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(54) **A Reciprocating Piston Combustion Engine and an Apparatus and a Method for Controlling Such an Engine**

(57) A reciprocating piston combustion engine (1) is presented that has at least one cylinder (4), at least one piston (6) which is movably arranged within the at least one cylinder, and a crankshaft (2) which is rotatably arranged in a crankshaft housing, with every piston (6) being connected to the crankshaft (2) via a connecting rod (9) having an upper and lower bearing (14a, 14b) to drive the crankshaft. The reciprocating piston combustion engine (1) is additionally provided with an eccentric tappet (15) at the lower bearing (14b) of the at least one connecting rod (9) and with a locking mechanism (16) for locking the eccentric tappet (15) either to the connecting rod (9) or to a corresponding crank pin (2a) of the crankshaft (2) to operate the reciprocating piston combustion engine changeably at a first or second compression ratio respectively.

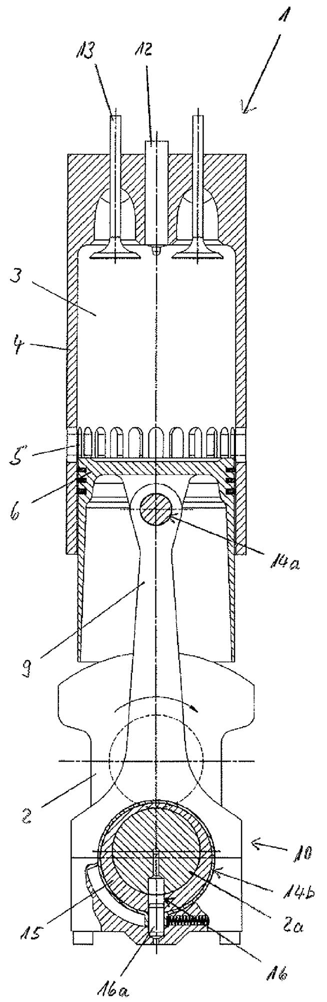

Fig. 1

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Description

[0001] The invention relates to a reciprocating piston combustion engine according to the preamble of claim 1 and to an apparatus and a method for controlling the compression ratio of a reciprocating piston combustion engine according to the preamble of claims 9 and 12 respectively.

[0002] In a reciprocating piston combustion engine the compression ratio is an important parameter for the combustion, the thermal efficiency and for the exhaust gas emissions. The compression ratio is usually chosen to yield the best engine performance. Often the high load engine performance is the most relevant point for the choice. For optimal performance over the whole operating range a variable compression ratio would be desirable but due to complications with such a system a compromise is usually made defining a constant compression ratio.

[0003] For reciprocating piston combustion engines capable of running on different fuel qualities having different ignition properties or for so called dual fuel engines capable of running on both liquid diesel oil according to the diesel cycle and on gas according to the otto cycle the problem becomes even more critical. Since the common compression ratio range where it is possible to run both the diesel cycle with diesel oil and the otto cycle with gas is very narrow. In such a case a compromise has to be made on both the diesel cycle and the otto cycle performance. This may be possible in some cases, but for optimum engine performance a variable compression ratio is needed.

[0004] Different solutions are known for varying the compression ration in reciprocating piston combustion engines, such as an eccentric tappet, either at the upper or lower bearing of the connecting rod. To enable a change of compression ratio the eccentric tappet has to be turned between intermediate positions (in case of continuous variability) or between two fix positions by a hydraulic or mechanical mechanism. Thus, the piston is axially moved and its position at Top Dead Center (TDC) and Bottom Dead Center (BDC) is changed. The stroke remains unchanged in case of an eccentric tappet, rotatably fixed at the upper or lower connecting rod bearing shell.

[0005] In two-stroke engines a system with rotatably fixed eccentric tappet or another kind of mechanism to displace the piston leads to an unnecessary extension of the stroke below scavenging ports at the adjustment for low compression ratio; so the height of the engine is additionally increased and the time for scavenging is significantly longer than at the adjustment for high compression ratio.

[0006] It is an object of the present invention to provide a reciprocating piston combustion engine and a control apparatus and method for controlling the compression ratio of a reciprocating piston combustion engine which allow to change the compression ratio without affecting scavenging in two stroke engines and with no or only slight increase in engine height.

[0007] This object is satisfied in accordance with the invention by the large reciprocating piston combustion engine defined in claim 1, and by the control apparatus and by the method defined in claim 9 and 12 respectively.

[0008] The reciprocating piston combustion engine according to the invention has at least one cylinder or cylinder liner, at least one piston which is movably arranged within the at least one cylinder or cylinder liner, and a crankshaft which is rotatably arranged in a crankshaft housing, with every piston being connected to the crankshaft via a connecting rod having an upper and lower bearing to drive the crankshaft. The reciprocating piston combustion engine according to the invention is additionally provided with an eccentric tappet at the lower bearing of the at least one connecting rod and with a locking mechanism for locking the eccentric tappet either to the connecting rod or to a corresponding crank pin of the crankshaft to operate the reciprocating piston combustion engine changeably at a first or second compression ratio respectively. Typically, the second compression ratio is higher than the first compression ratio.

[0009] In an advantageous embodiment the locking mechanism includes at least one locking element or locking pin for locking the eccentric tappet alternatively to the connecting rod or to the corresponding crank pin of the crankshaft.

[0010] Advantageously the compression ratio can be changed by activating the locking mechanism manually or hydraulically or pneumatically to switch from a state in which the eccentric tappet is locked to the connecting rod to a state in which the eccentric tappet is locked to the corresponding crank pin of the crankshaft and vice versa.

[0011] The compression ratio of every cylinder can be changed conveniently at BDC position of the corresponding piston or in a range of the engine angle of -90° to 90° from the BDC position.

[0012] In a further advantageous embodiment the reciprocating piston combustion engine is configured for changing the compression ratio at slow rotational speed of the engine not exceeding for example 30 % or 15 % of full rotational speed.

[0013] In another advantageous embodiment the maximum radius of the eccentric tappet is directed downwardly at BDC position.

[0014] Independent of the embodiment the reciprocating piston combustion engine can include a control unit connected to the locking mechanism to control the compression ratio of the reciprocating piston combustion engine.

[0015] The invention further includes an apparatus for controlling the compression ratio of a reciprocating piston combustion engine, wherein the engine has at least one cylinder, at least one piston which is movably arranged within the at least one cylinder, and a crankshaft which is rotatably arranged in a crankshaft housing, and wherein the apparatus includes a connecting rod for connecting the piston to the crankshaft in operation, and wherein the connecting rod has a first bearing for connection to the piston or to a crosshead fixed to the piston rod and a second bearing for connection to a crank pin of the crankshaft. The apparatus according to the invention is additionally provided with an eccentric tappet at the second bearing of the connecting rod and with a locking mechanism for locking the eccentric tappet either to the connecting rod or to the crank pin of the crankshaft to operate the reciprocating piston combustion engine changeably at a first or second compression ratio respectively.

[0016] In an advantageous embodiment the apparatus includes at least one locking element or locking pin for locking the eccentric tappet alternatively to the connecting rod or to the corresponding crank pin of the crankshaft.

[0017] In a further advantageous embodiment the apparatus includes a control unit connected to the locking mechanism to control the compression ratio of the reciprocating piston combustion engine.

[0018] The invention further includes a method for controlling the compression ratio of a reciprocating piston combustion engine that has at least one cylinder, at least one piston which is movably arranged within the at least one cylinder, and a crankshaft which is rotatably arranged in a crankshaft housing, with every piston being connected to the crankshaft via a connecting rod having an upper and lower bearing to drive the crankshaft. In the method according to the invention the reciprocating piston combustion engine is additionally provided with an eccentric tappet at the lower bearing of the at least one connecting rod, and the eccentric tappet is locked by a locking mechanism either to the connecting rod or to a corresponding crank pin of the crankshaft, so that the reciprocating piston combustion engine can changeably be operated at a first or second compression ratio respectively.

[0019] In an advantageous embodiment of the method the compression ratio is changed by activating the locking mechanism manually or hydraulically or pneumatically to switch from a state in which the eccentric tappet is locked to the connecting rod to a state in which the eccentric tappet is locked to the corresponding crank pin of the crankshaft and vice versa.

[0020] In a further advantageous embodiment of the method the compression ratio is changed when the reciprocating piston combustion engine 1 is slowly running or at rest.

[0021] In other words, the reciprocating piston combustion engine and the apparatus and method for controlling the compression ratio of a reciprocating piston combustion engine according to the invention make use of an eccentric tappet at the lower bearing of a connecting rod. To switch the compression ratio between two fix ratios, the eccentric tappet is not turned actively or by use of mass- and/or gas forces, but it changes its connection between the corresponding crankpin on the crankshaft and the connecting rod at BDC. So the position of the piston at BDC remains unchanged for low and high compression ratio adjustments while at TDC the two adjustments result in two different axial positions of the piston and herewith in two different compression ratios.

A) Adjustment for low compression ratio:

> The eccentric tappet looks downwards, i.e. the maximum radius of the eccentric tappet looks downwards, and the eccentric tappet is connected with or locked to the connecting rod. So the alignment of the tappet remains the same at TDC and BDC and the piston is at a low position at TDC.

B) Adjustment for high compression ratio:

> The eccentric tappet is connected with or locked to the corresponding crankpin on the crankshaft. At BDC it looks downwards and at TDC upwards due to the turning movement of 180°. So the piston is at high position at TDC.

[0022] Between adjustment A and B there is a difference of stroke-length; at adjustment B the crank radius is increased by the value of eccentricity of the eccentric tappet, so the stroke is increased by twice this eccentricity.

[0023] To change the compression ratio from high to low or opposite, the connection of the eccentric tappet has to be switched from the crankpin to the connecting rod or opposite. This can be done advantageously at BDC because only there the orientation of the eccentric tappet is for both adjustments identical (looking downwards). A positive effect is that at BDC the relative angular speed between crank and connecting rod is minimal; so if the connection-switch is done during engine running, the acceleration-shock for the eccentric tappet is relatively low.

[0024] In operation the system which connects the eccentric tappet to the crankpin has to transmit a torque, defined by the radius of eccentricity, the axial mass-and gas forces, the mass forces of the swinging movement of connecting rod and the friction-force in the bearing.

[0025] The system which connects the eccentric tappet to the connecting rod has only to transmit a relative small torque in operation resulting from the friction-force in the bearing and the mass forces of the swinging movement of connecting rod.

[0026] The apparatus and method and the different embodiments described above can be used on trunk piston engines (two- and four-stroke) and also on crosshead engines (two-stroke) including large two-stroke reciprocating piston combustion engines having a cylinder bore of greater than 270 mm or greater than 300 mm diameter and large four-stroke reciprocating piston combustion engines having a cylinder bore of greater than 160 mm or greater than 200 mm.

[0027] The reciprocating piston combustion engine according to the invention can be implemented as a two-stroke or four-stroke engine, for example as a four-stroke engine having a cylinder bore of greater than 160 mm or greater than 200 mm, or as a two-stroke engine having a cylinder bore of greater than 270 mm or greater than 300 mm diameter. Moreover, the reciprocating piston combustion engine can be implemented as a reciprocating piston combustion engine of the diesel type.

[0028] The reciprocating piston combustion engine and the apparatus and method for controlling the compression ratio of a large reciprocating piston combustion engine according to the invention have the advantage that in two-stroke engines there is no extension of the stroke below scavenging ports at the adjustment for low compression ratio; so the height of the engine is not or only slightly increased and the time for scavenging is not significantly longer than at the adjustment for high compression ratio while in most other engines having a rotatable eccentric tappet or another kind of mechanism to displace the piston the time for scavenging at the adjustment for low compression ratio is significantly longer than at the adjustment for high compression ratio. Moreover, it is advantageous that there is nearly no increase of oscillating masses compared to a rotatable eccentric tappet at the upper connecting rod bearing, only rotating masses are higher.

[0029] A further advantage of the inventive solution is a slightly higher stiffness of the crankshaft due to reduced crank-radius since the protruding eccentric tappet increases the stroke at high compression mode. In addition, the inventive solution features two adequate bearings between the lower end of the connecting rod and crankpin. Arising fretting marks at the inactive bearing will be removed when this bearing is reactivated. This favorably compares to the bearings of eccentric tappets which have to be rotated by 180° for changing compression ratio. In case of a rotatable eccentric tappet one bearing is a swing bearing in which fretting marks will not be removed.

[0030] The above description of the embodiments and variants serves merely as an example. Further advantageous embodiments can be seen from the dependent claims and the drawing. Moreover, in the context of the present invention, individual features from the described or illustrated embodiments and from the described or illustrated variants can be combined with one another in order to form new embodiments.

[0031] In the following the invention will be explained in more detail with reference to the specific embodiments and with reference to the drawing.

Fig. 1 is a longitudinal section through a cylinder of an embodiment of a reciprocating piston combustion engine according to the present invention at low compression ratio adjustment and BDC;

Fig. 2 is the embodiment of Fig. 1 at low compression ratio adjustment and TDC;

Fig. 3 is the embodiment of Fig. 1 at high compression ratio adjustment and BDC;

Fig. 4 is the embodiment of Fig. 1 at high compression ratio adjustment and TDC;

Fig. 5 is an axial section through a cylinder of a second embodiment of a reciprocating piston combustion engine according to the present invention during change from high to low compression ratio adjustment or vice versa;

Fig. 6 is an enlarged detail of Fig. 5;

Fig. 7 is an embodiment of an apparatus according to the present invention at low compression ratio adjustment and BDC;

Fig. 8 is the embodiment of Fig. 7 at low compression ratio adjustment and TDC;

Fig. 9 is the embodiment of Fig. 7 at high compression ratio adjustment and BDC;

Fig. 10 is the embodiment of Fig. 7 at high compression ratio adjustment and TDC; and

Fig. 11 is an embodiment of a large two-stroke reciprocating piston combustion engine of the diesel type according to the invention.

[0032] Fig. 1 shows a longitudinal section through a cylinder of an embodiment of a reciprocating piston combustion engine 1 according to the present invention. The embodiment is shown at low compression ratio adjustment and BDC. The reciprocating piston combustion engine 1 according to the invention has at least one cylinder 4, at least one piston 6 which is movably arranged within the at least one cylinder, and a crankshaft 2 which is rotatably arranged in a crankshaft housing, with every piston 6 being connected to the crankshaft 2 via a connecting rod 9 having an upper and lower bearing 14a, 14b to drive the crankshaft. The reciprocating piston combustion engine 1 according to the invention is additionally provided with an eccentric tappet 15 at the lower bearing 14b of the at least one connecting rod 9 and with a locking mechanism 16 for locking the eccentric tappet 15 either to the connecting rod 9 or to a corresponding crank pin 2a of the crankshaft 2 to operate the reciprocating piston combustion engine changeably at a first or second compression ratio respectively. Typically, the second compression ratio is higher than the first compression ratio.

[0033] In addition, the reciprocating piston combustion engine 1 can optionally contain one ore more of the following components: a combustion space 3, one ore more scavenging openings 5 in the lower part of the cylinder 4 for the inlet of scavenging air, one or more injection nozzles 12 arranged at the cylinder cover for injecting fuel, and at least one exit valve 13 for controlling the discharge of exhaust gas.

[0034] The connecting rod 9 provided with an eccentric tappet 15 at the lower bearing 14b of the connecting rod and with a locking mechanism 16 for locking the eccentric tappet 15 either to the connecting rod 9 or to a corresponding crank pin 2a of the crankshaft 2 to operate the reciprocating piston combustion engine changeably at a first or second compression ratio respectively is designated an apparatus for controlling the compression ratio of a reciprocating piston combustion engine and is given the reference number 10 in the following.

[0035] In an advantageous embodiment of reciprocating piston combustion engine 1 the locking mechanism 16 includes at least one locking element or locking pin 16a for locking the eccentric tappet 15 alternatively to the connecting rod 9 or to the corresponding crank pin 2a of the crankshaft 2.

[0036] Advantageously the compression ratio can be changed by activating the locking mechanism 16 manually or hydraulically or pneumatically to switch from a state in which the eccentric tappet 15 is locked to the connecting rod 9 to a state in which the eccentric tappet is locked to the corresponding crank pin 2a of the crankshaft 2 and vice versa.

[0037] The compression ratio of every cylinder can be changed conveniently at BDC position of the corresponding piston 6 or in a range of the engine angle of -90° to 90° from the BDC position.

[0038] In a further advantageous embodiment the reciprocating piston combustion engine 1 is configured for changing the compression ratio at slow rotational speed of the engine not exceeding for example 30 % or 15 % of full rotational speed.

[0039] In another advantageous embodiment the maximum radius of the eccentric tappet 15 is directed downwardly at BDC position.

[0040] Independent of the embodiment the reciprocating piston combustion engine 1 can include a control unit connected to the locking mechanism 16 to control the compression ratio of the reciprocating piston combustion engine, including for example controlling the timing of the locking mechanism 16 with respect to the angular position of the crankshaft 2.

[0041] Figures 2, 3 and 4 show the embodiment illustrated in Fig. 1 at low compression ratio adjustment and TDC, at high compression ratio adjustment and BDC, and high compression ratio adjustment and TDC respectively.

[0042] Operation of the reciprocating piston combustion engine according to the present invention is described below with reference to Figures 1 to 4. As shown in Figures 1 to 4 the crank pin2a, eccentric tappet 15 and bottom side of the connecting rod 9 can for example dispose of a bore each, with the bores laying in line at BCD position. A locking pin 16a, moveable in the bores, connects either crankpin 2a with eccentric tappet 15, as shown in Figures 3 and 4, or eccentric tappet 15 with connecting rod 9, as shown in Figures 1 and 2.

[0043] At low compression ratio adjustment the eccentric tappet 15 looks downwards and is connected with or locked to the connecting rod 9. The alignment of the tappet thus remains the same at BDC and TDC as shown in Figures 1 and 2 respectively and the piston 6 is at a low position at TDC corresponding to a low compression ratio in engine operation.

[0044] At high compression ratio adjustment the eccentric tappet 15 is connected with or locked to the corresponding crankpin 2a of the crankshaft 2. At BDC the eccentric tappet 15 looks downwards, as shown in Fig. 3, and at TDC upwards, as shown in Fig. 4, due to the turning movement of 180° of the crank pin 2a between BDC and TDC. Thus, the piston 6 is at high position at TDC corresponding to a high compression ratio in engine operation.

[0045] Between low and high compression ratio adjustment there is a difference of stroke-length; at high compression ratio adjustment the crank radius is increased by the value of eccentricity of the eccentric tappet 15, so the stroke is increased by twice this eccentricity.

[0046] Changing the compression ratio can for example be done when the engine is at rest and the corresponding piston 6 is at BDC. To change the compression ration from low to high the locking pin 16a has to be moved from a position connecting the eccentric tappet 15 with the connecting rod 9, as shown in Fig. 1, to a position connecting the eccentric tappet 15 with the crankpin 2a, as shown in Fig. 3. To change the compression ration from high to low the locking pin 16a has to be moved in the opposite direction until the eccentric tappet 15 is connected with or locked to the connecting rod 9. The locking pin 16a can for example be moved manually, pneumatically or hydraulically.

[0047] A procedure for changing the compression ratio at slowly running engine is described in a subsequent paragraph in connection with the description of the method for controlling the compression ratio of a reciprocating piston combustion engine according to the present invention.

[0048] Fig. 7 shows an embodiment of an apparatus 10 according to the present invention. The embodiment is shown at low compression ratio adjustment and BDC. The apparatus according to the present invention is suitable for controlling the compression ratio of a reciprocating piston combustion engine, wherein the engine has at least one cylinder, at least one piston which is movably arranged within the at least one cylinder, and a crankshaft 2 which is rotatably arranged in a crankshaft housing. The apparatus 10 includes a connecting rod 9 for connecting the piston to the crankshaft 2 in operation, wherein the connecting rod 9 has a first bearing 14a for connection to the piston or to a crosshead fixed to the piston rod and a second bearing 14b for connection to a crank pin 2a of the crankshaft 2. The apparatus 10 according to the invention is additionally provided with an eccentric tappet 15 at the second bearing 14b of the connecting rod 9 and with a locking mechanism 16.1, 16.2 for locking the eccentric tappet 15 either to the connecting rod 9 or to the crank pin 2a of the crankshaft 2 to operate the reciprocating piston combustion engine changeably at a first or second compression ratio respectively.

[0049] In an advantageous embodiment the apparatus 10 includes at least one locking element or locking pin 16.1 a, 16.2a for locking the eccentric tappet alternatively to the connecting rod 9 or to the corresponding crank pin 2a of the crankshaft.

[0050] In a further advantageous embodiment of the apparatus 10 the locking mechanism 16.1, 16.2 includes a first locking element 16.1 a for locking the eccentric tappet 15 to the connecting rod 9 and a second locking element 16.2a for locking the eccentric tappet 15 to the corresponding crank pin 2a of the crankshaft with the second locking element being for example implemented as a locking pin.

[0051] The first and second locking elements 16.1 a, 16.2 are advantageously moved by a hydraulic piston each, with the piston being moveably arranged in a bore 11.1, 11.2 respectively. If one or both locking elements are implemented as locking pins it or they can be used as hydraulic piston respectively. The apparatus can optionally include one or more control valves 17.1, 17.2 for controlling the actuation of the hydraulic pistons and thus of the locking elements associated with each piston.

[0052] In another advantageous embodiment the apparatus 10 includes a control unit connected to the locking mechanism 16 to control the compression ratio of the reciprocating piston combustion engine.

[0053] Further advantageous embodiments of the apparatus can be taken or derived from the embodiments and variants of the reciprocating piston combustion engine described above.

[0054] Figures 8, 9 and 10 show the embodiment illustrated in Fig. 7 at low compression ratio adjustment and TDC, at high compression ratio adjustment and BDC, and at high compression ratio adjustment and TDC respectively.

[0055] Operation of the apparatus according to the present invention for controlling the compression ratio of a reciprocating piston combustion engine is described below with reference to Figures 7 to 10. As shown in the Figures the locking mechanism 16.1, 16.2 includes a first locking element 16.1 a for locking the eccentric tappet 15 to the connecting rod 9, as shown in Figures 7 and 8, and a second locking element 16.2a for locking the eccentric tappet 15 to the corresponding crank pin 2a of the crankshaft, as shown in Figures 9 and 10, with the second locking element being for example implemented as a locking pin.

[0056] The locking elements 16.1 a, 16.2a can for example include a rounded and/or spherical surface for engaging with the eccentric tappet 15. A rounded and/or spherical surface has the advantage that the locking element does not need an actuator for unlocking. It is pressed out of the cavity at eccentric tappet 15 when the locking element 16.2 is closed and the hydraulic pressure on locking element 16.1 is dropped down. Advantageously, this kind of locking element is used for locking the eccentric tappet 15 to the connecting rod 9, because here the torque to transmit is relatively low.

[0057] At low compression ratio adjustment the eccentric tappet 15 looks downwards and is connected with or locked to the connecting rod 9. Locking to the connecting rod can e.g. be effected by charging a hydraulic piston that is connected to a locking element 16.1 a and is moveably arranged in a bore 11.1. The locking element 16.1 a typically engages with an indentation or a hole provided either in the eccentric tappet 15 or in the connecting rod 9. The apparatus can optionally include a control valve 17.1 for charging the hydraulic piston. The alignment of the eccentric tappet 15 remains the same at BDC and TDC as shown in Figures 7 and 8 respectively and the piston 6 is at a low position at TDC. The engine is thus operated at low compression ratio.

[0058] At high compression ratio adjustment the eccentric tappet 15 is connected with or locked to the corresponding crankpin 2a of the crankshaft 2. Locking to the corresponding crankpin can e.g. be effected by charging a hydraulic piston that is connected to a locking element or locking pin 16.2a and is moveably arranged in a bore 11.2. The locking element 16.2a typically engages with an indentation or a hole provided either in the eccentric tappet 15 or in the corresponding crankpin 2a of the crankshaft 2. The apparatus can optionally include a control valve 17.2 for charging the hydraulic piston. At BDC the eccentric tappet 15 looks downwards, as shown in Fig. 9, and at TDC upwards, as shown in Fig. 10, due to the turning movement of 180° of the crankpin 2a between BDC and TDC. Thus, the piston 6 is at high position at TDC and the engine is operated at high compression ratio.

[0059] Between low and high compression ratio adjustment there is a difference of stroke-length; at high compression ratio adjustment the crank radius is increased by the value of eccentricity of the eccentric tappet 15, so the stroke is increased by twice this eccentricity.

[0060] The compression ratio can e.g. be changed by activating the locking mechanism 16.1, 16.2 manually or hydraulically or pneumatically to switch from a state in which the eccentric tappet 15 is locked to the connecting rod 9 to a state in which the eccentric tappet 15 is locked to the corresponding crank pin 2a of the crankshaft 2 and vice versa.

[0061] The compression ratio is typically changed when the reciprocating piston combustion engine 1 is at rest and the corresponding piston 6 is at BDC. To change the compression ration from low to high the locking element 16.1 a has to be moved from a position connecting the eccentric tappet 15 with the connecting rod 9, as shown in Fig. 7, to a position in which the eccentric tappet 15 is free to rotate in the lower bearing 14b of the connecting rod 9, as shown in Fig. 9. Moreover, the locking element 16.2a has to be moved from a position in which the corresponding crank pin 2a of the crankshaft 2 is free to rotate in the eccentric tappet 15, as shown in Fig. 7, to a position in which the eccentric tappet 15 is connected to the corresponding crank pin 2a of the crankshaft 2.

[0062] To change the compression ration from high to low the locking element or locking pin 16.2a has to be moved in the opposite direction until the corresponding crank pin 2a of the crankshaft 2 is free to rotate in the eccentric tappet 15 and the locking element 16.1 a has to be moved until the eccentric tappet 15 is connected with or locked to the connecting rod 9. The locking elements can for example be moved manually, pneumatically or hydraulically.

[0063] A procedure for changing the compression ratio at slowly running engine is described in a subsequent paragraph in connection with the description of the method for controlling the compression ratio of a reciprocating piston combustion engine according to the present invention.

[0064] The reciprocating piston combustion engine according to the present invention can be implemented as a two-stroke crosshead engine or as a two-or four-stroke trunk piston engine or as a car engine. In the same way the apparatus according to the present invention for controlling the compression ratio of a reciprocating piston combustion engine can be used in a two-stroke crosshead engine or in a two- or four-stroke trunk piston engine or in a car engine.

[0065] Fig. 11 shows an embodiment of a large two-stroke reciprocating piston combustion engine of the diesel type according to the invention. The engine 1 shown has at least one cylinder 4, at least one piston 6 which is movably arranged within the at least one cylinder, and a crankshaft 2 which is rotatably arranged in a crankshaft housing, with every piston 6 being connected to the crankshaft 2 via a connecting rod 9 having an upper and lower bearing to drive the crankshaft. The reciprocating piston combustion engine 1 according to the invention is additionally provided with an eccentric tappet 15 at the lower bearing of the at least one connecting rod 9 and with a locking mechanism for locking the eccentric tappet 15 either to the connecting rod 9 or to a corresponding crank pin 2a of the crankshaft 2 to operate the reciprocating piston combustion engine changeably at a first or second compression ratio respectively. Typically, the second compression ratio is higher than the first compression ratio.

[0066] In the embodiment shown in Fig 11 the piston 6 is in each case connected to a crosshead 8 via a piston rod 7 and the crosshead is in each case connected to the crankshaft 2 via the connecting rod 9 to drive the crankshaft. Each piston rod 7 is typically guided rectilinearly along its longitudinal axis, and the respective crosshead 8 converts the rectilinear movement of the piston rod into a non-rectilinear movement of the connecting rod 9. The cylinder 4 or cylinder liner is usually closed upwardly by a cylinder cover so that a combustion space 3 is respectively formed in the cylinder 4 between the piston 6 and the cylinder cover.

[0067] Such large reciprocating piston combustion engines and in particular large two-stroke reciprocating piston combustion engines of the diesel type are used, for example, in ships and power stations.

[0068] In case of hydraulic actuation, the locking mechanism can be actuated with oil supply through the connecting rod 9 or through the crankshaft 2.

[0069] In addition, the reciprocating piston combustion engine 1 can optionally contain one ore more of the following components: one ore more scavenging openings 5 in the lower part of the cylinder 4 or cylinder liner for the inlet of scavenging air, one or more injection nozzles 12 arranged at the cylinder cover for injecting fuel, and at least one exit valve 13 for controlling the discharge of exhaust gas.

[0070] The connecting rod 9 provided with an eccentric tappet 15 at the lower bearing of the connecting rod and with a locking mechanism for locking the eccentric tappet 15 either to the connecting rod 9 or to a corresponding crank pin 2a of the crankshaft 2 is designated an apparatus 10 for controlling the compression ratio of a reciprocating piston combustion engine. Advantageous embodiments of the reciprocating piston combustion engine 1 and of the apparatus 10 can be taken or derived from the embodiments and variants of the reciprocating piston combustion engine described above with reference to Figures 1 to 4 and from the embodiments and variants of the apparatus for controlling the compression ratio of a reciprocating piston combustion engine described above with reference to Figures 7 to 10.

[0071] The embodiment of a large two-stroke reciprocating piston combustion engine of the diesel type according to the invention described above has the advantage that the position of the eccentric tappet 15 remains unchanged at BDC. Thus, an unnecessary extension of the stroke of the piston 6 below scavenging ports 5 is avoided (variable stroke).

[0072] Comparison of engine- and piston dismantling height at a two-stroke crosshead engine with different systems for variable compression ratio:

o Conventional displacement of piston with a mechanism in the crosshead:

- Distance between axe of crankshaft and bottom of cylinder jacket has to be increased with the same value as the diameter of crosshead increases.
- Length of piston rod and cylinder liner has to be increased by the value of piston displacement between high and low compression ratio.

o Displacement of piston with the proposed eccentric tappet at lower connecting rod bearing as described above:

- Distance between axe of crankshaft and bottom of engine has to be increased by half the value as the diameter of lower connecting rod bearing increases.

- Length of piston rod and cylinder liner remain unchanged.

[0073] The total engine height and the piston dismantling height is significantly lower with the proposed system to change the compression ratio.

[0074] Another advantage of the embodiment of a large two-stroke reciprocating piston combustion engine of the diesel type according to the invention is that there is nearly no increase in oscillating masses, only rotating masses are higher.

[0075] Existing two- and four-stroke trunk piston engines can easily be adapted to the use of an apparatus according to the invention for controlling the compression ratio of a reciprocating piston combustion engine because the piston position at BDC remains unchanged for both compression ratios. The locking mechanism can be actuated with oil supply through the crankshaft.

[0076] An advantage of trunk piston engines according to the invention is that the position of the piston is nearly the same for high and for low compression ratio adjustment when the scavenging openings are closed. This means that the timing of the inlet control of the scavenging air remains nearly unchanged when engine operation is switched from high to low compression ratio and vice versa.

[0077] This further means that also the outlet timing does not need to be changed if the engine includes outlet valves. This is a great advantage if the engine comprises a conventional camshaft for controlling the outlet valves since a second cam and a complex switching mechanism would be needed in this case.

[0078] In cars the reciprocating piston combustion engine and the apparatus according the invention offer two modes of operation:

o An economic modus: High compression ratio, low supercharging pressure, long stroke (low speed); and

o a sport modus: Low compression ratio, high supercharging pressure, short stroke (allows high speed). Reduced engine displacement is overcompensated by high charging pressure and engine speed.

[0079] An embodiment of a method in accordance with the invention for controlling the compression ratio of a reciprocating piston combustion engine will be described in the following with reference to Figures 1 to 6. In this embodiment the reciprocating piston combustion engine 1 has at least one cylinder 4, at least one piston 6 which is movably arranged within the at least one cylinder, and a crankshaft 2 which is rotatably arranged in a crankshaft housing, with every piston 6 being connected to the crankshaft 2 via a connecting rod 9 having an upper and lower bearing 14a, 14b to drive the crankshaft. In the method according to the invention the reciprocating piston combustion engine 1 is additionally provided with an eccentric tappet 15 at the lower bearing 14b of the at least one connecting rod 9, and the eccentric tappet 15 is locked by a locking mechanism 16 either to the connecting rod 9 or to a corresponding crank pin 2a of the crankshaft 2, so that the reciprocating piston combustion engine can changeably be operated at a first or second compression ratio respectively.

[0080] In an advantageous embodiment of the method the compression ratio is changed by activating the locking mechanism 16 manually or hydraulically or pneumatically to switch from a state in which the eccentric tappet 15 is locked to the connecting rod 9 to a state in which the eccentric tappet is locked to the corresponding crank pin 2a of the crankshaft 2 and vice versa.

[0081] In a second advantageous embodiment of the method the compression ratio is typically changed when the corresponding piston 6 is at BDC and the reciprocating piston combustion engine 1 is at rest. To change the compression ration from low to high the locking element or locking pin 16a has to be moved from a position connecting the eccentric tappet 15 with the connecting rod 9, as shown in Fig. 1, to a position connecting or locking the eccentric tappet 15 with or to the crankpin 2a, as shown in Fig. 3. To change the compression ration from high to low the element or locking pin 16a has to be moved in the opposite direction until the eccentric tappet 15 is connected with or locked to the connecting rod 9. The locking pin 16a can for example be moved manually, pneumatically or hydraulically.

[0082] In a third advantageous embodiment of the method the compression ratio is changed when the reciprocating piston combustion engine 1 is slowly running. In this embodiment a bearing shell 14b' is rotatably supported between eccentric tappet 15 and connecting rod 9 and is able to turn by an angle of about 90°. A spring 16b connects the bearing shell 14b' to the connecting rod and keeps it in a defined angular position. When the connection of the eccentric tappet 15 has to be changed from the crankpin 2a to the connecting rod 9 (change of compression ratio from high to low as shown in Figures 5 and 6), the locking pin16a starts to move radial outwards and penetrates a bore in the bearing shell 14b'. Now crankpin, eccentric tappet and bearing shell are connected and they turn together during a short period. Before the bearing shell 14b' reaches its maximum rotation angel relative to the connecting rod 9, the locking pin 16a has to leave the bore in the crankpin 2a. Now the spring 16b pulls the bearing shell 14b' together with locking pin

16a and the eccentric tappet 15 back to the initial position. In this position the bores of eccentric tappet 15, bearing shell 14b' and connecting rod 9 are lying in a line and the locking pin can move further radial outwards and penetrates the bore of connecting rod 9. Now connecting rod 9, bearing shell 14b' and eccentric tappet 15 are connected by the locking pin 16a. To change the compression ratio from low to high, the process runs in opposite direction. The locking pin 16a can for example be moved manually, pneumatically or hydraulically.

[0083] The reciprocating piston combustion engine and the apparatus and method for controlling the compression ratio of a large reciprocating piston combustion engine according to the invention have the advantage that in two-stroke engines there is no extension of the stroke below scavenging ports at the adjustment for low compression ratio; so the height of the engine is not or only slightly increased and the time for scavenging is not significantly longer than at the adjustment for high compression ratio while in most other engines having a rotatable eccentric tappet or another kind of mechanism to displace the piston the time for scavenging at the adjustment for low compression ratio is significantly longer than at the adjustment for high compression ratio. Moreover, it is advantageous that there is nearly no increase of oscillating masses compared to a rotatable eccentric tappet at the upper connecting rod bearing, only rotating masses are higher.

Claims

1. A reciprocating piston combustion engine (1) having at least one cylinder (4), at least one piston (6) which is movably arranged within the at least one cylinder, and a crankshaft (2) which is rotatably arranged in a crankshaft housing, with every piston (6) being connected to the crankshaft (2) via a connecting rod (9) having an upper and lower bearing (14a, 14b) to drive the crankshaft, **characterized in that** the reciprocating piston combustion engine (1) is additionally provided with an eccentric tappet (15) at the lower bearing (14b) of the at least one connecting rod (9) and with a locking mechanism (16, 16.1, 16.2) for locking the eccentric tappet (15) either to the connecting rod (9) or to a corresponding crank pin (2a) of the crankshaft (2) to operate the reciprocating piston combustion engine (1) changeably at a first or second compression ratio respectively.

2. The reciprocating piston combustion engine according to claim 1,
wherein the second compression ratio is higher than the first compression ratio.

3. The reciprocating piston combustion engine according to claim 1 or 2,
wherein the locking mechanism (16, 16.1, 16.2) includes at least one locking element or locking pin (16a, 16.1 a, 16.2a) for locking the eccentric tappet (15) alternatively to the connecting rod (9) or to the corresponding crank pin (2a) of the crankshaft (2).

4. The reciprocating piston combustion engine according to any of claims 1 to 3, wherein the compression ratio can be changed by activating the locking mechanism (16, 16.1, 16.2) manually or hydraulically or pneumatically to switch from a state in which the eccentric tappet (15) is locked to the connecting rod (9) to a state in which the eccentric tappet (15) is locked to the corresponding crank pin (2a) of the crankshaft (2) and vice versa.

5. The reciprocating piston combustion engine according to any of claims 1 to 4, wherein the maximum radius of the eccentric tappet (15) is directed downwardly at Bottom Dead Center (BDC) position of the respective piston (6).

6. The reciprocating piston combustion engine according to any of claims 1 to 5, wherein the compression ratio of every cylinder (4) is changeable at BDC position of the respective piston (6) or in a range of the engine angle of -90° to 90° from the BDC position.

7. The reciprocating piston combustion engine according to any of claims 1 to 6, wherein the reciprocating piston combustion engine (1) is configured for changing the compression ratio at slow rotational speed of the engine not exceeding for example 30 % or 15 % of full rotational speed.

8. The reciprocating piston combustion engine according to any of claims 1 to 7, including a control unit connected to the locking mechanism (16, 16.1, 16.2) to control the compression ratio of the reciprocating piston combustion engine.

9. An apparatus (10) for controlling the compression ratio of a reciprocating piston combustion engine (1), with the engine having at least one cylinder (4), at least one piston (6) which is movably arranged within the at least one cylinder, and a crankshaft (2) which is rotatably arranged in a crankshaft housing, wherein the apparatus (10) includes a connecting rod (9) for connecting the piston (6) to the crankshaft (2) in operation, and wherein the connecting rod (9) has a first bearing (14a) for connection to the piston (6) or to a crosshead (8) fixed to the piston rod (7) and a second bearing (14b) for connection to a crank pin (2a) of the crankshaft (2), **characterized in that** the apparatus (10) is additionally provided with an eccentric tappet (15) at the second bearing (14b) of the connecting rod (9) and with a locking mechanism (16, 16.1, 16.2) for locking the eccentric tappet (15) either to the connecting rod (9) or to the crank pin

(2a) of the crankshaft (2) to operate the reciprocating piston combustion engine (1) changeably at a first or second compression ratio respectively.

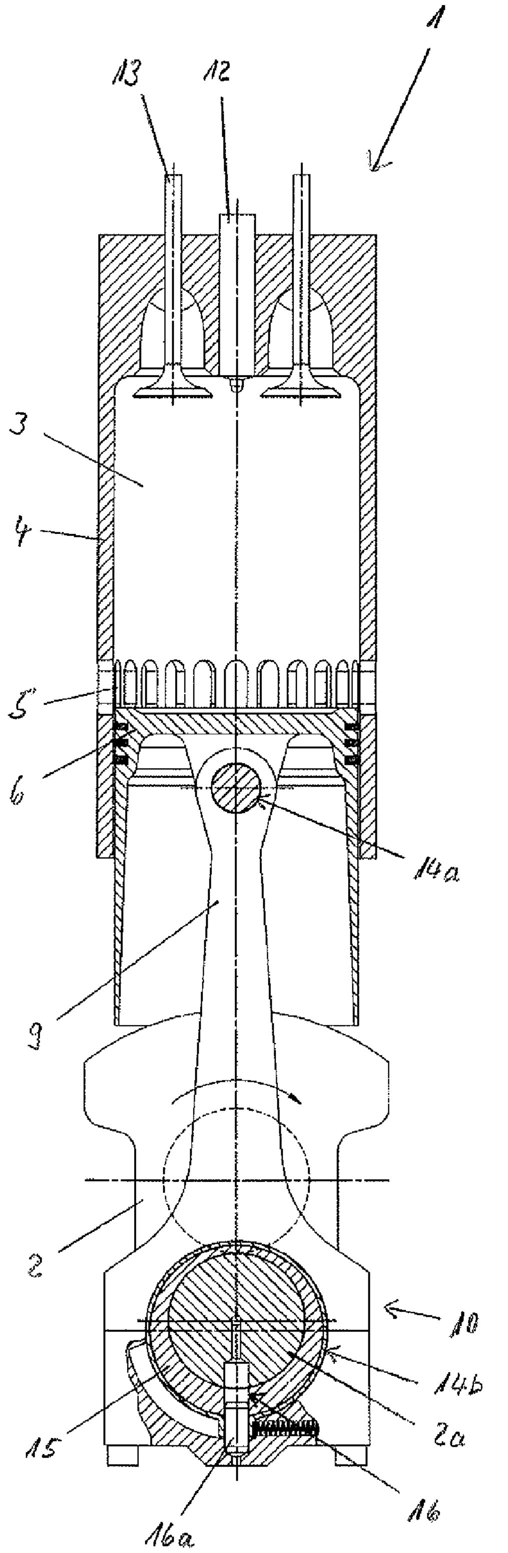
10. The apparatus according to claim 9, wherein the locking mechanism (16, 16.1, 16.2) includes at least one locking element or locking pin (16a, 16.1 a, 16.2a) for locking the eccentric tappet alternatively to the connecting rod (9) or to the corresponding crank pin (2a) of the crankshaft (2).

11. The apparatus according to claim 9 or 10 including a control unit connected to the locking mechanism (16, 16.1, 16.2) to control the compression ratio of the reciprocating piston combustion engine.

12. A method for controlling the compression ratio of a reciprocating piston combustion engine (1) having at least one cylinder (4), at least one piston (6) which is movably arranged within the at least one cylinder, and a crankshaft (2) which is rotatably arranged in a crankshaft housing, with every piston (6) being connected to the crankshaft (2) via a connecting rod (9) having an upper and lower bearing (14a, 14b) to drive the crankshaft (2), **characterized in that** the reciprocating piston combustion engine (1) is additionally provided with an eccentric tappet (15) at the lower bearing (14b) of the at least one connecting rod (9), and in that the eccentric tappet (15) is locked by a locking mechanism (16, 16.1, 16.2) either to the connecting rod (9) or to a corresponding crank pin (2a) of the crankshaft (2), so that the reciprocating piston combustion engine can changeably be operated at a first or second compression ratio respectively.

13. The method according to claim 12, wherein the compression ratio is changed by activating the locking mechanism (16, 16.1, 16.2) manually or hydraulically or pneumatically to switch from a state in which the eccentric tappet (15) is locked to the connecting rod (9) to a state in which the eccentric tappet is locked to the corresponding crank pin (2a) of the crankshaft (2) and vice versa.

14. The method according to claim 12 or 13, wherein the compression ratio is changed when the reciprocating piston combustion engine (1) is slowly running or at rest.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14b
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16a

Fig. 1

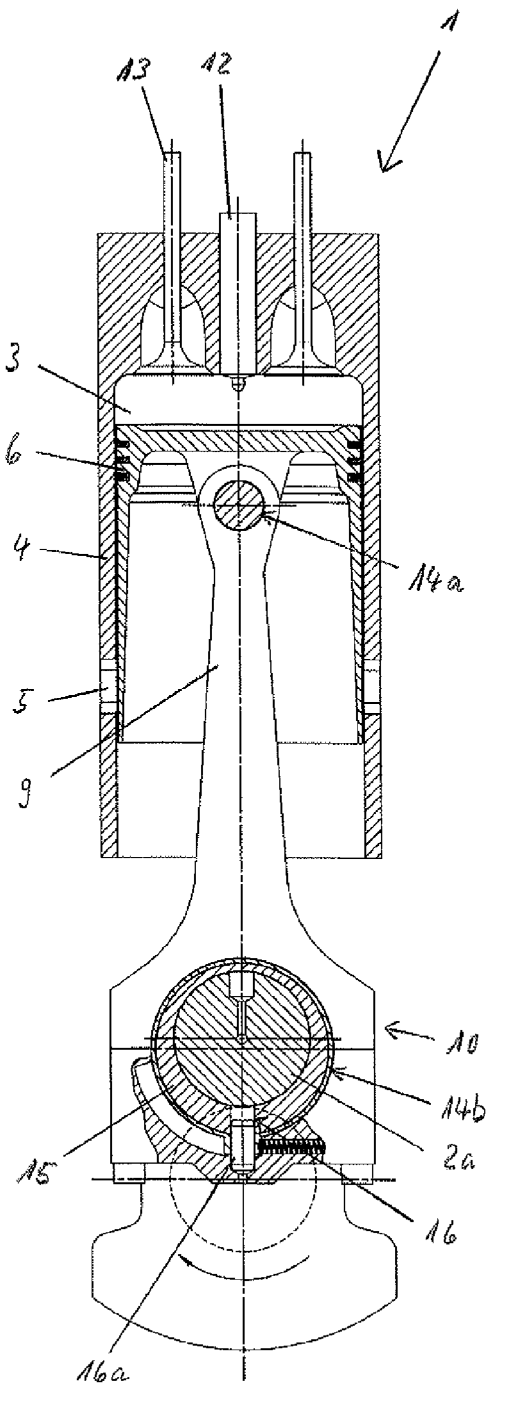
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Fig. 2

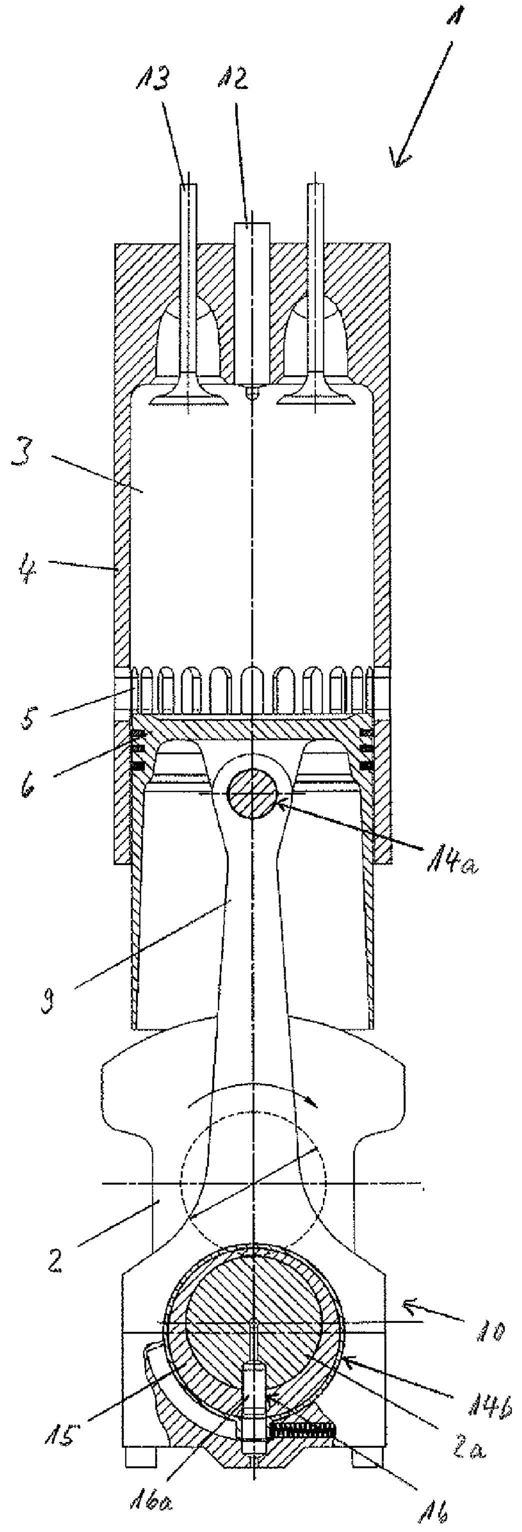
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Fig. 3

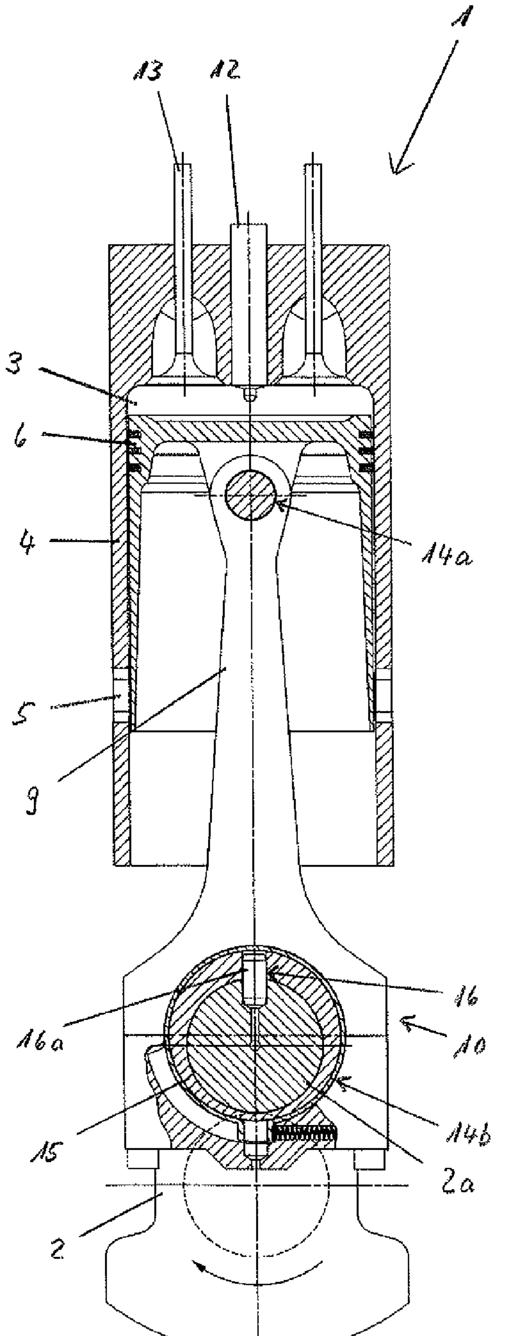
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Fig. 4

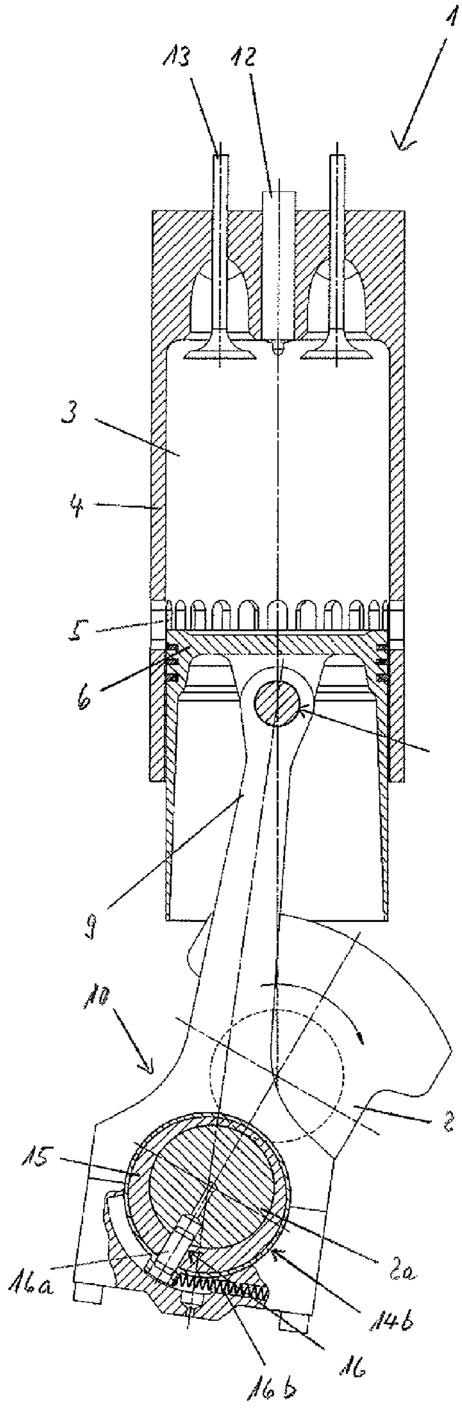


Fig. 5

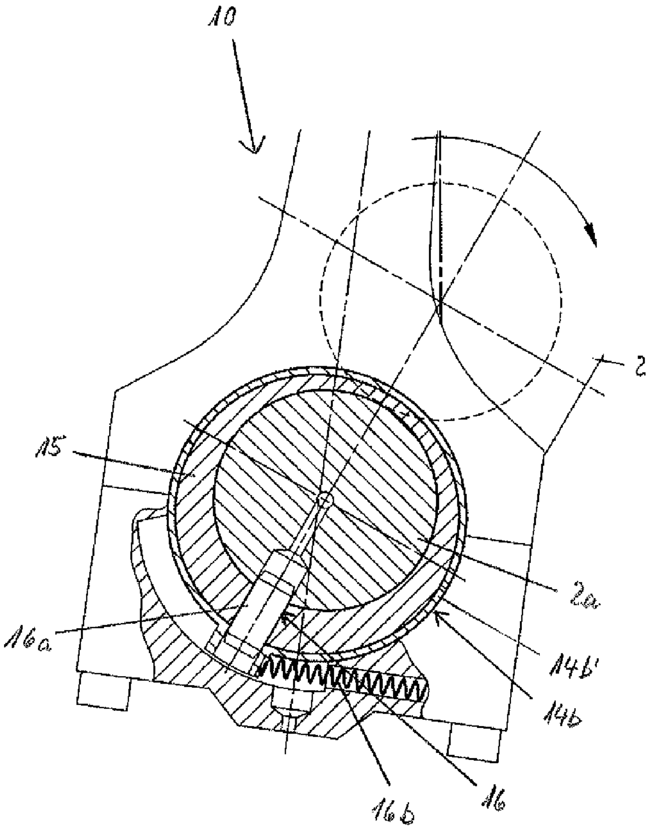
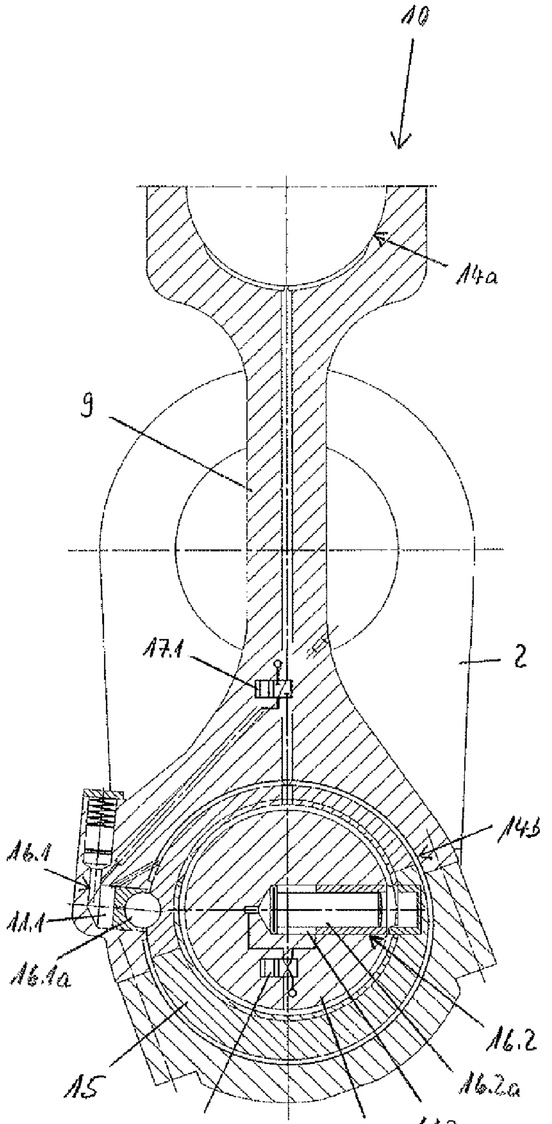
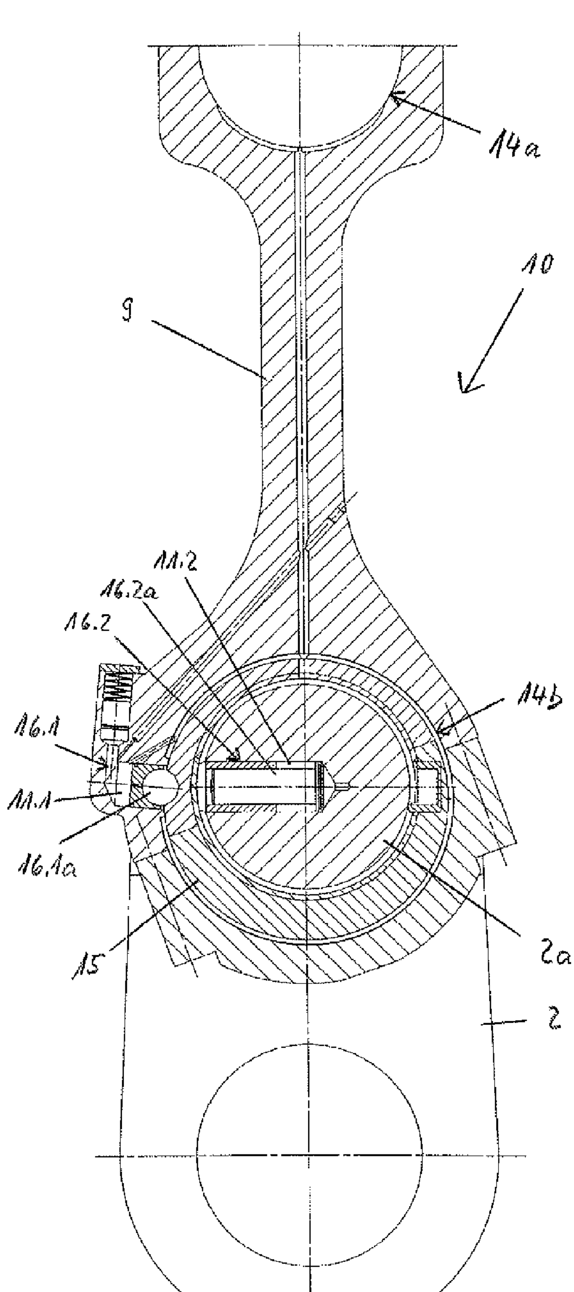


Fig. 6



10
14a
9
17.1
2
14b
16.1
11.1
16.1a
16.2
16.2a
15
17.2
2a
11.2

Fig. 7



14a
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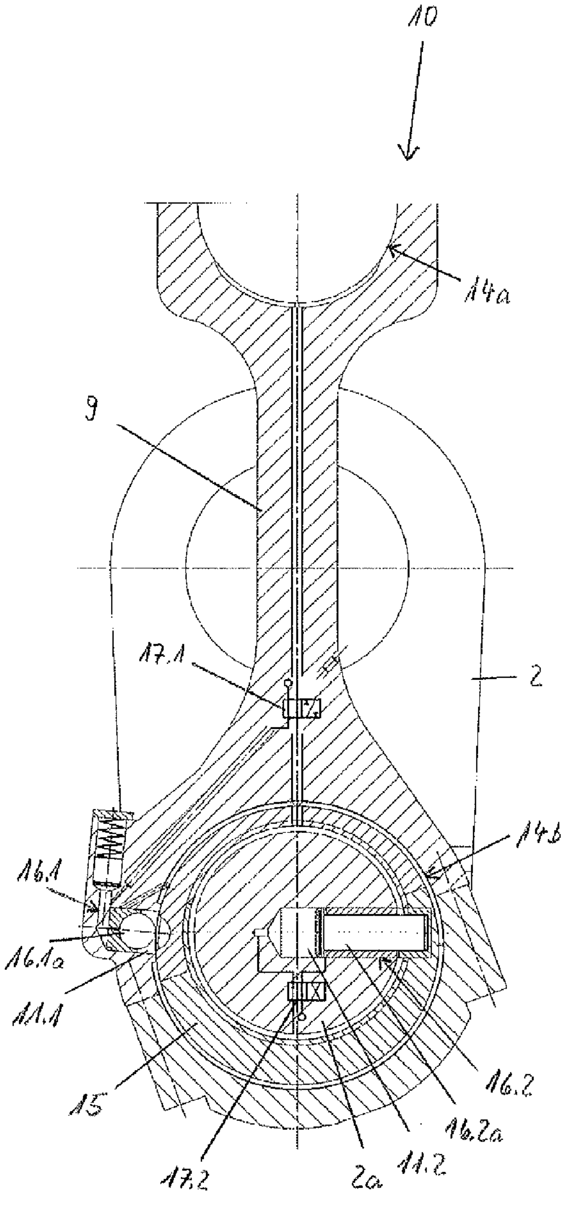
9
11.2
16.2a
16.2
14b
16.1
11.1
16.1a
2a
15
2

Fig. 8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16.2
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17.2
2a
11.2

Fig. 9

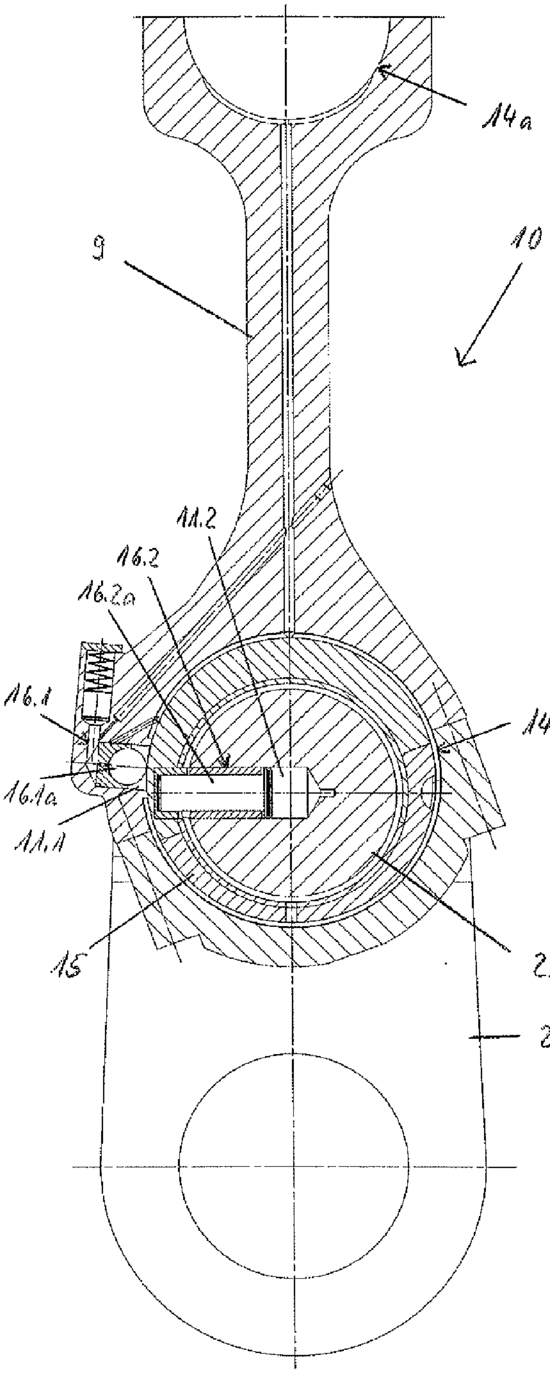
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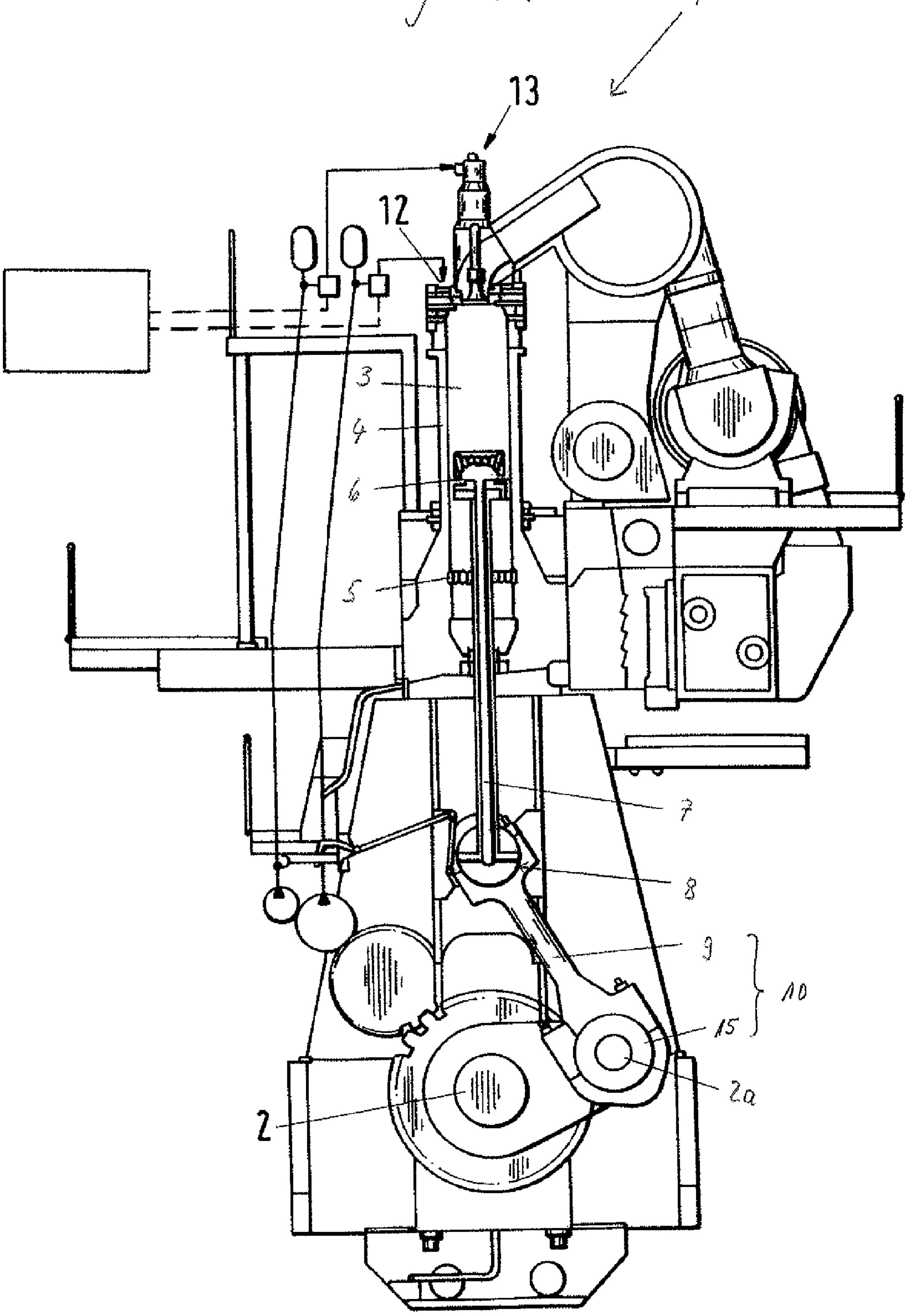
Fig. 10

Fig. 11



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EUROPEAN SEARCH REPORT

Application Number
EP 13 16 6767

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			F02B F02D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	24 October 2013	Tietje, Kai

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