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(54) **PILE-DRIVING DEVICE**

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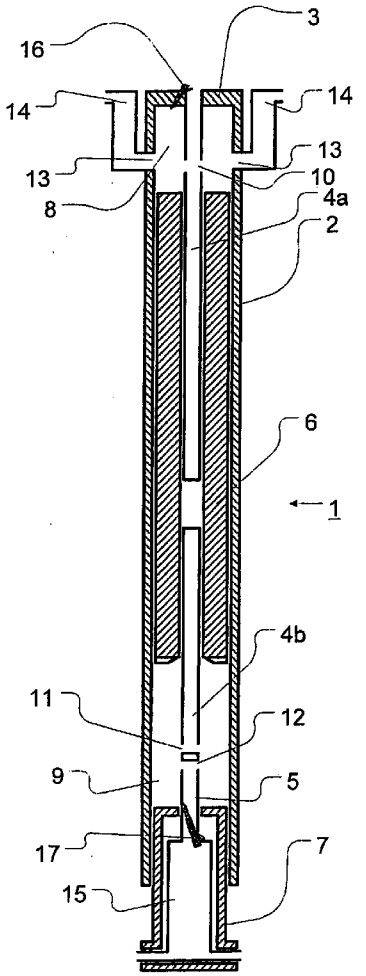
(57) **ABSTRACT**

The present invention relates to a combustion-type pile-driving device, comprising a cylinder having a closed upper end and an open lower end, which cylinder is freely movable as a piston with respect to an anvil which seals the lower end of the cylinder, a ram which is freely movable as a piston with respect to the cylinder and the anvil in the cylinder, and an injection device for injecting a fuel into a combustion chamber formed between the ram and the anvil in the cylinder for driving the ram upward by combustion of the injected fuel, wherein a second injection device is provided for injecting fuel into a second combustion chamber formed in the cylinder between the ram and the closed upper end of the cylinder for driving the ram downward and driving the cylinder upward by combustion of the injected fuel. The invention further relates to a method for using such a pile-driving device.



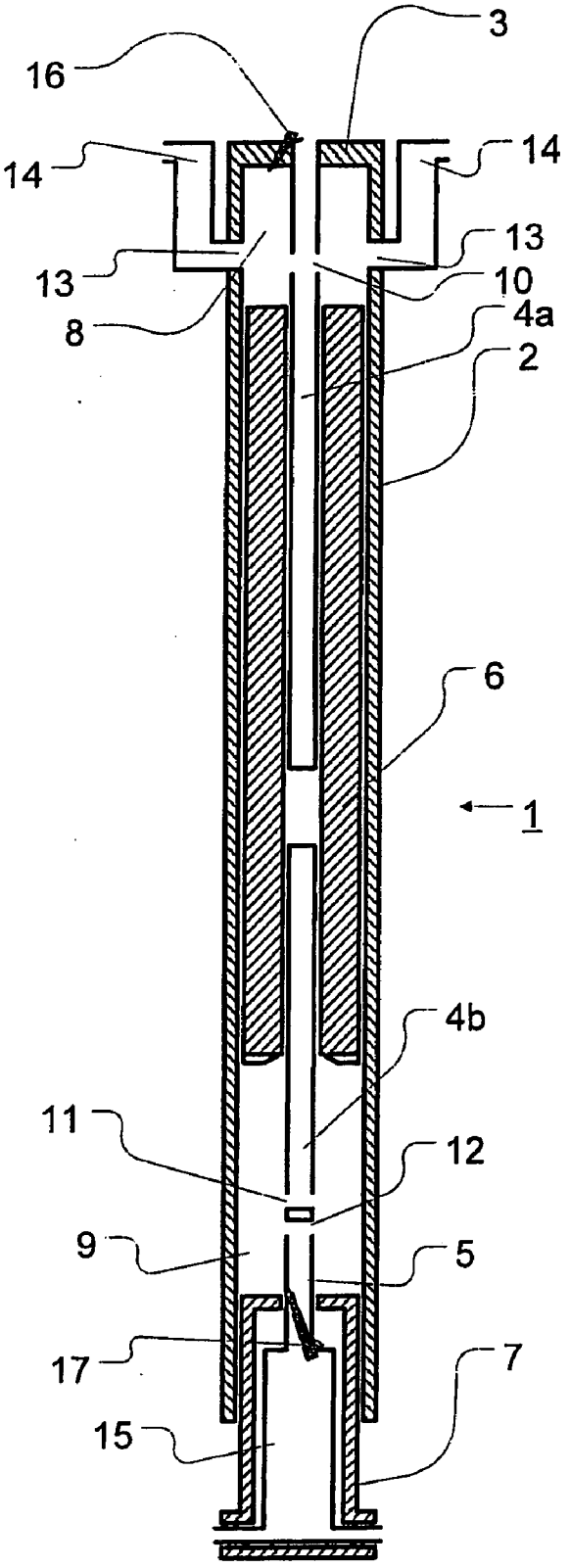


Fig 1

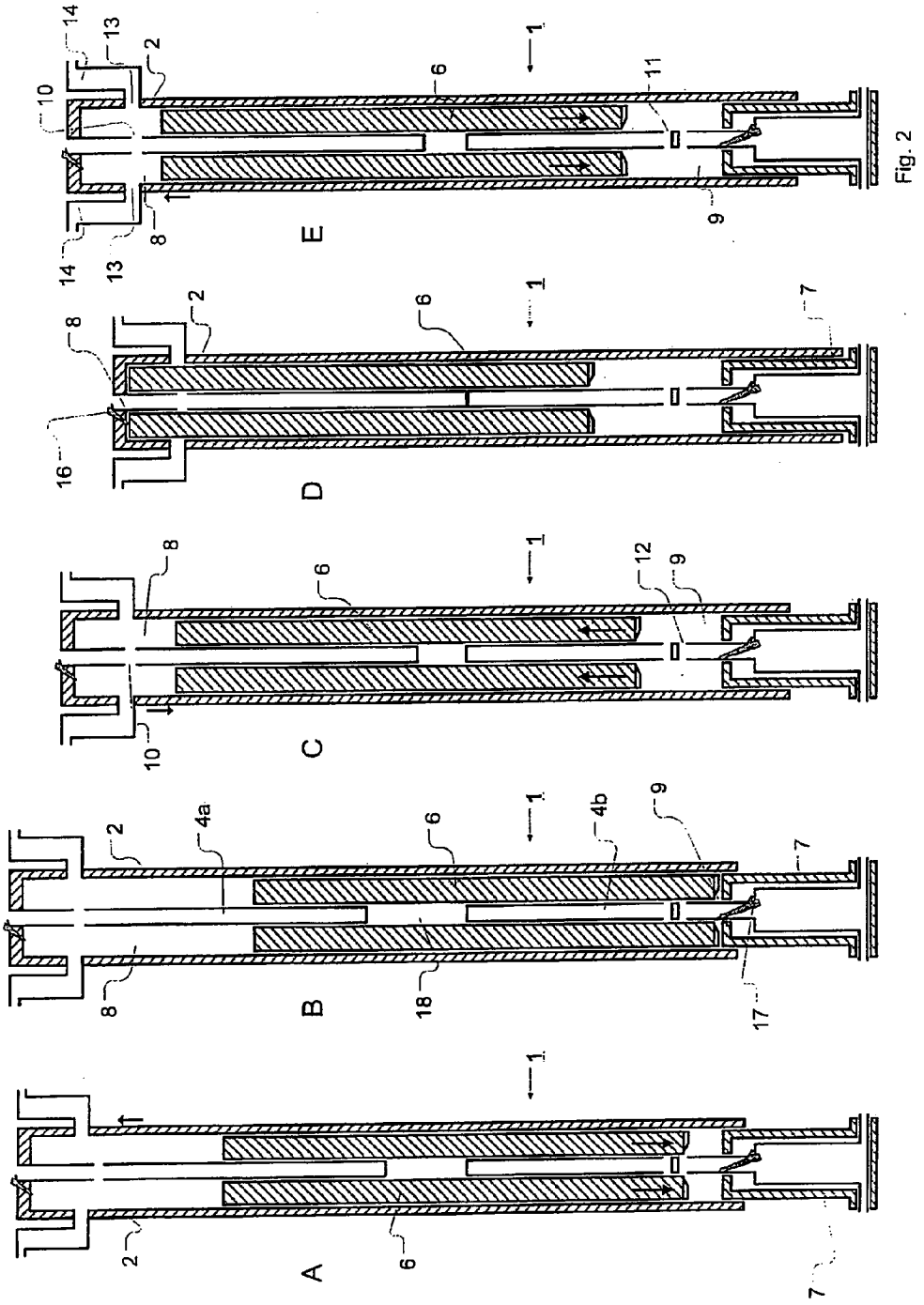


Fig. 2

PILE-DRIVING DEVICE

[0001] The present invention relates to a combustion-type pile-driving device, comprising a cylinder having a closed upper end and an open lower end, which cylinder is freely movable as a piston with respect to an anvil which seals the lower end of the cylinder, a ram which is freely movable as a piston with respect to the cylinder and the anvil in the cylinder, and an injection device for injecting a fuel into a combustion chamber formed between the ram and the anvil in the cylinder for driving the ram upward by combustion of the injected fuel.

[0002] Such a device is known from U.S. Pat. No. 2,633,832, which describes a similarly configured pile-driving device comprising an anvil, a cylinder and a piston. Diesel fuel is injected into the combustion chamber, which fuel ignites as a result of the compression of the gas in the combustion chamber and the heat being generated, inter alia as a result of the ram dropping, after the ram has struck the anvil. The combustion of the diesel fuel drives the ram upward in the cylinder. Said upward movement of the ram is decelerated by the force of gravity and by compression of a gas in the closed upper part of the cylinder. Eventually, said forces result in the direction of movement of the ram being reversed, and in the ram being driven downward by the compression and the force of gravity for a next impact on the anvil.

[0003] A drawback of the known device is the fact that the number of impacts, the number of strikes per unit time, and/or the amount of impact energy is (are) limited by the gravity-induced deceleration and acceleration of the ram.

[0004] Consequently it is an object of the present invention to provide a device according to the introduction by means of which a higher number of impacts and/or a higher impact energy can be achieved than with the known device. This object is accomplished by the present invention in that a second injection device is provided for injecting fuel into a second combustion chamber formed in the cylinder between the ram and the closed upper end of the cylinder for driving the ram downward and driving the cylinder upward by combustion of the injected fuel. The combustion in the space between the ram and the cylinder in the first place accelerates the downward movement of the ram in comparison with a pile-driving device not fitted with such a second injection device. As a result, the drop time of the cycle of the ram is shortened. In the second place, the device makes it possible to control the movement of the ram so that the cylinder will move downward when the ram moves upward as a result of combustion in the space between the anvil and the ram. The result of this is that the compression of the gas in the second combustion chamber is generated both by the force of the rising ram and by the force of the falling cylinder. The kinetic energy of the falling cylinder is thus transmitted to the ram. As a result, also the compression is accelerated in comparison with the known device and the cycle is shortened even further in the case of an unchanged impact energy of the ram on the anvil, or the impact energy of the ram on the anvil is increased in the case of a comparable cycle time. The device may also be adapted to combine these effects, of course, in which case the impact energy is increased and the cycle time is reduced as well.

[0005] The object of the present invention is thus accomplished by a pile-driving device having a higher impact energy per strike and/or a higher number of impacts than combustion-type pile-driving devices according to the prior art.

[0006] Combustion-type pile-driving devices with double combustion for increasing the impact force of the ram are known, to be true, but not in combination with the device according to the preamble of claim **1**. Moreover, those skilled in the art consider the fact that the cylinder can be driven upward by the combustion in the upper part of the cylinder to be a drawback. To prevent this, countermeasures have been taken so far, for example weighting the cylinder, which make the pile-driving device as a whole heavy, or reducing the amount of fuel that is injected. The present invention therefore disposes of the preconceived notion that the cylinder must be prevented from being driven upward by the combustion in the upper part of the cylinder. As a result, a larger part of the total weight of a ram is used in an effective manner for generating the impact energy. This is expressed in a larger number of impacts and/or impacts having a higher impact energy.

[0007] GB 656,493 discloses a combustion-type pile-driving device comprising a cylinder that is freely movable with respect to an anvil, wherein the lower end of the cylinder is closed by a piston rod. The piston is attached to the anvil and consequently it is not possible to drive the ram upward with respect to the anvil by combustion of injected fuel. Although the pile-driving device that is known from GB 656,493 has a second combustion chamber, said pile-driving device and its operation are principally different from the pile-driving device and the method according to the present invention.

[0008] In a preferred embodiment of the present invention, a first air pipe extends upward through the cylinder, parallel to the longitudinal axis of the cylinder, which air pipe is in communication with the combustion chamber for supplying and discharging air to or from, respectively, the combustion chamber. The first air pipe may be provided with auxiliary means, such as a compressor, a non-return valve or a control valve to prevent air from undesirably flowing back into the first air pipe from the combustion chamber or to prevent air from undesirably flowing from the first air pipe into the combustion chamber. It is also possible, however, that the prevention of undesirable flows of air or exhaust gases through the air pipe is effected by the overpressure that is present and by the timing of the ram passing the exhaust ports. Prior art pile-driving devices are provided with an opening in the cylinder wall some distance above the anvil for providing an inlet and an outlet for fresh air and air polluted by combustion, respectively.

[0009] Preferably, the first air pipe is in communication with the second combustion chamber for supplying or discharging air to or from, respectively, the second combustion chamber. When such a device is used, the advantages described in the preceding paragraph also apply to the second combustion chamber.

[0010] In a preferred embodiment of the invention, the first air pipe is a divided pipe, wherein the upper pipe section of the first air pipe moves along with the cylinder, wherein the lower pipe section of the first air pipe is, at least substantially, static relative to the anvil and wherein a space that may be present between said upper and said lower pipe section is surrounded by a connecting tube. In this way the upper pipe section can be formed integral with the cylinder, which is advantageous for constructional and kinetic reasons in comparison with a cylinder that moves with respect to an entire first air pipe. Such

a construction is also advantageous in comparison with a device in which the entire first air pipe forms an integral part of the cylinder, and in which the first air pipe is thus moved with respect to the combustion chamber upon movement of the cylinder. The first air pipe must of course form part of a channel that is closed between the two ends of the first air pipe. This is realised by means of a connecting tube that connects the upper and the lower pipe section together for forming such a channel.

[0011] In a preferred embodiment of the present invention, the ram forms the connecting tube. During the upward and downward movement of the ram, the upper end of the ram, in the lowermost position of the ram, is positioned higher than the lower end of the ram in the uppermost position of the ram. By positioning the separation between the upper pipe section and the lower pipe section of the first air pipe at a location where part of the ram is present at all times, the ram can perform the function of the connecting tube, so that no additional parts are needed for forming said connecting tube.

[0012] In a preferred embodiment of the present invention, a second air pipe extends in the anvil, parallel to the longitudinal axis of the cylinder, which second air pipe is in communication with the combustion chamber for supplying or discharging air to or from, respectively, the combustion chamber. The advantage of such a device is that the location where the air is introduced into the combustion chamber is determined by the fact that the ram is substantially static. Since the ram is relatively short in comparison with the cylinder, the second air pipe need not extend downward for supplying or discharging air to or from, respectively, the combustion chamber. The second air pipe, too, may be provided with a non-return valve or a control valve.

[0013] To achieve an adequate regulation of the supply and discharge of air it is preferable if the air inlet and the air outlet of the combustion chamber are separated.

[0014] In a preferred embodiment of the present invention, air purification means are provided for purifying discharged exhaust gases. The exhaust gases contain pollutants such as soot particles, uncombusted fuel particles and particles of lubricants that are used for lubricating the pile-driving device for reducing friction during movement of the ram. The provision of filter means, for example, for filtering discharged exhaust gases, reduces the extent to which the surrounding air is polluted. In particular when the air inlet and air outlet of the combustion chamber are separated, the filter means will not adversely affect the intake of fresh air for the combustion chamber. The air purification means may alternatively be realised in the form of a cartridge inside an air pipe, for example, or by controlling the flow of air through an air pipe such that the air is driven in the direction of the inner wall of the air pipe. Solid particles will be driven against said inner wall and deposit thereon in that case. In this way the air can be purified.

[0015] To achieve a regulated supply of fresh air to the combustion space, pump means are preferably provided for pumping fresh air into the combustion space for the combustion. An important second aspect is that the cooling of the combustion space can be controlled by pumping air into the combustion space through the first or the second air pipe, for example. In comparison with the known device, in which air is sucked in as a result of the upward movement of the ram within the cylinder, a much better cooling effect is achieved in a pile-driving device which comprises an air pipe and pump means. The forced supply of fresh air makes it possible to control the combustion in the combustion chamber better because the scavenging of the combustion chamber does not depend on the jump height of the ram. In this way a better control also of the timing and the course of the combustion process can be achieved.

[0016] Preferably, further filter means are provided for filtering fresh air to be supplied. At construction sites the air is often polluted by particles which cause wear on the pile-driving device and which have a negative effect on the combustion process in the combustion chamber. This negative effect is eliminated by filtering the air. In particular if means are provided for pumping fresh air into the combustion space, the filter means are prevented from having a throttling effect on the supply of fresh air, whilst in addition an adequate cooling of the combustion chamber is realised. An important side effect is the fact that the present invention also provides possibilities for reducing the consumption of lubricants. The overpressure that prevails in the space in the piston remote from the lubricants, i.e. in a space into which lubricants might leak, impedes the flow of the lubricants, for example lubricating oil, from the desired location in question. The overpressure prevents lubricating oil from leaking out, as it were. By moreover providing an inlet and an outlet for lubricating oil in the cylinder wall, and cooling the lubricating oil outside the cylinder before it is returned to the cylinder, for example by means of a pump, the lubricating oil can contribute to an effective cooling of the ram within the cylinder. As a result of this, the extent to which the ram expands, for example as a result of the reciprocating movement of the ram within the cylinder and the impact on the anvil, will be comparatively smaller, so that less clearance needs to be provided between the outer wall of the ram and the inner wall of the cylinder.

[0017] A second aspect of the present invention relates to a method for driving a support into a ground surface by means of a pile-driving device according to the first aspect of the invention, wherein the cylinder is driven upward upon combustion of fuel in the second combustion chamber. The advantages of such a method have already been discussed in the foregoing.

[0018] It is preferable in that regard if the movements of the ram and the cylinder take place at least substantially in counterphase. In this way the drop motion of the cylinder is optimally utilised for compressing the gas in the second combustion chamber and transmitting kinetic drop energy of the cylinder to the ram.

[0019] The present invention will now be explained in more detail by means of a description, merely by way of example, of an embodiment of the present invention with reference to the appended drawings, in which:

[0020] FIG. **1** is a longitudinal sectional view of a pile-driving device according to the present invention; and

[0021] FIG. **2** shows the relative positions of the ram and the cylinder of the pile-driving device of FIG. **1** during various stages of a cycle.

[0022] FIG. **1** shows a longitudinal sectional view of a pile-driving device **1** according to the present invention, comprising a cylinder **2** with a closed upper end **3**. A ram **6** is movably accommodated within the cylinder **2**, and the cylinder **2** encloses an anvil **7** at the bottom end. An upper combustion chamber **8** is defined between the closed upper end **3** of the cylinder **2** and the upper end of the ram **6** within the cylinder **2**. At the bottom of the cylinder **2**, the ram **6** and the anvil **7** define a lower combustion chamber **9**. An inlet pipe for air to be combusted, consisting of an upper section **4***a* and a

lower pipe section **4***b*, extends through the cylinder **2** from the upper end **3** to the lower combustion chamber **9**. The upper pipe section **4***a* is provided with an inlet opening **10** for the supply of fresh air to the upper combustion chamber **8**. The lower pipe section **4***b* is provided with an inlet opening **11** for the supply of fresh air to the lower combustion chamber **9**. Outlet openings **13** are provided in the wall of the cylinder **2**, which outlet openings connect the upper combustion chamber **8** to an exhaust pipe **14** for combusted exhaust gases. An outlet opening **12** is provided in the lower combustion chamber **9** for discharging air from the combustion chamber **9** through the exhaust pipe **15**. In this embodiment the inlet and outlet openings are provided with control valves (not shown). Injection devices **16** and **17** are provided in the upper combustion chamber **8** and the lower combustion chamber **9**, respectively, for injecting fuel under pressure into the respective combustion chambers **8** and **9**. Filters (not shown) are provided in the inlet pipe sections **4***a*, **4***b* and the outlet pipes **14**, **15** for filtering air to be supplied to a combustion chamber and exhaust gases to be discharged from a combustion chamber, respectively. A pump (not shown) is provided at the upper end of the upper pipe section **4***a*.

[0023] FIG. **2** shows five situations (A-E) of the pile-driving device **1** of FIG. **1** during successive stages of a pile-driving cycle. In situation A, the cylinder **2** and the ram **6** move upward and downward, respectively. Situation B is the situation in which the ram **6** strikes the anvil **7**. In situation C, the cylinder **2** and the ram **6** move downward and upward, respectively. Situation D is the situation in which the cylinder **2** is in its lowermost position and the ram **6** is in its uppermost position. In situation E the cylinder **2** and the ram **6** move apart again, towards the positions shown in situation A.

[0024] The operation of the pile-driving device **1** will now be explained in more detail with reference to the appended figures. Starting with situation B, the ram **6** strikes the anvil **7** and the volume of the lower combustion chamber **9** is at its minimum. At that moment the atomised diesel fuel, which has been injected into the lower combustion chamber **9** under pressure by the injection device **17** at a point in time depending on the composition, the temperature and the pressure of gas in the combustion chamber **9**, is combusted as a result of auto-ignition, as a result of which the air pressure in the combustion chamber **9** increases enormously. This increase in the air pressure drives the ram **6** upward. This is shown in situation C. In situation B the cylinder **2** is in the uppermost position, or the cylinder **2** has just started to drop after reaching its uppermost position. The volume of the upper combustion chamber **8** is at its maximum in situation B. Since the lower pipe section **4***b* of the fresh air inlet pipe is fixed in position relative to the anvil **7** and the upper pipe section **4***a* of the fresh air inlet pipe is fixedly connected to the cylinder **2**, the spacing between the two pipe sections **4***a*, **4***b* is at its maximum as well. The space **18** between the pipe sections **4***a* and **4***b* is enclosed by the inner circumference of the ram **6**, which thus forms part of the fresh air inlet pipe, as it were, and which interconnects the upper and lower pipe sections **4***a*, **4***b*.

[0025] In situation C the ram **6** moves upward as a result of the aforesaid pressure increase in the lower combustion chamber **9**. Exhaust gases are now discharged from the lower combustion chamber **9** through the outlet opening **12**. The cylinder **2** moves downward in a fall motion, whilst fresh air is pumped into the upper combustion chamber **8** through the inlet opening **10**. As a result of the upward movement of the ram **6**, the downward movement of the cylinder **2** and the supply of fresh air, the gas in the upper combustion chamber **8** is compressed.

[0026] Shortly afterwards, situation D is reached, in which the ram **6** and the cylinder **2** preferably stay just shy of making contact with each other, thus minimising the volume in the upper combustion chamber **8**. Diesel fuel that has been injected into the upper combustion chamber **8** under pressure by the upper injection device **16** now combusts, causing the pressure of the gas mixture in the combustion chamber **8** to increase enormously. In addition, the cylinder **2** is driven upward as a result of the increase of the pressure in the upper combustion chamber **8**.

[0027] Situation E shows how the ram **6** and the cylinder **2** move away from each other as a result of the pressure increase in the upper combustion chamber **8**. Exhaust gases from the upper combustion chamber **8** are discharged from the upper combustion chamber **8** through the outlet openings **13** and the exhaust pipe **14**. In addition, fresh air is pumped into the lower combustion chamber **9** under pressure through the upper pipe section **4***a*, the lower pipe section **4***b* and the inlet opening **11**. A side effect, which should not be underestimated, of supplying fresh air for the combustion in this manner is the cooling effect thereof on the parts surrounding the lower combustion chamber **9**, as a result of which the temperature in the lower combustion chamber **9** is controlled, at least to a larger degree than with the pile-driving devices known so far, in which air is sucked in through an inlet opening.

[0028] Subsequently, situation A is reached again, in which the ram **6** has nearly reached its maximum velocity for striking the anvil **7**, and in which the cylinder **2** slowly moves upward and has nearly reached its uppermost position.

[0029] A device and a method as described in the foregoing and shown in the drawings maximally utilise the combustion of fuel in the second combustion chamber for driving the ram **6** downward and driving the cylinder **2** upward, as a result of which an accelerated compression can be realised in the upper combustion chamber **8** during a subsequent stage.

[0030] Only one embodiment of the present invention is shown in the figures and described in the foregoing. However, the figures and the description by no means have a limitative effect on the scope of the present invention, which is determined by the appended claims. Various adaptations to the embodiment as described herein are available to those skilled in the art without departing from the scope of the invention. Thus, an opening may be provided in the cylinder wall, as is often the case with conventional pile-driving devices, for allowing fresh air to flow into the combustion chamber and discharging exhaust gases therefrom. Furthermore, the pile-driving device has been described herein in relation to driving a support, such as a pile, into a ground surface. The pile-driving device according to the present invention may also be used for compacting soil, however, or for breaking rocky ground, for example.

1. A combustion-type pile-driving device, comprising a cylinder having a closed upper end and an open lower end, which cylinder is freely movable as a piston with respect to an anvil which seals the lower end of the cylinder, a ram which is freely movable as a piston with respect to the cylinder and the anvil in the cylinder, and an injection device for injecting a fuel into a combustion chamber formed between the ram and the anvil in the cylinder for driving the ram upward by combustion of the injected fuel, and a second injection device is provided for injecting fuel into a second combustion chamber

formed in the cylinder between the ram and the closed upper end of the cylinder for driving the ram downward and driving the cylinder upward by combustion of the injected fuel.

2. The pile-driving device according to claim **1**, wherein a first air pipe extends upward through the cylinder, parallel to a longitudinal axis of the cylinder, which air pipe is in communication with the combustion chamber for supplying and discharging air to and from, respectively, the combustion chamber.

3. The pile-driving device according to claim **2**, wherein the first air pipe is in communication with the second combustion chamber for supplying or discharging air to and from, respectively, said combustion chamber.

4. The pile-driving device according to claim **2**, wherein the first air pipe is a divided pipe, wherein the upper pipe section of the first air pipe moves along with the cylinder, wherein the lower pipe section of the first air pipe is, at least substantially, static relative to the anvil and wherein a space that may be present between said upper and said lower pipe section is surrounded by a connecting tube.

5. The pile-driving device according to claim **4**, wherein the ram forms the connecting tube.

6. The pile-driving device according to claim **1** wherein a second air pipe extends in the anvil, parallel to the longitudinal axis of the cylinder, which second air pipe is in communication with the combustion chamber for supplying or discharging air to or from, respectively, the combustion chamber.

7. The pile-driving device according to claim **1** wherein the air inlet and the air outlet of the combustion chamber are separated.

8. The pile-driving device according to claim **1** wherein filter means are provided for filtering discharged exhaust gases.

9. The pile-driving device according to claim **1** wherein pump means are provided for pumping fresh air into the combustion space.

10. The pile-driving device according to claim **1** wherein further filter means are provided for filtering fresh air to be supplied.

11. A method which comprises:

i) providing a combustion-type pile-driving device, comprising a cylinder having a closed upper end and an open lower end, which cylinder is freely movable as a piston with respect to an anvil which seals the lower end of the cylinder, a ram which is freely movable as a piston with respect to the cylinder and the anvil in the cylinder, and an injection device for injecting a fuel into a combustion chamber formed between the ram and the anvil in the cylinder for driving the ram upward by combustion of the injected fuel, and a second injection device provided for injecting fuel into a second combustion chamber formed in the cylinder between the ram and the closed upper end of the cylinder for driving the ram downward and driving the cylinder upward by combustion of the injected fuel; and then

ii) driving a support into a ground surface by means of the pile-driving device wherein the cylinder is driven upward upon combustion of fuel in the second combustion chamber.

12. The method according to claim **11**, wherein the movements of the ram and the cylinder are at least substantially in counterphase.

13. The pile-driving device according to claim **3** wherein the first air pipe is a divided pipe, wherein the upper pipe section of the first air pipe moves along with the cylinder, wherein the lower pipe section of the first air pipe is, at least substantially, static relative to the anvil and wherein a space that may be present between said upper and said lower pipe section is surrounded by a connecting tube.

14. The pile-driving device according to claim **13**, wherein the ram forms the connecting tube.

15. The pile-driving device according to claim **2** wherein a second air pipe extends in the anvil, parallel to the longitudinal axis of the cylinder, which second air pipe is in communication with the combustion chamber for supplying or discharging air to or from, respectively, the combustion chamber.

16. The pile-driving device according to claim **3** wherein a second air pipe extends in the anvil, parallel to the longitudinal axis of the cylinder, which second air pipe is in communication with the combustion chamber for supplying or discharging air to or from, respectively, the combustion chamber.

17. The pile-driving device according to claim **4** wherein a second air pipe extends in the anvil, parallel to the longitudinal axis of the cylinder, which second air pipe is in communication with the combustion chamber for supplying or discharging air to or from, respectively, the combustion chamber.

18. The pile-driving device according to claim **13** wherein a second air pipe extends in the anvil, parallel to the longitudinal axis of the cylinder, which second air pipe is in communication with the combustion chamber for supplying or discharging air to or from, respectively, the combustion chamber.

19. The pile-driving device according to claim **5** wherein a second air pipe extends in the anvil, parallel to the longitudinal axis of the cylinder, which second air pipe is in communication with the combustion chamber for supplying or discharging air to or from, respectively, the combustion chamber.

20. The pile-driving device according to claim **14** wherein a second air pipe extends in the anvil, parallel to the longitudinal axis of the cylinder, which second air pipe is in communication with the combustion chamber for supplying or discharging air to or from, respectively, the combustion chamber.

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