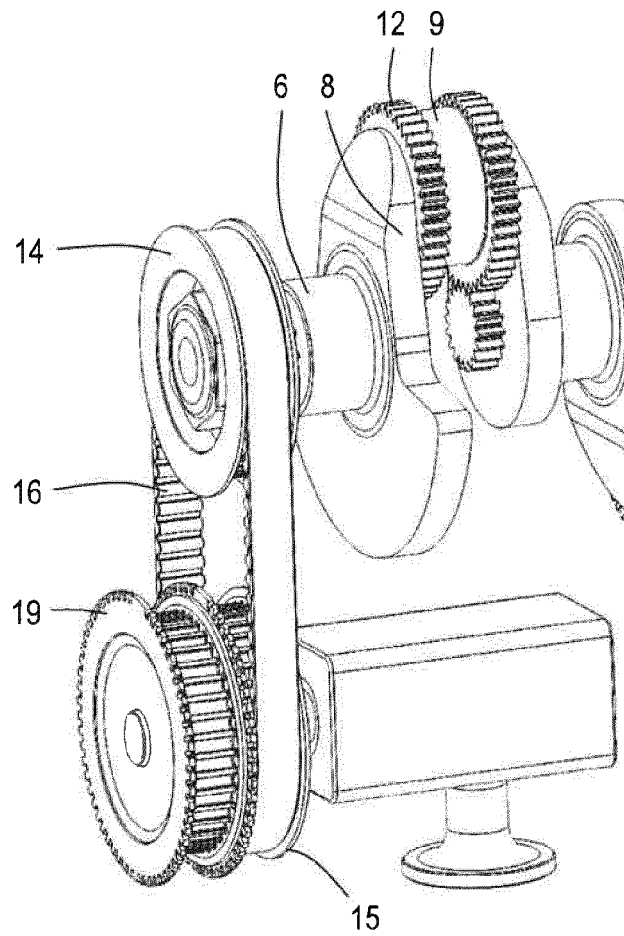
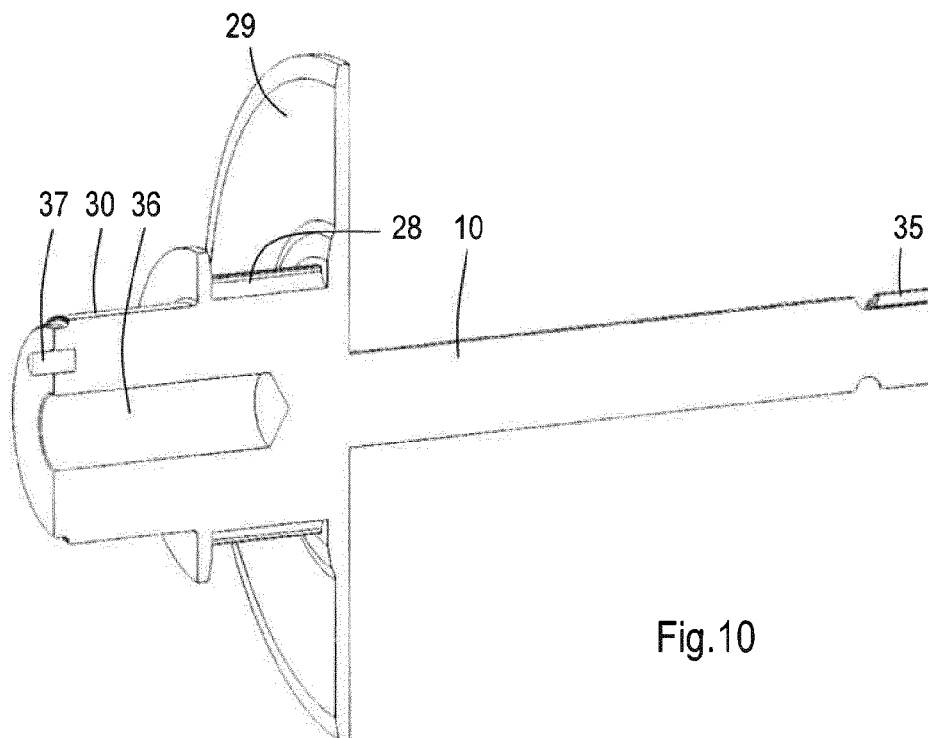
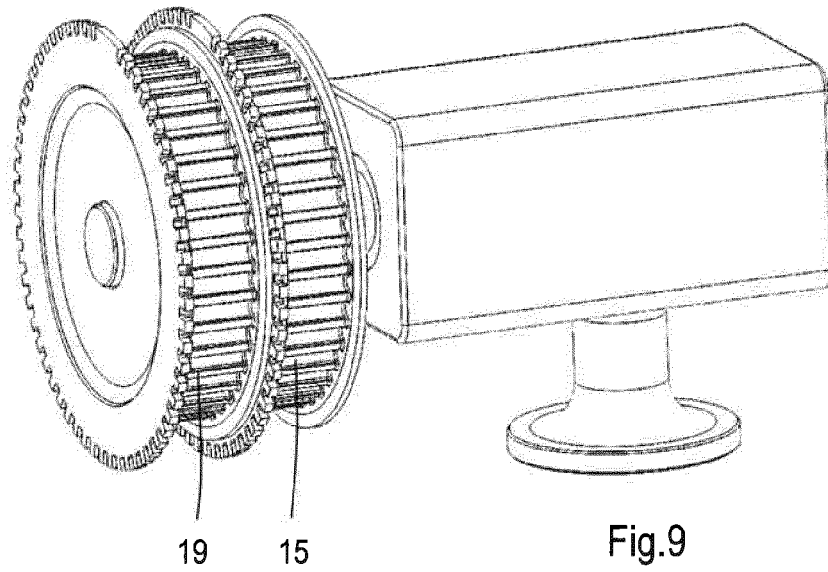


Fig.6





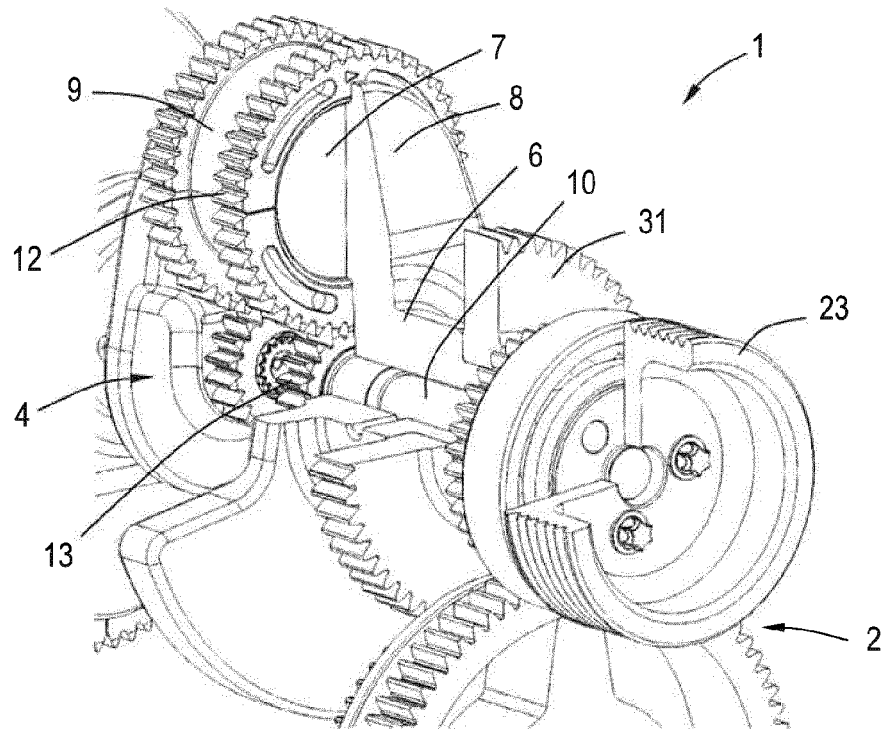


Fig.11

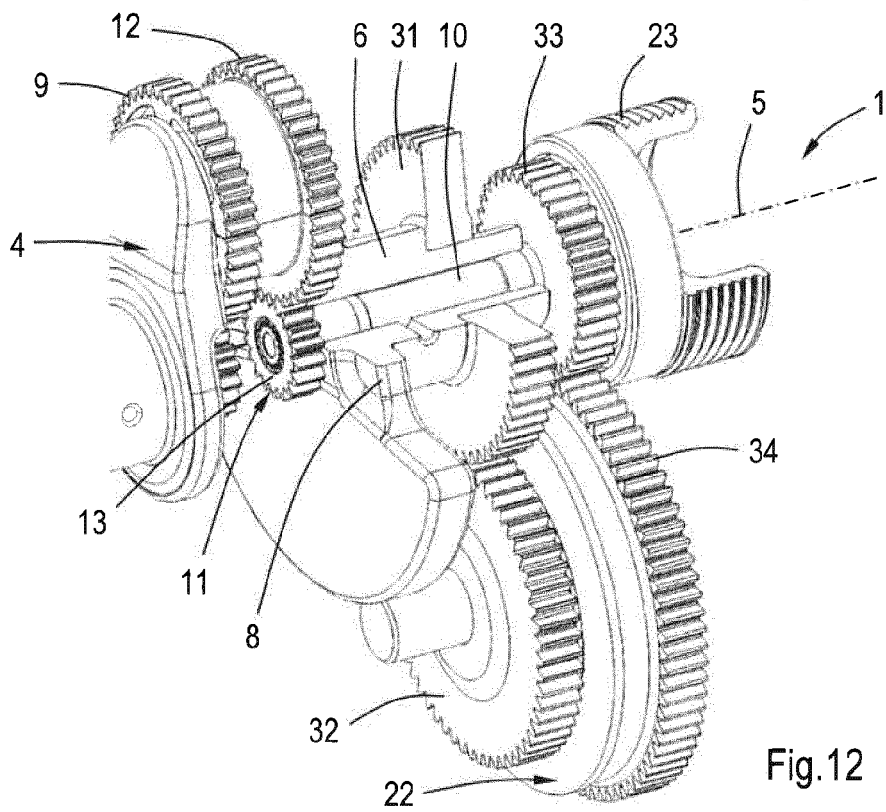
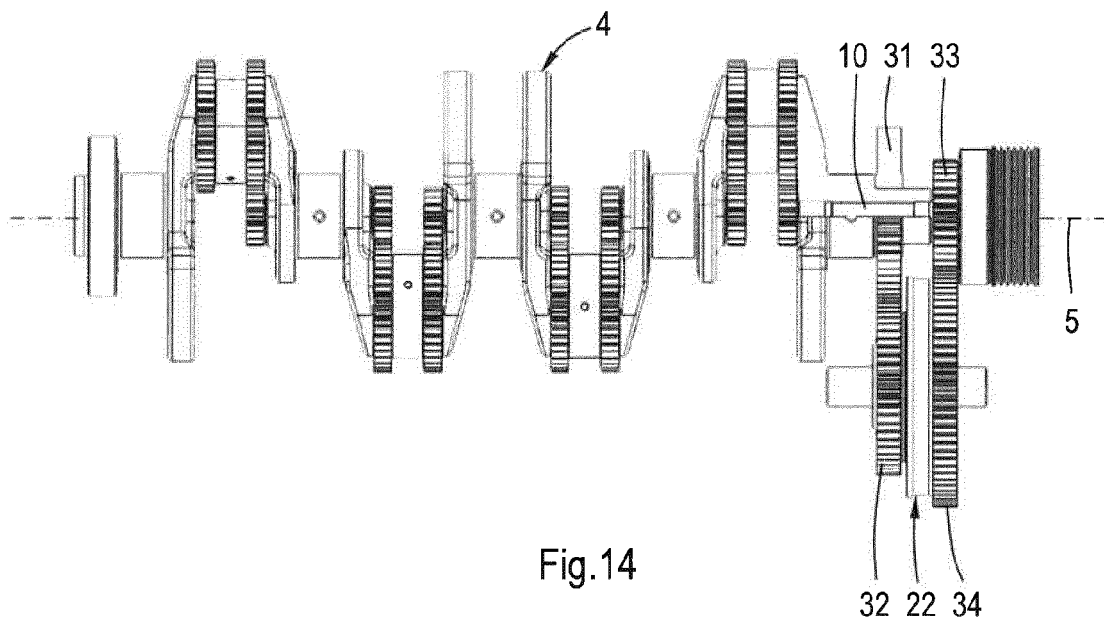
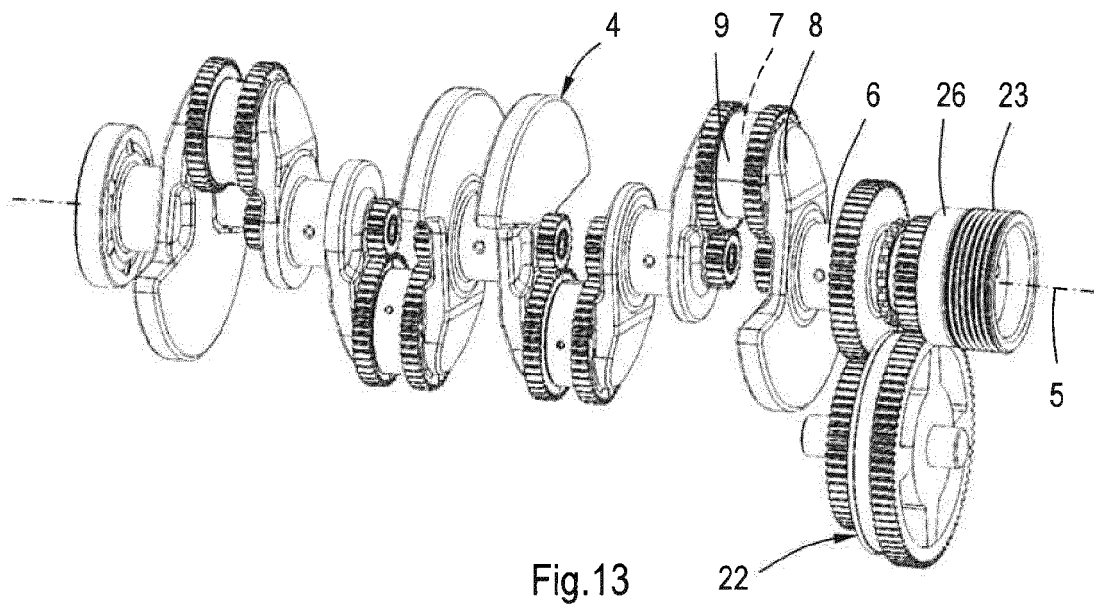


Fig.12





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Place of search The Hague		Date of completion of the search 11 June 2014	Examiner Mouton, Jean
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