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(54) Title: INTERNAL COMBUSTION ENGINE WITH TURBOCHARGE ARRANGEMENT

(57) Abstract: The invention concerns an internal combustion engine comprising a combustion cylinder provided with a piston (5, 6, 104, 105, 106, 205, 206, 207, 208) and a combustion chamber (2, 3, 101, 102, 103, 201, 202, 203, 204); an inlet valve (7, 9, 113, 215); an exhaust valve (8, 10, 112, 216); an exhaust duct (17) and a turbocharge arrangement (26, 27). The engine further comprises an exhaust cylinder provided with an exhaust piston (4) and an exhaust chamber (1), wherein the exhaust chamber (1) is arranged in fluid communication with the combustion chamber (2, 3, 101, 102, 103, 201, 202, 203, 204) via a channel or opening (14, 15, 109, 110, 111, 211, 212, 213, 214) that can be closed by the exhaust valve (8, 10, 112, 216), and wherein the exhaust chamber (1) is arranged in open fluid communication with the exhaust duct (17) so that exhaust gas exiting the combustion chamber (2, 3, 101, 102, 103, 201, 202, 203, 204) when the exhaust valve (8, 10, 112, 216) is open is allowed to distribute between the exhaust chamber (1) and the exhaust duct (17).

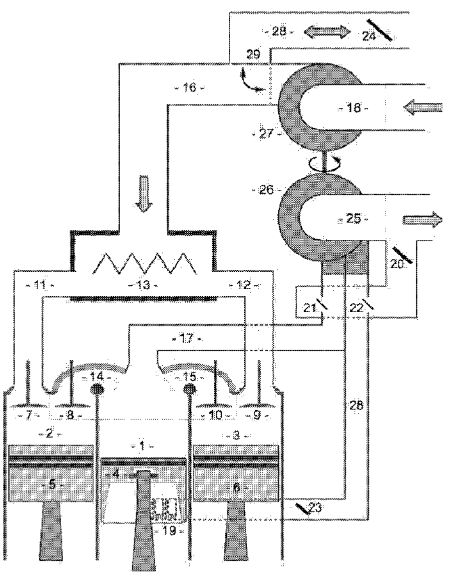

Figure 11: Variant of the design according to figure 8 (2 + 1 cylinder). This variant is adaptable to different rpm/workloads.

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Internal combustion engine with turbocharge arrangement

TECHNICAL FIELD

This invention relates to an internal combustion engine provided with a turbocharge arrangement according to the preamble of claim 1. The invention also relates to a method for operating such an engine and to a vehicle provided with such an engine for propulsion of the vehicle.

BACKGROUND OF THE INVENTION

Exhaust gas from internal combustion engines contains energy that can be used in turbochargers where the exhaust gas drives a turbine connected to a compressor that compresses the intake air fed to the engine.

A combustion cylinder has 100% volumetric efficiency (VE) if the air volume sucked in is as large as the stroke volume, at normal air pressure. Naturally aspired engines can reach 100% VE when there's resonance in the intake and exhaust manifold. Turbo engines can reach VE > 100%.

Generally, small turbochargers are efficient when engine rpm (revolutions per minute) is low, i.e. when the engine speed is low. At high rpm the volume of the exhaust gas is too great for being handled by the turbocharger and some exhaust is allowed to pass through a waste-gate. Small turbo's are therefore not efficient at high rpm's. On the other hand, large turbo's are efficient at high engine speeds but not when the rpm is low, and large turbo’s also have more turbo lag, i.e. a more significant response delay.

With electric-hybrid technology, the disadvantage of large turbochargers can be reduced or eliminated since electric motors give instant torque and can compensate for the turbo lag. Turbochargers may also be provided with electric engines/generators that can use electricity to spin the turbo faster or slow it down to store energy. However, such measures require some supply of energy.

Exhaust gas with high pressure can transfer a lot of energy to the turbo. However, if the pressure is too high, too much exhaust gas will be left in the cylinder at the exhaust stroke due to the high back pressure. Exhaust gas left in the combustion chamber dilutes the air introduced in the subsequent intake stroke and has a negative effect on the efficiency of the engine.

Engines with few cylinders have uneven exhaust, i.e. the pressure of the exhaust varies considerably with time, and such engines cannot provide as high average exhaust pressure to the turbo as engines with more cylinders.

Figures 1-3 show exhaust flow from 4-stroke engines with 1, 2, and 3 cylinders, respectively. The x-axis shows the revolution of the crankshaft in degrees (and it thus also shows time) and the y-axis shows a representation of the flow of exhaust gas out from the cylinder(s). The flow from each cylinder has been approximated with a sinus curve, as this would be the piston motion if the connection rod had infinite length. This sinus curve has then been multiplied with one during the period when a piston pushes exhaust out, and multiplied with zero during the rest of the time when the exhaust valve(s) is/are closed. One complete 4-stroke cycle corresponds to two revolutions of the crankshaft (720 degrees). Exhaust gas is expelled from each cylinder during ½ a revolution (180 degrees); no exhaust is expelled during the remaining 1 ½ revolution (540 degrees). In practice the exhaust valve may open slightly earlier and close slightly later so each exhaust cycle may therefore in practice be slightly longer than 180 degrees and more powerful in the beginning.

The pressure to the turbocharger can be increased if the volume of the exhaust manifold is small. This works well if the rpm's are low, but at higher rpm's the back pressure of the exhaust manifold will prevent the cylinders from breathing out and too much exhaust gas will remain in the cylinder.
It would thus be an advantage if a high exhaust gas pressure could be

provided while avoiding the negative effect related to the high back pressure.

To reduce the back pressure it has been proposed to increase the volume of the exhaust manifold. Disadvantages associated with such an arrangement is a delay of the turbo response and that a larger exhaust manifold requires more space. Further, the pressure of the exhaust gas delivered to the turbo is lowered.

A general desire is also to adapt turbochargers to different workloads. For this purpose variable geometry turbo arrangements have been proposed. Some general challenges associated with such arrangements are costs, reliability and control.

There is still a need for improvements in this field.

SUMMARY OF THE INVENTION

A general object of the invention is to improve the efficiency of turbocharged internal combustion engines.

The invention concerns an internal combustion engine comprising

- at least a first combustion cylinder provided with a first piston arranged to move back and forth in an axial direction of the first combustion cylinder;
- a first combustion chamber associated with an end portion of the first cylinder, wherein a volume of the first combustion chamber varies with the position of the first piston;
- an arrangement for supplying air and fuel to the first combustion chamber;
- a first inlet valve for controlling the flow of air to the first combustion chamber;
- a first exhaust valve for controlling the outflow of exhaust gas from the first combustion chamber;
- an exhaust duct for leading away exhaust gas that has flown out from the first combustion chamber,

- a turbocharge arrangement for compressing air supplied to the engine, wherein the turbocharge arrangement comprises a turbine arranged in fluid communication with the exhaust duct so as to allow the turbine to be driven by the flow of exhaust gas,

The invention is characterized in that the engine further comprises:
- an exhaust cylinder provided with an exhaust piston arranged to move back and forth in an axial direction of the exhaust cylinder,
- an exhaust chamber associated with an end portion of the exhaust cylinder, wherein a volume of the exhaust chamber varies with the position of the exhaust piston,
wherein the exhaust chamber is arranged in fluid communication with the first combustion chamber via a channel or opening that can be closed by the first exhaust valve, and
wherein the exhaust chamber is arranged in open fluid communication with the exhaust duct via an exhaust duct inlet arranged in association with the end portion of the exhaust cylinder so that, during operation of the engine, exhaust gas exiting the first combustion chamber when the first exhaust valve is open is allowed to distribute between the exhaust chamber and the exhaust duct.

The inventive engine thus comprises one or more combustion cylinders, which may be of conventional type, and at least one exhaust cylinder that is capable of influencing the flow of exhaust gas from the combustions cylinder(s) via an open exhaust duct, but where no combustion occurs. Thus, no inlet air or fuel is fed to the exhaust cylinder, only exhaust gas.

A main advantage of such an engine is that it allows for control of the pressure properties of the exhaust gas flowing through the exhaust duct towards the turbocharge arrangement. This can be used to increase the efficiency of the turbocharge arrangement, which in turn can be used to improve the fuel efficiency of the engine.

By moving the exhaust piston in a direction away from the exhaust chamber while the first exhaust valve is open, i.e. while exhaust gas flows out from the first combustion chamber during an exhaust stroke of the first combustion cylinder, the exhaust gas will distribute between the exhaust duct and the expanding exhaust chamber. This reduces the back pressure. In the following back stroke of the exhaust piston the portion of exhaust gas that entered the exhaust chamber during the previous stroke will be pushed out from the exhaust chamber into the exhaust duct. The exhaust pulse from the first combustion cylinder will thus be distributed over a longer time period. This is useful at high load situations for cutting and distributing the peaks of the exhaust pulses, i.e. in a situation where the turbine of the turbocharge arrangement cannot handle the high pressure at the peaks of the pulses. Instead of having to let a portion of the exhaust (over)flow bypass the turbine, this portion is delayed due to the exhaust cylinder and can be used in the turbo without bypass. This increases the efficiency of the turbocharge arrangement.

The first exhaust valve may be kept open over a slightly longer time than the expansion stroke of the exhaust piston, i.e. slightly longer than it takes for the exhaust piston to move from its top dead centre to its lower dead centre, but it will typically be open at least during the time period during which the exhaust piston moves away from the end portion of the exhaust cylinder and expands the exhaust chamber, i.e. as long as the exhaust piston moves from its top dead centre towards its lower dead centre.

By instead moving the exhaust piston in a direction towards the exhaust chamber while the first exhaust valve is open, the exhaust gas is still allowed to distribute between the exhaust duct and the expanding exhaust chamber, but in this case the size of the exhaust chamber is decreasing so the exhaust piston contributes in compressing the exhaust gas transferred to the exhaust duct so as to increase the pressure in the exhaust pulse. This is useful at low load conditions where the exhaust gas pressure peak height is lower than the design limit of the turbocharger turbine and where an increased peak height increases the efficiency in the turbocharger arrangement.

Preferably, the engine is configured to allow phase shift between work cycles of the first combustion cylinder and the exhaust cylinder so that the exhaust piston can be moved in a direction away from or towards the exhaust chamber while the first exhaust valve is open depending on the mode of operation of the engine. Thereby the back pressure and pressure peak height can be reduced at high load situations and the pressure increased during low load situations.

Such phase shift can be provided by arranging the combustion piston(s) and the exhaust piston on separate crank shafts and let the “combustion crankshaft” drive the “exhaust crankshaft” via a wheel capable of providing phase shift (e.g. in similarity with variable cam phasers that are used to change the phase of cam shafts). Alternatively, the exhaust piston may be a free piston that can be controlled independently of the “combustion crankshaft” by a linear engine/generator.

That the exhaust chamber is arranged in open fluid communication with the exhaust duct means that the exhaust duct is continuously open to the exhaust chamber and that there is no valve or similar that prevents exhaust gas originating from the first combustion chamber to flow into the exhaust duct.

That the exhaust duct inlet is arranged in association with the end portion of the exhaust cylinder means that the exhaust chamber is in fluid communication with the exhaust duct irrespective of the position of the exhaust piston. This means that the exhaust duct inlet is not covered by the exhaust piston as it moves between its top and lower dead centres. Typically, the inlet to the exhaust duct is arranged in a cylinder head of the engine.

The fluid communication between the first combustion chamber and the exhaust chamber can be arranged in various ways, for instance simply by a channel arranged at a port/opening that can be closed by the first exhaust valve.

The size of the exhaust cylinder/piston/chamber depends on the application. Typically, the size of the exhaust cylinder (i.e. the size of the exhaust chamber when expanded) can be similar to that of (each of) the combustion cylinder(s). If the exhaust piston is of the free piston type the stroke length can be varied and thus also the volume of the exhaust chamber.

An exhaust cylinder can more or less even out the exhaust flow to the turbo. The combustion cylinders can then more easily breathe out and the exhaust pressure can be used more efficiently in the turbo, which will improve turbo power and fuel consumption. Too high pressure at exhaust gas pulse peaks are “cut” and distributed over time periods with lower pressure. This allows for the use of a smaller turbo that can be used more efficiently, or for the possibility to let the engine work harder without lowering the turbo efficiency.

For an engine with 2+1 cylinders, i.e. two combustion cylinders and one exhaust cylinder, the exhaust piston can have a smaller displacement.

The use of an additional exhaust cylinder is known as such from e.g. US6553977. However, US6553977 does not address turbo efficiency but focuses on increasing energy output and power density of an internal combustion engine by decoupling the compression and expansion ratios and allowing a second expansion of the exhaust gases in a relatively large and closed exhaust cylinder before evacuating the gases via an additional exhaust valve in a fifth stroke. The engine proposed in US6553977 does not reduce the exhaust gas back pressure. Further, the large exhaust cylinder/piston together with the additional exhaust valve give high friction.

In an embodiment of the invention the engine is configured to be capable of moving the exhaust piston in a direction away from the exhaust chamber while the first exhaust valve is open.

In an embodiment of the invention the engine is configured to be capable of moving the exhaust piston in a direction towards the exhaust chamber while the first exhaust valve is open.

In an embodiment of the invention the engine is configured to allow phase shift between work cycles of the first combustion cylinder and the exhaust cylinder so that the exhaust piston can be moved in a direction away from or towards the exhaust chamber while the first exhaust valve is open depending on the mode of operation of the engine.

In an embodiment of the invention the engine comprises at least one further combustion cylinder provided with a further piston, a further combustion chamber, a further exhaust valve etc. in similarity with the first combustion cylinder, wherein the exhaust chamber is arranged in fluid communication also with the further combustion chamber via the further exhaust valve so that, during operation of the engine, exhaust gas exiting also the further combustion chamber when the further exhaust valve is open is allowed to distribute between the exhaust chamber and the exhaust duct.

In an embodiment of the invention the first piston is arranged onto a first crankshaft for driving the first piston and wherein the exhaust piston also is arranged onto the first crankshaft for driving the exhaust piston.

In an embodiment of the invention the first piston is arranged onto a first crankshaft for driving the first piston and wherein the exhaust piston is arranged onto a second crankshaft for driving the exhaust piston.

In an embodiment of the invention the engine comprises a driving arrangement allowing the first crankshaft to drive the second crankshaft.

In an embodiment of the invention the driving arrangement for driving the second crankshaft comprises a wheel configured to allow phase shift between the first and second crankshafts.

In an embodiment of the invention the exhaust piston is a free piston driven by a linear actuator/generator.

In an embodiment of the invention a bypass channel is arranged to allow exhaust gas flowing through the exhaust duct to bypass the turbine of the turbocharge arrangement, wherein a first valve/flap is arranged to control the distribution of the flow in the exhaust duct between the turbine and the bypass channel.

In an embodiment of the invention a bypass valve/flap is arranged in the bypass channel to control the flow through the bypass channel.

In an embodiment of the invention the engine comprises an additional exhaust duct having an inlet arranged in the exhaust cylinder at a distance from the end portion of the exhaust cylinder so as to be open to and in fluid communication with the exhaust chamber only when the exhaust piston is at or close to its lower dead centre position.

In an embodiment of the invention a second valve/flap is arranged to control the distribution of the flow in the additional exhaust duct between the turbine and the bypass channel.

In an embodiment of the invention a third valve/flap is arranged in the additional exhaust duct to control the flow through the additional exhaust duct.

In an embodiment of the invention the exhaust duct is connected to a first inlet of the turbine wherein the additional exhaust duct is connected to a second inlet of the turbine.

In an embodiment of the invention the turbo bypass channel is arranged to be in fluid communication with the exhaust duct and the additional exhaust duct upstream the turbine via the first and second valves/flaps, respectively.

The invention also concerns a method for operating an internal combustion engine of the above type. The method is characterized in that it comprises the step of: moving the exhaust piston in a direction away from the exhaust chamber while keeping the first exhaust valve open; or moving the exhaust piston in a direction towards the exhaust chamber while keeping the first exhaust valve open.

In an embodiment of the invention the method further comprises the step of: shifting phase between work cycles of the first combustion cylinder and the exhaust cylinder so as to move the exhaust piston in a direction away from or towards the exhaust chamber while keeping the first exhaust valve open depending on the mode of operation of the engine.

The invention also concerns a method for operating an internal combustion engine of the above type comprising turbo bypass channel and valves/flaps for controlling the exhaust flow downstream the exhaust chamber. This method comprises the step of: moving the exhaust piston in a direction away from the exhaust chamber while keeping the first exhaust valve open, and the method further comprises one of the following steps:

i) keeping all valves/flaps open so that exhaust gas is allowed to flow through the turbo bypass channel or the turbine via the exhaust duct or the additional exhaust duct;

ii) keeping all valves/flaps closed so that exhaust gas is prevented from flowing through the turbo bypass channel and the additional exhaust duct but allowed to flow through the exhaust duct towards and into the turbine via the first inlet thereof;

iii) keeping the third valve/flap open and the other valves/flaps closed so that exhaust gas is prevented from flowing through the turbo bypass channel but allowed to flow through the exhaust duct or the additional exhaust duct towards and into the turbine via corresponding first and second inlets; or

iv) keeping the first, second and third valves/flaps open and the bypass valve/flap closed so that exhaust gas is prevented from flowing through the turbo bypass channel but allowed to flow through the exhaust duct or the additional exhaust duct towards the turbine and further allowed to mix upstream the turbine so that the combined flow of exhaust gas in the exhaust duct and the additional exhaust duct is allowed to distribute between the first and second inlets of the turbine.

The invention also concerns a vehicle comprising an internal combustion engine arranged for propulsion of the vehicle, wherein the internal combustion engine is of the above type.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1: Exhaust flow from 4-stroke engine with 1 cylinder.

Figure 2: Exhaust flow from 4-stroke engine with 2 cylinders.

Figure 3: Exhaust flow from 4-stroke engine with 3 cylinders.

Figure 4: Exhaust flow 4-stroke engine with 3 cylinders + 1 exhaust cylinder

Figure 5: Torque 4-stroke engine 2 cylinders (estimated amplitude -0,5 to 0,8).

Figure 6: Torque 4-stroke 2 cylinders + exhaust cylinder (smaller amplitude -0,3 to 0,7)

Figure 7: 2 cylinders + 1 exhaust cylinder + 1 further exhaust cylinder

Figure 8: Basic layout 2 + 1 cylinder

Figure 9a: 1:st stroke of 4 of design according to figure 8. Cylinder (1) venting remaining gases to the turbo. Cylinder (2) intake stroke. Cylinder (3) power stroke.

Figure 9b: 2:nd stroke of 4 of design according to figure 8. Cylinder (1) ca 50% of exhaust push piston (4), the rest is vented directly to turbo. Cylinder (2) compression stroke. Cylinder (3) exhaust stroke.

Figure 9c: 3:rd stroke of 4 of design according to figure 8. Cylinder (1) venting remaining gases to the turbo. Cylinder (2) power stroke. Cylinder (3) intake stroke.

Figure 9d: 4:th stroke of 4 of design according to figure 8. Cylinder (1) ca 50% of exhaust push piston (4), the rest is vented directly to turbo. Cylinder (2) exhaust stroke. Cylinder (3) compression stroke.

Figure 10a: Exhaust from design according to figure 8 (2 + 1 cylinder). Grey line – combustion cylinders. Black line – exhaust cylinder.

Figure 10b: Exhaust from design according to figure 8 (2 + 1 cylinder). Combined exhaust from combustion cylinders and exhaust cylinder.

Figure 11: Variant of the design according to figure 8 (2 + 1 cylinder). This variant is adaptable to different rpm/workloads.

Figure 12a: Variant of figure 11 at idling conditions – no turbo. Valves 20, 21, 22 & 23 are open.

Figure 12b: Variant of figure 11 at low rpm/workload. Half of twin scroll turbo is used. Valves 20, 21, 22, 23 are closed.

Figure 12c: Variant of figure 11 at medium rpm/workload. Twin scrolls in turbo are used. Valve 23 open, 20, 21 & 22 closed.

Figure 12d: Variant of figure 11 at high rpm/workload. Twin scrolls are used. Valves 21, 22, 23 open. Valve 20 closed.

Figure 12e: Variant of figure 11 at overflow. Twin scrolls are used. Valves 20, 21, 22 & 23 open.

Figure 13: Variant with 3+1 cylinders. To the left are cylinders (101), (102) & (103), to the right is exhaust cylinder (1). Wheel (107) drives wheel (108) at a ratio of 1.5, to allow one exhaust cylinder to serve 3 combustion cylinders.

Figure 14a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift 0°. Black line – combustion cylinders. Grey line – exhaust cylinder.

Figure 14b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift 0°. Combined exhaust from combustion cylinders and exhaust cylinder.

Figure 15a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -60°. Black line – combustion cylinders. Grey line – exhaust cylinder.

Figure 15b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -60°. Combined exhaust from combustion cylinders and exhaust cylinder.

Figure 16a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -120°. Black line – combustion cylinders. Grey line – exhaust cylinder.

Figure 16b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -120°. Combined exhaust from combustion cylinders and exhaust cylinder.

Figure 17a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -180°. Black line – combustion cylinders. Grey line – exhaust cylinder.

Figure 17b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -180°. Combined exhaust from combustion cylinders and exhaust cylinder.

Figure 18a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -240°. Black line – combustion cylinders. Grey line – exhaust cylinder.

Figure 18b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -240°. Combined exhaust from combustion cylinders and exhaust cylinder.

Figure 19: Variant with 4+1 cylinders. To the left are cylinders (201), (202), (203) & (204), to the right is exhaust cylinder (1). Wheel (209) drives wheel (201) at a ratio of 2, to allow one exhaust cylinder to serve 4 combustion cylinders. Phase shift is possible.

Figure 20a: Exhaust from design according to figure 19 (4 + 1 cylinder) at phase shift 0°. Upper line – combustion cylinders. Lower line – exhaust cylinder.

Figure 20b: Exhaust from design according to figure 19 (4 + 1 cylinder) at phase shift 0°. Combined exhaust from combustion cylinders and exhaust cylinder.

Figure 21: Free piston variant with 3+1 cylinders. This variant comprises 3 combustion pistons connected to a normal crankshaft and 1 exhaust piston connected to a linear actuator/engine/generator.

Figure 22: Free piston variant with 6+2 cylinders. This variant comprises 6 combustion pistons (left) connected to a normal crankshaft and dual exhaust pistons (right) connected to a linear actuator/engine/generator.

DESCRIPTION OF EXAMPLE EMBODIMENTS OF THE INVENTION

Figures 10a-10b shows schematically the exhaust flow from a 4-stroke engine with 2 cylinders + 1 exhaust cylinder. No fuel is burnt in the exhaust cylinder and this cylinder is totally open towards the exhaust manifold and has no valves. The task of the exhaust cylinder is to first receive part of the exhaust from one of the combustion cylinders (the other part of the exhaust goes directly to the exhaust manifold/duct), then wait half an engine revolution and, by means of the exhaust piston, send the housed part of the exhaust to the exhaust duct and the turbo, then receive a part of exhaust from the other combustion cylinder and repeat. This gives exhaust manifold resonance at all rpm's.

A 4-stroke engine with 2 cylinders + 1 exhaust cylinder gives a positive torque when the exhaust piston is pressed down (away from the exhaust chamber), which results in a less varying torque curve compared to a conventional 2-cylinder 4-stroke engine. This can be seen by comparing figures 5 and 6 where figure 5 shows the torque for a conventional 4-stroke engine with 2 cylinders (estimated amplitude -0,5 to 0,8) and the torque for a 4-stroke engine with 2 cylinders + one exhaust cylinder (smaller amplitude -0,3 to 0,7).

The invention works with different numbers of cylinders. The digits within brackets below indicate the number of connected cylinders in the following way: (X+Y) means that the number of combustion cylinders is X and that the number of exhaust cylinders is Y.

(1+1) While one combustion piston move two revolutions (one 4-stroke cycle – two revolutions of crankshaft), one exhaust piston moves one revolution.

(2+1) With two combustion pistons (4-stroke) the exhaust piston can move at the same rpm. See e.g. figures 8-12.

(3+1) When three combustion pistons move two revolutions (one 4-stroke cycle), one small exhaust piston can move three revolutions. The 50% higher rpm of the exhaust piston is not a problem, as this piston has less load and the cylinder has no valves.

Figure 3 shows the exhaust flow from a conventional 4-stroke engine with three cylinders and figure 4 shows the exhaust flow from a (3+1) engine. An exhaust piston cuts the peaks and moves this flow to the valleys. One full 4-stroke cycle is 720 degrees for the 3 large combustion pistons, while the small exhaust piston moves 1080 degrees. With no exhaust cylinder the exhaust flow varies between 0 and 1, but with exhaust cylinder the flow varies between around 0.7 and 1. This (3+1) solution is very suitable.

By comparing figures 4 and 10b it can be seen that (3+1) gives a more even exhaust flow than (2+1).

(4+1) or (4+2) With 4 combustion pistons/cylinders one can choose two different configurations. (4+1) can have 4 combustion pistons in a row and 1 exhaust piston rotating at twice the rpm. (4+2) can be a 90 degree V4 similar to 2 joined (2+1). Regarding exhaust flow none of these versions are significantly better than (3+1). Figures 23-24 show an example of a (4+1).

(5+1) is possible to build, but does not offer much of an advantage.

(6+1), (6+2) or (6+3) are all possible. Normal V6 engines gives rather even exhaust flow, but (6+3) in W-layout as 3 joined (2+1) gives even smother exhaust flow. And (6+2) is similar to 2 x (3+1) in V-layout.

Configurations with 7, 8, 9, 10 or 11 combustion pistons are possible, but offer no particular advantages. But a (12+6) configuration will give extremely even exhaust flow and could be of interest, even if it is costly to build.

The exhaust flow from a (2+1) engine, see figure 10b, can be made even smoother by using an additional second exhaust cylinder arranged with its exhaust chamber in open fluid communication with that of the first exhaust chamber. The second exhaust cylinder can have half the stroke volume of the first, but twice the rpm. This second exhaust cylinder can take exhaust from the four peaks shown in figure 10b and add this exhaust to the four valleys. It's possible to add a third, fourth and more exhaust cylinders, if desired, in principal also to the other variants of the engine.

For the 2+1 configuration it's possible to have all pistons (i.e. two combustion pistons and one exhaust piston) connected to the same crank shaft.

For the 3+1 configuration, the small exhaust piston can be connected to a separate crank shaft rotating three turns, while the crank shaft of the three combustion pistons rotates two turns. But there are also other solutions that do not require an additional crank shaft. The exhaust piston needs no additional external energy to move as it absorbs energy from the exhaust pulse which can be used for rebound when the pressure is lower. The exhaust piston can therefore act upon a spring that can be tuned to resonate with the rpm needed. It's also possible to add pneumatic, hydraulic, electromagnetic or other power to control the exhaust piston movement. This also allows the exhaust piston to have different stroke length and phase depending on engine load, rpm, etc. It's also possible to extract energy from the exhaust piston movement.

These design principles can be used on other internal combustion engines with pulsed exhaust, like piston-less rotary engines (also called rotary combustion engines).

Figure 8 shows an embodiment of a 4-stroke (2+1) cylinder engine. The engine comprises a main air intake duct 16 and air ducts 11, 12 leading to first and second combustion cylinders having first and second combustion pistons 5, 6 and first and second combustion chambers 2, 3, respectively, arranged at an end portion of the cylinders in association with a cylinder head of the engine. First and second air inlet valves 7, 9 are arranged to control the flow of air from the ducts 11, 12 into the combustion chambers 2, 3. The engine is also provided with an arrangement for supplying fuel (not shown) into the combustion chambers 2, 3.

A heat exchanger 13 is provided in the main air intake duct 16.

The engine is further provided with an exhaust cylinder having an exhaust piston 4 and an exhaust chamber 1. First and second exhaust valves 8, 10 are arranged to control the flow of exhaust gas out from the combustion chambers 2, 3 via channels 14, 15 to the exhaust chamber and an exhaust duct 17. An inlet to the exhaust duct 17 is in this example arranged in the cylinder head in the middle of the end portion of the exhaust cylinder at the top of the exhaust chamber 1. The exhaust duct inlet is continuously open.

No combustion occurs in the exhaust chamber 1 and no fresh air or fuel is thus fed to the exhaust chamber 1, only exhaust gas from the combustion cylinders.

The exhaust duct 17 is arranged on the same side of the cylinders as the chambers 1-3 in association with the cylinder head and leads to a turbocharge arrangement (not shown) for compressing air supplied to the engine via intake 16. The turbocharge arrangement comprises a turbine arranged in fluid communication with the exhaust duct 17 so as to allow the turbine to be driven by the flow of exhaust gas.

The exhaust chamber 1 is arranged in fluid communication (in this case via channels 14 and 15) to the first and second combustion chamber 2, 3 via the first and second exhaust valves 8, 10. That is, when the exhaust valves 8, 10 are closed there is no fluid communication between the combustion chambers 2, 3 and the exhaust chamber 1, and when one of the exhaust valves 8, 10 is open there is fluid communication between the exhaust chamber 1 and the corresponding combustion chamber. (Both exhaust valves are not open at the same time during normal operation of the engine. On the other hand, both exhaust valves are closed at the same time during around half of the time during operation, see below.)

Further, the exhaust chamber 1 is arranged in open fluid communication with the exhaust duct 17 (irrespective of the position of the exhaust piston 4, see further embodiment below). This means there is no further exhaust valve or similar that prevents fluid communication between the exhaust chamber 1 and the exhaust duct 17. This means that, during operation of the engine, exhaust gas exiting the first or second combustion chamber 2, 3 when the first or second exhaust valve 8, 10 is open is allowed to distribute between the exhaust chamber 1 and the exhaust duct 17.

All pistons 4-6 are in this example connected to the same crank shaft (not shown) so as to oscillate back and forth in an axial direction of the cylinders with the same frequency. The combustion cylinders, the air inlet valves and the exhaust valves work substantially in the same way as in a conventional internal combustion engine.

The variant of the engine shown in figure 8 works best at the rpm/workload the turbo is designed for. Adaptable variants that are more efficient at varying rpm/workloads are described below.

Figures 9a-9d show the four strokes of the engine of figure 8.

Figure 9a illustrates a 1:st stroke where the exhaust valves 8, 10 are closed and where the exhaust piston 4 of the exhaust cylinder moves towards the exhaust chamber 1 (upwards) and pushes remaining exhaust gas to the exhaust 17 and further to the turbocharge arrangement. The first combustion cylinder has started an intake stroke; the air inlet valve 7 is open and air flows into the first combustion chamber 2 while the first combustion piston 5 moves away from the first combustion chamber 2 (downwards). The second combustion cylinder 3 has started a power stroke (expansion stroke) with the second combustion piston 6 moving away from the second combustion chamber 3 (downwards) and with both valves 9, 10 closed .

Figure 9b illustrates a 2:nd stroke where all pistons 4-6 has passed a dead center (top or lower) and now moves in the opposite direction compared to figure 9a. The first combustion cylinder has started a compression stroke with both valves 7, 8 closed. The second combustion cylinder has started an exhaust stroke where the second exhaust valve 10 is open and the inlet valve 9 closed so that exhaust is pushed out from the second combustion chamber 3 via the channel 15 into the exhaust chamber 1 and the exhaust duct 17. Around 50% of the exhaust gas expelled from the second combustion cylinder pushes onto the exhaust piston 4 and remains in the exhaust chamber 1 (the volume of which gets greater as the exhaust piston 4 moves downwards) while the rest of the exhaust is vented directly to the exhaust duct 17 and further to the turbocharge arrangement.

Figure 9c illustrates a 3:rd stroke where all pistons 4-6 again has passed a dead center (top or lower) and now moves in the same direction as in figure 9a. Figure 9c shows the same thing as figure 9a, except that in figure 9c the first combustion cylinder 2 has started a power stroke (expansion stroke) and the second combustion cylinder 3 has started an intake stroke.

Figure 9d illustrates a 4:th stroke where all pistons 4-6 again has passed a dead center (top or lower) and now moves in the same direction as in figure 9b. Figure 9d shows the same thing as figure 9b, except that in figure 9d the first combustion cylinder 2 has started an exhaust stroke (with exhaust valve 8 open) and the second combustion cylinder has started a compression stroke (with both valves closed). The exhaust gas pushed out from the first combustion chamber 2 via channel 14 is distributed in a similar way as described in relation to figure 9b.

Figures 10a-10b illustrate the flow of exhaust gas from the engine design according to figure 8 (2 + 1 cylinder). Figure 10a shows separate lines for the combustion cylinders (grey line) and the exhaust cylinder (black line) while figure 10b shows the resulting combined exhaust from the combustion cylinders and the exhaust cylinder.

From the above it can be seen and understood that the exhaust cylinder reduces the backpressure significantly by expanding and enlarging the exhaust chamber 1 so as to house a portion of the exhaust gas expelled during the exhaust stroke of the combustion cylinders. Since this portion of exhaust gas is pushed into the exhaust duct during a stroke where there, in a conventional engine, is no supply of exhaust gas into the exhaust duct, the resulting flow of exhaust gas to the turbocharger arrangement becomes more evened out. By comparing figure 10b with the grey line of figure 10a (or figure 2) it can be seen that the arrangement shown in figure 8 significantly makes the resulting exhaust flow that reaches the turbo arrangement more uniform over time.

Figure 11 shows a variant of the design according to figure 8 (2+1 cylinders). The air intake 16, 11, 12, cylinders, pistons 4-6, chambers 1-3, valves 7-10 and main exhaust duct 17 are similar to what is shown in figure 8. These parts function as already described above. The variant in figure 11 comprises further components related to air intake and exhaust.

The engine in figure 11 is provided with a turbocharge arrangement comprising turbine 26 connected to a compressor 27, an air inlet 18 to the compressor 27 and an exhaust outlet 25 from the turbine 26. The turbocharge arrangement in figure 11 is a so-called twin-scroll turbo having two exhaust gas inlets adapted for different exhaust gas flows. Twin-scroll turbo’s are known as such.

The main exhaust duct 17 is connected to a first inlet of the turbine 26. An additional exhaust duct 28 is connected to a second inlet of the turbine 26. An inlet 19 to the additional exhaust duct 28 is arranged in the exhaust cylinder at a distance from the end portion of the exhaust cylinder so as to be open to and in fluid communication with the exhaust chamber 1 only when the exhaust piston 4 is at or close to its lower dead centre. The inlet 19 to the additional exhaust duct 28 is thus positioned at a distance (downwards in figure 11) from the cylinder head of the engine where exhaust valves etc. are located. Accordingly, the inlet 19 is closed to the exhaust chamber 1 most of time during operation of the engine (since the exhaust piston 4 most of time is not located at or close to its lower dead centre).

A turbo bypass duct/channel is arranged to allow exhaust gas to partly or fully bypass the turbine 26. A bypass valve/flap 20 is arranged for closing/opening the bypass duct. The bypass duct is arranged to be in fluid communication with the main exhaust duct 17 and the additional exhaust duct 28 upstream the turbine 26 via first and second valves/flaps 21 and 22, respectively.

When the valve/flap 21 is closed the exhaust gas in the main exhaust duct 17 is directed to flow into the turbine 26 (via the first turbine inlet). When the valve/flap 22 is closed the exhaust gas in the additional exhaust duct 28 is directed to flow into the turbine 26 (via the second turbine inlet).

When the valve/flap 21 is open the exhaust gas in the main exhaust duct 17 is directed to flow into the turbine bypass duct (and through the bypass duct in case also the bypass valve/flap 20 is open). When the valve/flap 22 is open the exhaust gas in the additional exhaust duct 28 is directed to flow into the turbine bypass duct (and through the bypass duct in case also the bypass valve/flap 20 is open). The valves/flaps 21, 22 may be arranged so that when they are open to the bypass duct they are also open to the inlets to the turbine 26.

When both valves/flaps 21 and 22 are open the exhaust gases in the main and additional exhaust ducts 17, 28 may mix upstream the turbine 26 so that exhaust from main duct 17 enters additional duct 28 upstream of the turbine and vice versa.

A third valve/flap 23 is arranged in the additional exhaust duct 28 for closing/opening the additional exhaust duct 28.

The engine shown in figure 11 further comprises a throttle valve 24, auxiliary intake manifold 28 and a flap/valve 29 for providing air to the engine when the turbo is not operating, such as at start up.

The engine can be adapted to different workloads as will now be described with reference to figures 12a-12e. Grey areas indicate the location of flowing exhaust gas. All figures show a moment where the exhaust piston 4 is located at its lower dead centre with inlet 19 open to the additional exhaust duct 28.

Figure 12a shows the engine of figure 11 at idling conditions. All valves 20-23 are open so that all exhaust gas bypass the turbine 26. Thus, the turbo arrangement is not in operation. All valves are open to provide as low flow resistance as possible. The exhaust gas may be allowed to flow through the turbine 26 but at idling conditions with low exhaust gas pressure the exhaust generally flows through the bypass channel.

Figure 12b shows the engine of figure 11 at low rpm/workload. Half of the twin scroll turbo is used (first inlet). All valves 20-23 are closed so that exhaust flows only via main exhaust duct 17 to the first inlet of the turbine 26. Here, the exhaust gas flow is not sufficient to create a sufficient pressure drop over both turbo scrolls.

Figure 12c shows the engine of figure 11 at medium rpm/workload. Twin scrolls in turbo are used (both inlets). Valve 23 is open, whereas valves 20-22 are closed. The exhaust gas thus flows via both ducts 17, 28 to the corresponding inlet at the turbine 26. Here, the exhaust gas flow is sufficient to create the pressure drop that the two scrolls are designed for.

Figure 12d shows the engine of figure 11 at high rpm/workload. Twin scrolls in turbo are used (both inlets). Valves 21-23 are open, whereas valve 20 is closed and the exhaust gas thus flows via both ducts 17, 28. Since both valves 21 and 22 are open a crossflow of exhaust gas is allowed between the ducts 17 and 28 upstream of the turbine 26. This evens out the exhaust flow between the two ducts 17, 28 and thereby the two turbine inlets, and the maximum amount of exhaust gas can pass through the twin scroll turbo.

Figure 12e shows the engine of figure 11 at overflow (too high rpm/workload). Twin scrolls in turbo are used (both inlets). All valves 20-23 are open. The difference compared to the high workload in figure 12d is that the bypass valve 20 has been opened to allow a portion of the exhaust gas to bypass the turbine 26. Both valves 21-22 are open so that exhaust gas from both ducts 17 and 28 is allowed to both mix and to flow via the bypass duct. The valves 20-24 are arranged in the same way as in figure 12a but in this case the exhaust gas pressure is sufficient for driving the turbine 26 while also flowing through the bypass channel.

In principle, a single scroll turbo can be used if exhaust gas from both ducts 17 and 28 is allowed to mix upstream the turbine 26.

Figure 13 shows a variant of a four-stroke engine with 3+1 cylinders. To the left is arranged three combustion cylinders with corresponding combustion chambers 101, 102, 103 and combustion pistons 104, 105, 106 similar to the combustion cylinders described above in relation to figures 8 and 11. The three combustion cylinders are arranged in a row and only a first (closest) combustion cylinder is shown in figure 13. Each of the three combustion chambers is provided with an air inlet valve and an exhaust valve in similarity with what is described above. Figure 13 shows the exhaust valve 112 and the air inlet valve 113 of the first combustion chamber 101. The further exhaust and inlet valves of the second and third combustion chambers 102, 103 are not shown in the figure.

To the right is arranged an exhaust cylinder having an exhaust chamber 1 and an exhaust piston 4 similar to what has been described above in relation to figures 8 and 11. Channels 109, 110, 111 connect each of the combustion chambers 101, 102, 103 with the exhaust chamber 1 via the corresponding exhaust valve (of which only the first exhaust valve 112 is shown in figure 13). Thus, when the exhaust valve of a combustion chamber 101, 102, 103 is open the exhaust gas is allowed to flow via the corresponding channel 109, 110, 111 to the exhaust chamber 1 and distribute between the exhaust chamber 1 and the main exhaust duct 17.

The exhaust system in figure 13 is similar to what is described above in relation to figure 11 (main exhaust duct 17, additional exhaust duct 28, valves 20-23, twin-scroll turbine arrangement with turbine 26, etc.).

As described in relation to figure 11, when the exhaust piston 4 is close to its lower dead centre and when the valve 23 in the additional exhaust duct 28 is open, the exhaust gas distributed into the exhaust chamber 1 can also flow further via the additional exhaust duct 28.

The combustion pistons 104-106 are connected to and drive a first crankshaft (not shown) onto which is arranged a first wheel 107. The exhaust piston 4 is connected to and driven by a second crankshaft (not shown) onto which is arranged a second wheel 108. A belt is arranged to connect the first and second wheels 107, 108 so that the first crankshaft can drive (rotate) the second crankshaft and thus the exhaust piston 4 via the two wheels 107, 108. A chain, gears, etc. may be used instead of a belt for operatively connecting the first and second crankshafts.

The size of the wheels are adapted so that the first wheel 107 drives the second wheel 108 at a ratio of 1.5, i.e. while the first crankshaft and first wheel 107 make two turns (720°, four strokes for one combustion cylinder) the second wheel 108 and the second crankshaft make three turns. During three turns the exhaust piston 4 oscillates three times between the lower dead centre to the top dead centre and back to the lower dead centre. The engine is arranged so that the four strokes of the combustion cylinders are evenly distributed in time, i.e. there are 720/3 = 240° between one stroke of a certain type, such as an exhaust stroke, of one of the combustion cylinders and the same type of stroke of the next combustion cylinder. Accordingly, there will be three strokes of each type during 720°. The driving ratio 1:1.5 thus allows the single exhaust cylinder to serve the three combustion cylinders in a similar way as described above for a 2+1 engine (where the driving ratio is 1:1).

The first wheel 107 has in this example a structure principally similar to variable cam phasers that are used to change the phase of camshafts. The principal structure of the first wheel 107 is thus known as such and is not further described here. In this case that principal structure is used for a different purpose, namely to allow phase shift between the first and second crankshafts (via the first and second wheels 107 and 108).

Figures 14-18 show the flow of exhaust gas from the engine according to figure 13 at certain different phase shifts. Figure “a” of these figures show a separated exhaust flow with black line for the three combustion cylinders and grey line for the single exhaust cylinder, and figure “b” of these figures show the combined exhaust to the turbo.

Figure 14a and 14b relates to 0° phase shift. The phase shift has been decreased by 60° for each figure.

As can be seen in figures 14a and 14b, the exhaust pulses have been evened out in a similar way as shown for the 2+1 engine in figures 10a and 10b. At 0° phase shift the exhaust piston 4 moves away from the exhaust chamber 1 (i.e. it moves downwards in the figure and expands the exhaust chamber 1) at the same time as one of the combustion cylinders performs an exhaust stroke with the combustion piston 104-106 moving upwards in the figure with its corresponding exhaust valve 112 open.

As can be seen in figures 16a and 16b, which show a phase shift of -120°, the exhaust peaks are produced at the same time and are positioned on top of each other (figure 16a) so as to produce largest possible combined peaks (figure 16b). At -120° phase shift the exhaust piston 4 moves towards the exhaust chamber 1 at the same time as one of the combustion cylinders performs an exhaust stroke. The effect is that the exhaust piston 4 increases the pressure of the exhaust gas that is forced out via the main exhaust duct 17.

Energy transfer from exhaust gas to the (turbine wheels) of the turbocharger is a function of exhaust flow mass flow rate and pressure difference before and after the turbine. For small exhaust mass flows it is generally an advantage if the flow comes in pulses because the turbine can handle pulses in small flows, and pulses give better pressure difference and enhanced energy transfer than constant flow. For large exhaust mass flows it is generally an advantage if the flow is constant (evened out). A pulsed large exhaust mass flow is not good as the turbine cannot handle the too high pressure at such a peak flow.

0° phase shift (figures 14a and 14b) gives a smooth flow to the turbine. This allows the turbine to handle a large flow and energy is absorbed by the exhaust piston and transferred to the crankshaft, which improves fuel economy.

-120° phase shift (figures 16a and 16b) gives sharp pulses. This transfers more energy to the turbine at small flows and is useful when extra boost is needed. The extra back pressure is not a problem at low airflow and the negative pressure in the valleys is helpful when extracting exhaust from the combustion cylinders, which is extra important when boost pressure has not yet been built up in the air intake manifold. In this scenario energy is transferred from the crankshaft to the exhaust piston and then to turbine.

Figure 19 shows a variant of a four-stroke engine with 4+1 cylinders. In principal the engine in figure 19 works in the same way as the engine shown in figure 13. A difference here is that the row of combustion cylinders contains an additional fourth combustion cylinder indicated by combustion chambers 201-204, combustion pistons 205-208 and channels 211-214 connecting each of the four combustion chambers 201-204 with the exhaust chamber 1 of the exhaust cylinder.

In similarity with figure 13, each combustion chamber 201-204 is provided with corresponding air inlet and exhaust valves, where the latter are capable of closing/opening the corresponding channel 211-214. Figure 19 shows only the air inlet valve 215 and the exhaust valve 216 associated with the “closest” combustion chamber.

The first wheel 209 (that is connected to a first crankshaft to which also the four combustion pistons 205-208 are connected) drives in this case the second wheel 210 (that is connected to a second crankshaft to which also the exhaust piston 4 is connected) at a ratio of 2 so as to allow one exhaust cylinder to serve four combustion cylinders. Thus, in this case the second crankshaft rotates two rounds and the exhaust piston 4 oscillates four times while the first crankshaft rotates two rounds (720°).

Also in this case the first wheel 209 has a structure principally similar to variable cam phasers to allow phase shift between the first and second crankshafts (via the first and second wheels 209 and 210).

Figures 20a and 20b show the flow of exhaust gas from the engine according to figure 23 at 0° phase shift. Figure 20a shows a separated exhaust flow with upper line for the four combustion cylinders and lower line for the single exhaust cylinder, and figure 20b shows the combined exhaust.

At a phase shift of 90° or -90° the pulses are located on top of each other in a similar way as 120° phase shift for the 3+1 engine (see figures 16a and 16b). This is useful for increasing the pressure difference at small flows as described above in relation to the 3+1 engine.

Figure 21 shows a free piston variant of a four-stroke engine with 3+1 cylinders, where the exhaust cylinder 4 is a free piston. Except for the driving mechanism for the exhaust piston 4 the engine in figure 21 is similar to the engine shown in figure 13. The three combustion pistons 104-106 are connected to a conventional crankshaft (without any wheel with phase shifting capabilities). The exhaust piston 4 is connected to a linear engine/generator.

Free piston engines and free pistons are known as such. A free-piston engine is a linear, 'crankless' internal combustion engine, in which the piston motion is not controlled by a crankshaft but by the interaction of forces from the combustion chamber gases, a rebound device (e.g., a piston in a closed cylinder where gas can be compressed, or another type of spring) and a load device (e.g. a gas compressor or a linear alternator).

The basic configuration of free-piston engines is commonly known as single piston, dual piston or opposed pistons, referring to the number of combustion cylinders. In this example, however, the free piston is used as an exhaust piston, not as a combustion piston. Advantages are that the free exhaust piston can absorb or give power to the exhaust pistons in the engines of interest and give great flexibility as it can phase shift and change stroke length, which can improve fuel efficiency or power from low to high rpm/workloads.

Figure 22 shows a free piston variant of a four stroke engine with 6+2 cylinders. This engine comprises six combustion cylinders arranged in two rows with three cylinders in each row. Only the closest cylinder/piston in each row is visible in figure 26. In line with what has been described above, each combustion cylinder comprises a combustion chamber and a combustion piston. The six combustion pistons are connected to a conventional crankshaft. Air inlet valves and exhaust valves are arranged in a similar way as described above for the other engine variants.

The exhaust cylinder comprises in this case a dual free exhaust piston connected to one common linear engine/generator. A first exhaust chamber is arranged on one side of the dual exhaust piston and a second exhaust chamber is arranged on the opposite side of the dual exhaust piston. A first side of the dual exhaust piston serves a first row of three combustion cylinders and a second side of the dual exhaust piston serves a second row of three combustion cylinders. First and second sets of channels connect each combustion chamber with its corresponding exhaust chamber.

The exhaust ducts etc. are also arranged in a similar way as described above.

The invention is not limited by the embodiments described above but can be modified in various ways within the scope of the claims.

CLAIMS

1. Internal combustion engine comprising:

- at least a first combustion cylinder provided with a first piston (5, 6, 104, 105, 106, 205, 206, 207, 208) arranged to move back and forth in an axial direction of the first combustion cylinder;

- a first combustion chamber (2, 3, 101, 102, 103, 201, 202, 203, 204) associated with an end portion of the first cylinder, wherein a volume of the first combustion chamber varies with the position of the first piston;

- an arrangement for supplying air (11, 12, 16, 18, 24, 28, 29) and fuel to the first combustion chamber;

- a first inlet valve (7, 9, 113, 215) for controlling the flow of air to the first combustion chamber;

- a first exhaust valve (8, 10, 112, 216) for controlling the outflow of exhaust gas from the first combustion chamber;

- an exhaust duct (17) for leading away exhaust gas that has flown out from the first combustion chamber,

- a turbocharge arrangement (26, 27) for compressing air supplied to the engine, wherein the turbocharge arrangement comprises a turbine (26) arranged in fluid communication with the exhaust duct (17) so as to allow the turbine to be driven by the flow of exhaust gas,

c h a r a c t e r i z e d i n

that the engine further comprises:

- an exhaust cylinder provided with an exhaust piston (4) arranged to move back and forth in an axial direction of the exhaust cylinder,

- an exhaust chamber (1) associated with an end portion of the exhaust cylinder, wherein a volume of the exhaust chamber (1) varies with the position of the exhaust piston (4),

wherein the exhaust chamber (1) is arranged in fluid communication with the first combustion chamber (2, 3, 101, 102, 103, 201, 202, 203, 204) via a channel or opening (14, 15, 109, 110, 111, 211, 212, 213, 214) that can be closed by the first exhaust valve (8, 10, 112, 216), and wherein the exhaust chamber (1) is arranged in open fluid communication with the exhaust duct (17) via an exhaust duct inlet arranged in association with the end portion of the exhaust cylinder so that, during operation of the engine, exhaust gas exiting the first combustion chamber (2, 3, 101, 102, 103, 201, 202, 203, 204) when the first exhaust valve (8, 10, 112, 216) is open is allowed to distribute between the exhaust chamber (1) and the exhaust duct (17).

2. Internal combustion engine according to claim 1, wherein the engine is configured to be capable of moving the exhaust piston (4) in a direction away from the exhaust chamber (1) while the first exhaust valve (8, 10, 112, 216) is open.

3. Internal combustion engine according to claim 1 or 2, wherein the engine is configured to be capable of moving the exhaust piston (4) in a direction towards the exhaust chamber (1) while the first exhaust valve (8, 10, 112, 216) is open.

4. Internal combustion engine according to claim 2 and 3, wherein the engine is configured to allow phase shift between work cycles of the first combustion cylinder and the exhaust cylinder so that the exhaust piston (4) can be moved in a direction away from or towards the exhaust chamber (1) while the first exhaust valve (8, 10, 112, 216) is open depending on the mode of operation of the engine.

5. Internal combustion engine according to anyone of the above claims, wherein the engine comprises at least one further combustion cylinder provided with a further piston, a further combustion chamber, a further exhaust valve etc. in similarity with the first combustion cylinder, wherein the exhaust chamber (1) is arranged in fluid communication also with the further combustion chamber via the further exhaust valve so that, during operation of the engine, exhaust gas exiting also the further combustion chamber when

the further exhaust valve is open is allowed to distribute between the exhaust chamber (1) and the exhaust duct (17).

6. Internal combustion engine according to anyone of the above claims, wherein the first piston (5, 6, 104, 105, 106, 205, 206, 207, 208) is arranged onto a first crankshaft for driving the first piston and wherein the exhaust piston (4) also is arranged onto the first crankshaft for driving the exhaust piston (4).

7. Internal combustion engine according to anyone of claims 1-5, wherein the first piston (5, 6, 104, 105, 106, 205, 206, 207, 208) is arranged onto a first crankshaft for driving the first piston and wherein the exhaust piston (4) is arranged onto a second crankshaft for driving the exhaust piston (4).

8. Internal combustion engine according to claim 7, wherein the engine comprises a driving arrangement allowing the first crankshaft to drive the second crankshaft.

9. Internal combustion engine according to claim 8, wherein the driving arrangement for driving the second crankshaft comprises a wheel (107, 209) configured to allow phase shift between the first and second crankshafts

10. Internal combustion engine according to anyone of claims 1-5, wherein the exhaust piston (4) is a free piston driven by a linear actuator/generator.

11. Internal combustion engine according to anyone of the above claims, wherein a bypass channel is arranged to allow exhaust gas flowing through the exhaust duct (17) to bypass the turbine (26) of the turbocharge arrangement, wherein a first valve/flap (21) is arranged to control the distribution of the flow in the exhaust duct (17) between the turbine (26) and the bypass channel.

12. Internal combustion engine according to claim 11, wherein a bypass valve/flap (20) is arranged in the bypass channel to control the flow through the bypass channel.

13. Internal combustion engine according to anyone of the above claims, wherein the engine comprises an additional exhaust duct (28) having an inlet (19) arranged in the exhaust cylinder at a distance from the end portion of the exhaust cylinder so as to be open to and in fluid communication with the exhaust chamber (1) only when the exhaust piston (4) is at or close to its lower dead centre position.

14. Internal combustion engine according to claim 11 and 13, wherein a second valve/flap (22) is arranged to control the distribution of the flow in the additional exhaust duct (28) between the turbine (26) and the bypass channel.

15. Internal combustion engine according to claim 13 or 14, wherein a third valve/flap (23) is arranged in the additional exhaust duct (28) to control the flow through the additional exhaust duct (28).

16. Internal combustion engine according to claim 13, wherein the exhaust duct (17) is connected to a first inlet of the turbine (26) and wherein the additional exhaust duct (28) is connected to a second inlet of the turbine (26).

17. Internal combustion engine according to claims 11-16, wherein the turbo bypass channel is arranged to be in fluid communication with the exhaust duct (17) and the additional exhaust duct (28) upstream the turbine (26) via the first and second valves/flaps (21, 22), respectively.

18. Method for operating an internal combustion engine according to anyone of the above claims, said method comprising the step of:

- moving the exhaust piston (4) in a direction away from the exhaust chamber (1) while keeping the first exhaust valve (8, 10, 112, 216) open, or
- moving the exhaust piston (4) in a direction towards the exhaust chamber (1) while keeping the first exhaust valve (8, 10, 112, 216) open.

19. Method according to claim 18, further comprising the step of:
- shifting phase between work cycles of the first combustion cylinder and the exhaust cylinder so as to move the exhaust piston (4) in a direction away from or towards the exhaust chamber (1) while keeping the first exhaust valve (8, 10, 112, 216) open depending on the mode of operation of the engine.

20. Method for operating an internal combustion engine according to claims 11-17, wherein the method comprises the step of:
- moving the exhaust piston (4) in a direction away from the exhaust chamber (1) while keeping the first exhaust valve (8, 10, 112, 216) open; and
wherein the method further comprises one of the following steps:
- i) keeping all valves/flaps (20-23) open so that exhaust gas is allowed to flow through the turbo bypass channel or the turbine (26) via the exhaust duct (17) or the additional exhaust duct (28);
- ii) keeping all valves/flaps (20-23) closed so that exhaust gas is prevented from flowing through the turbo bypass channel and the additional exhaust duct (28) but allowed to flow through the exhaust duct (17) towards and into the turbine (26) via the first inlet thereof;
- iii) keeping the third valve/flap (23) open and the other valves/flaps (20-22) closed so that exhaust gas is prevented from flowing through the turbo bypass channel but allowed to flow through the exhaust duct (17) or the additional exhaust duct (28) towards and into the turbine (26) via corresponding first and second inlets; or
- iv) keeping the first, second third valves/flaps (21-23) open and the bypass valve/flap (20) closed so that exhaust gas is prevented from flowing through the turbo bypass channel but allowed to flow through the exhaust duct (17) or

the additional exhaust duct (28) towards the turbine (26) and further allowed to mix upstream the turbine (26) so that the combined flow of exhaust gas in the exhaust duct (17) and the additional exhaust duct (28) is allowed to distribute between the first and second inlets of the turbine (26).

21. Vehicle comprising an internal combustion engine arranged for propulsion of the vehicle, wherein the internal combustion engine is arranged according to anyone of claims 1-17.

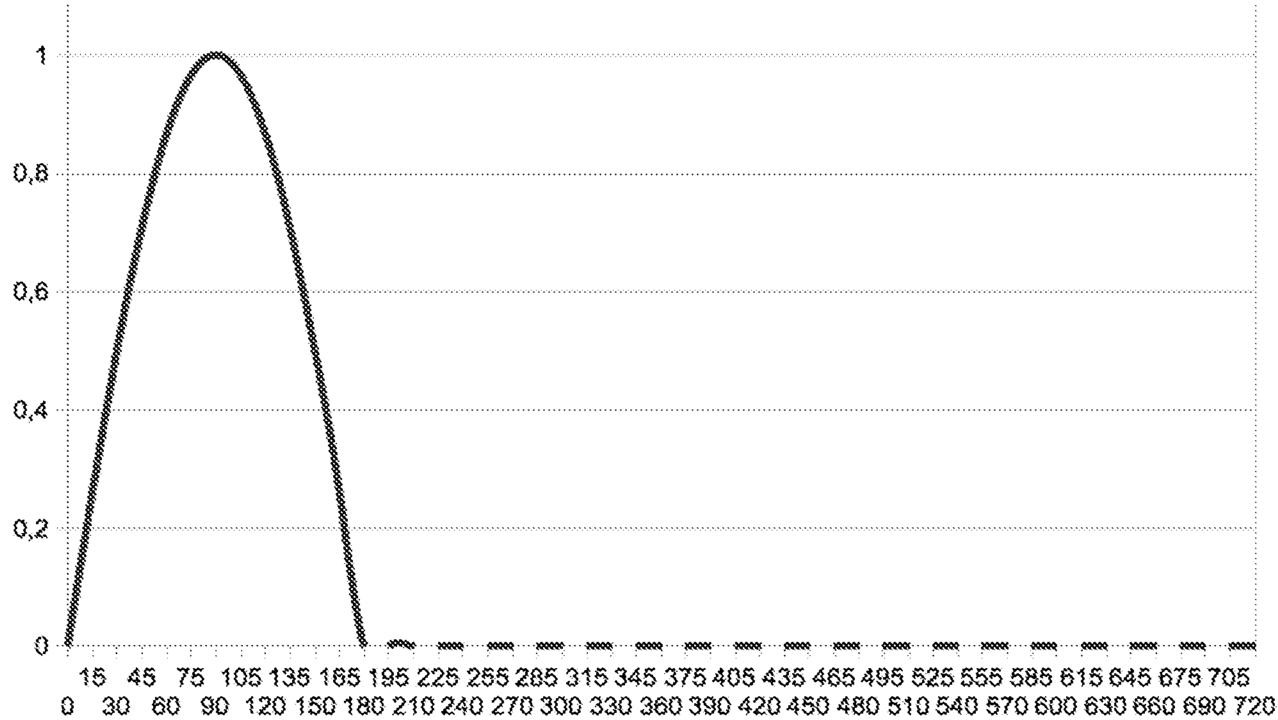

Figure 1: Exhaust flow from 4-stroke engine with 1 cylinder.

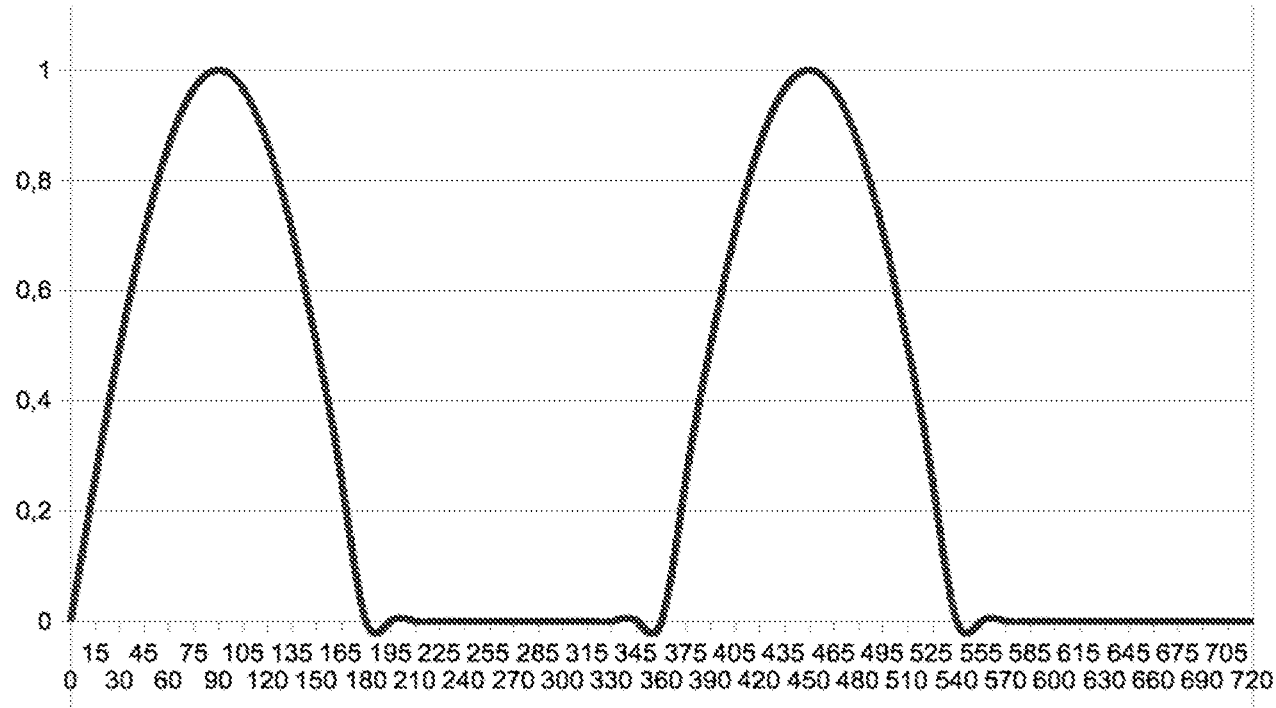

Figure 2: Exhaust flow from 4-stroke engine with 2 cylinders.

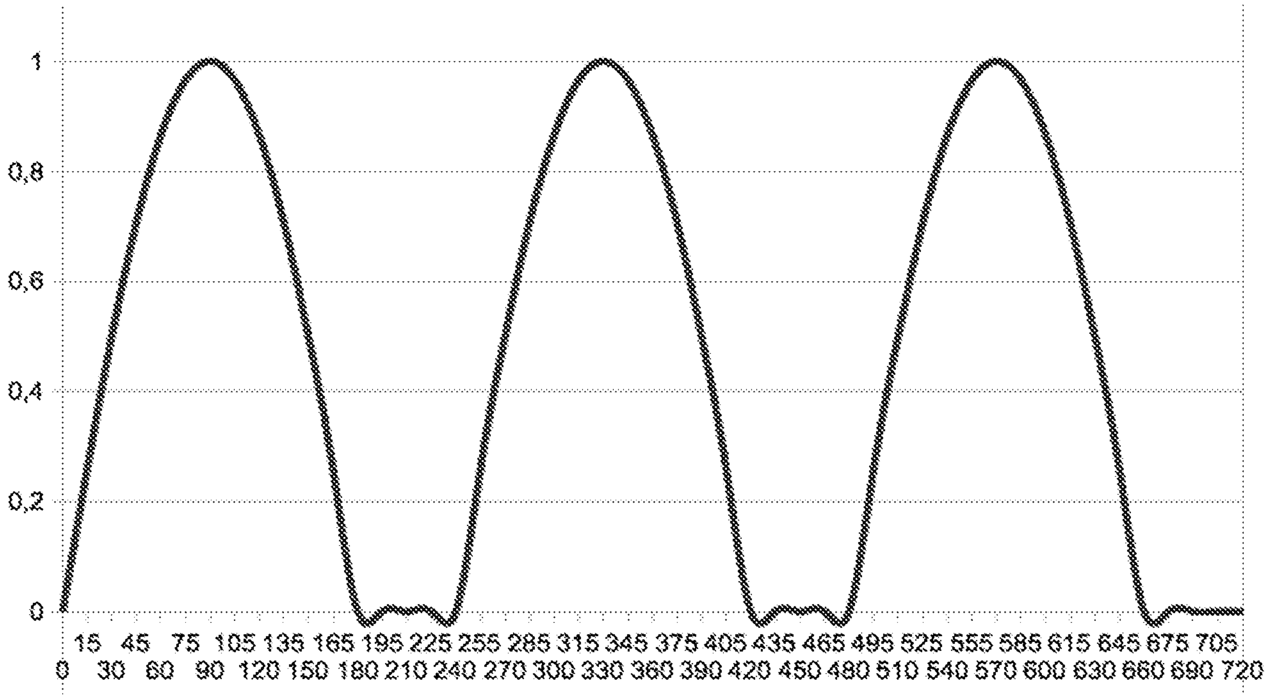

Figure 3: Exhaust flow from 4-stroke engine with 3 cylinders.

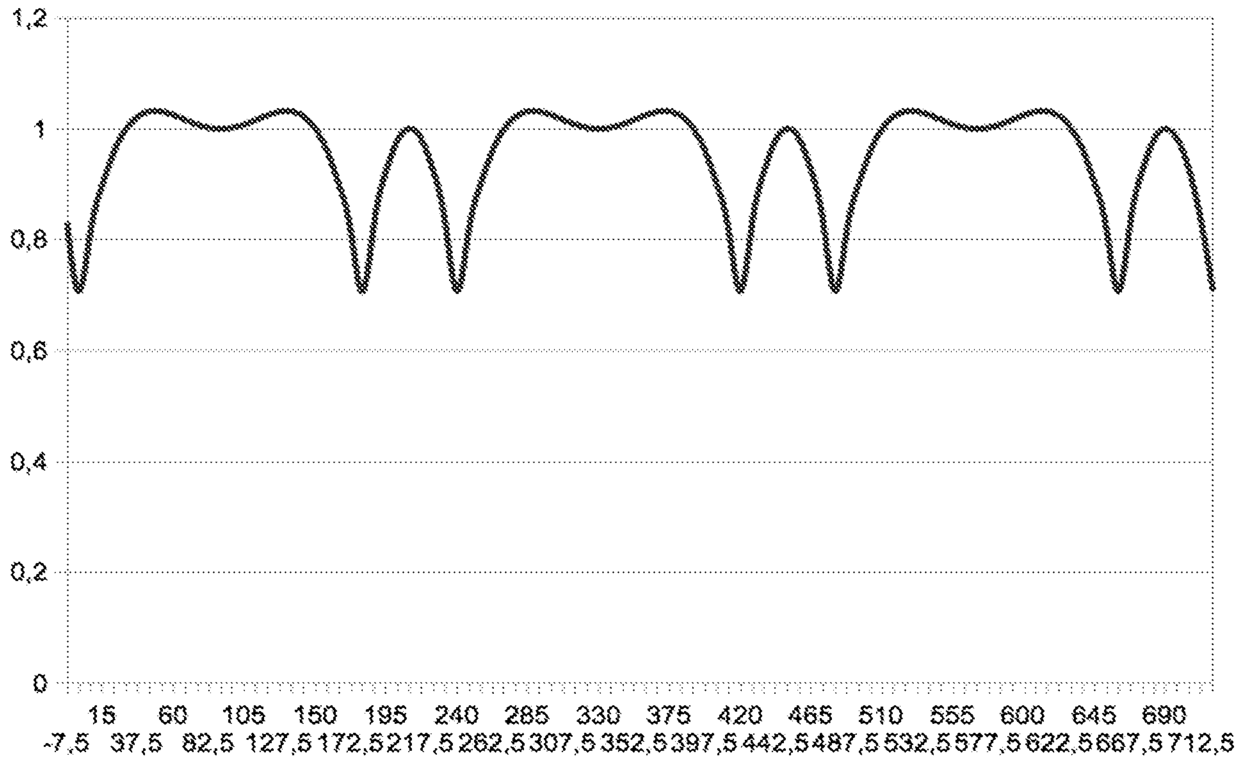

Figure 4: Exhaust flow 4-stroke engine with 3 cylinders + 1 exhaust cylinder

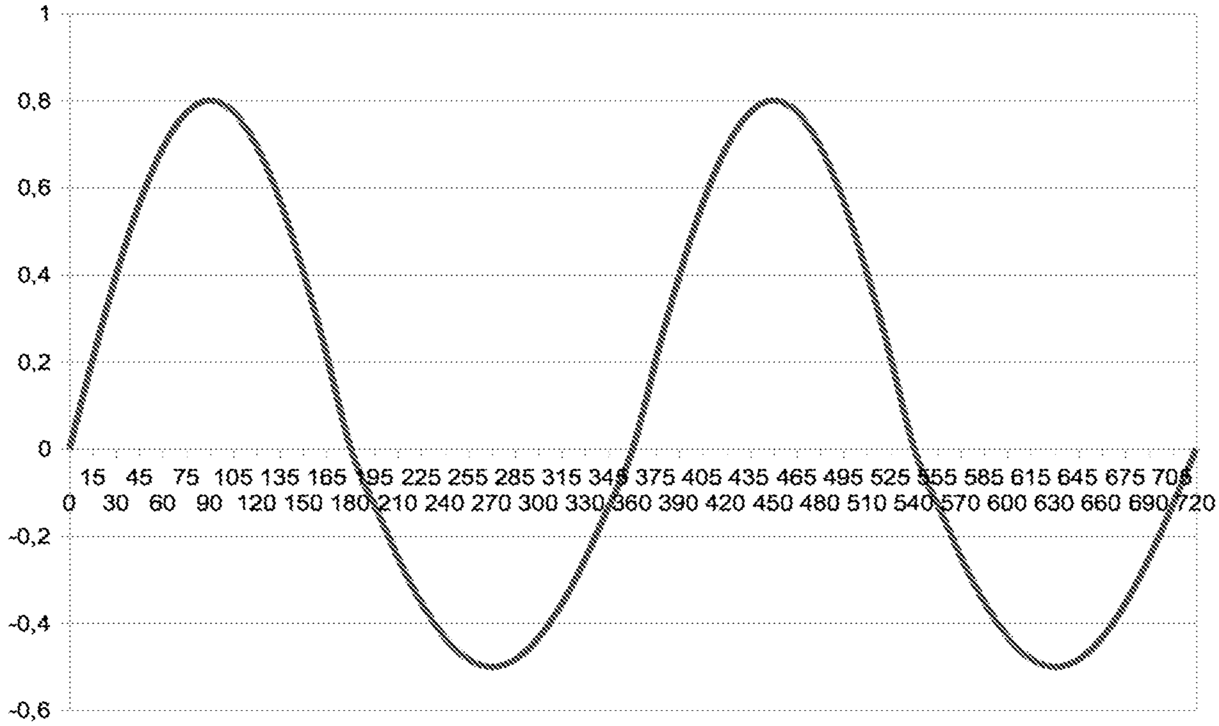

Figure 5: Torque 4-stroke engine 2 cylinders (estimated amplitude -0,5 to 0,8).

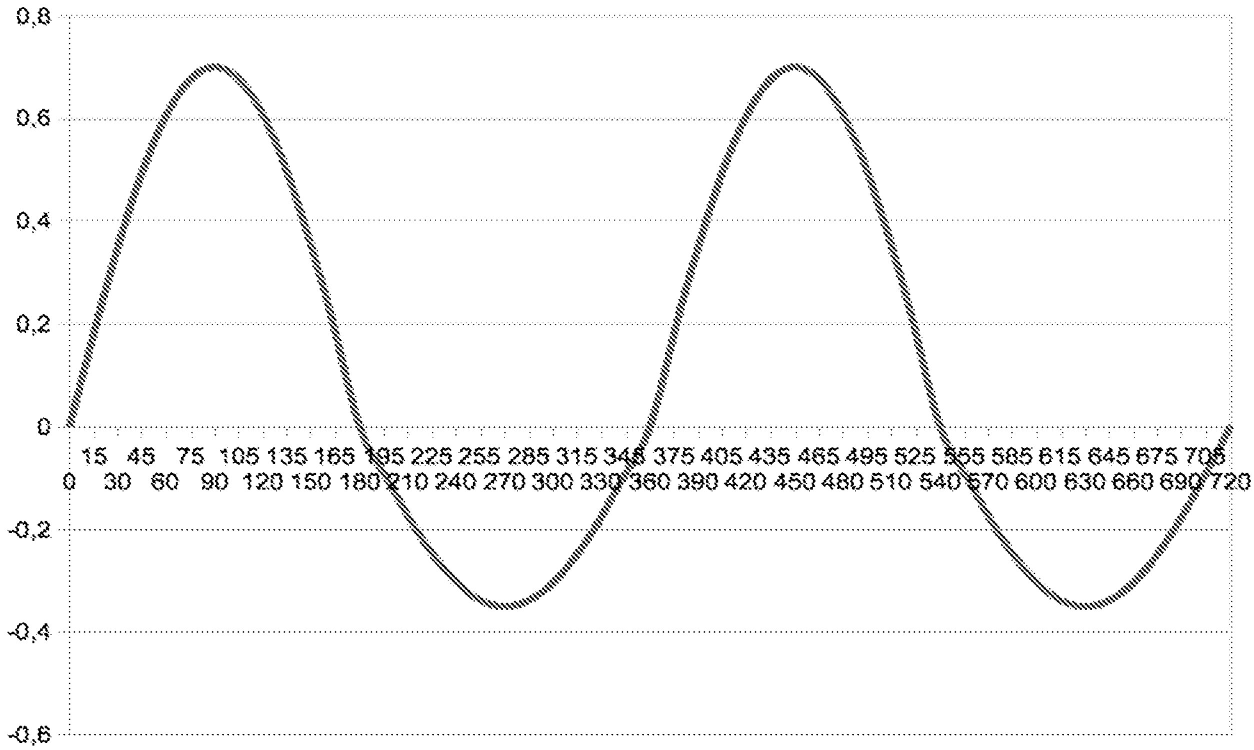

Figure 6: Torque 4-stroke 2 cylinders + exhaust cylinder (smaller amplitude -0,3 to 0,7)

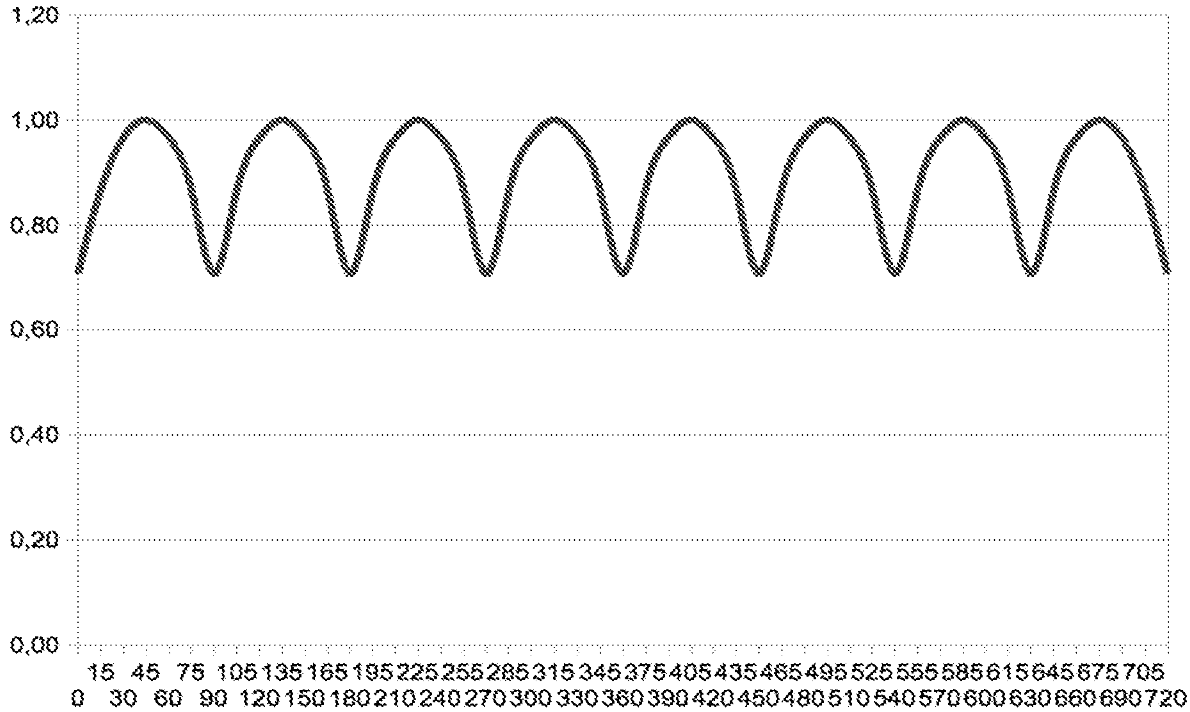

Figure 7: 2 cylinders + 1 exhaust cylinder + 1 further exhaust cylinder

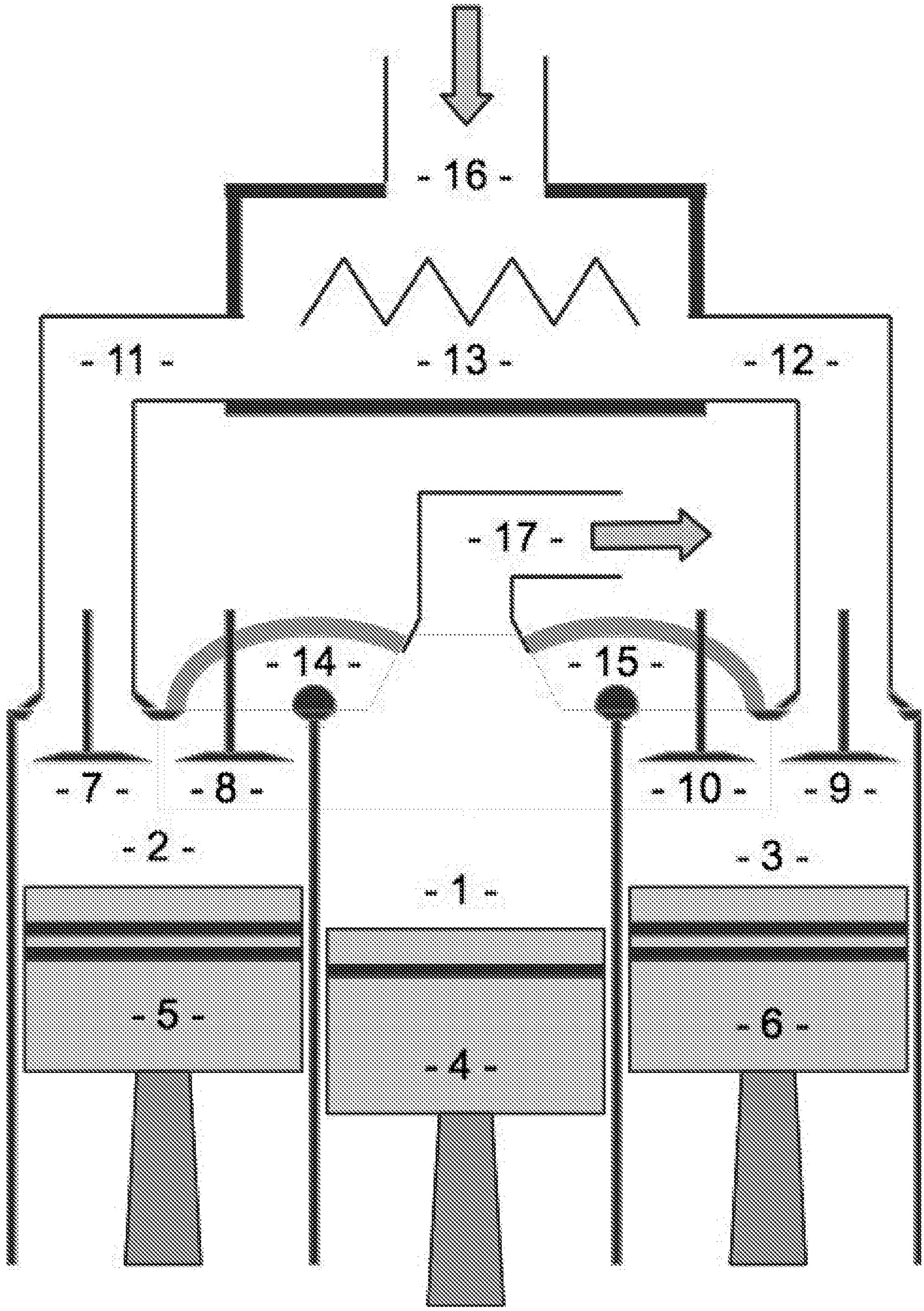

Figure 8: Basic layout 2 + 1 cylinder

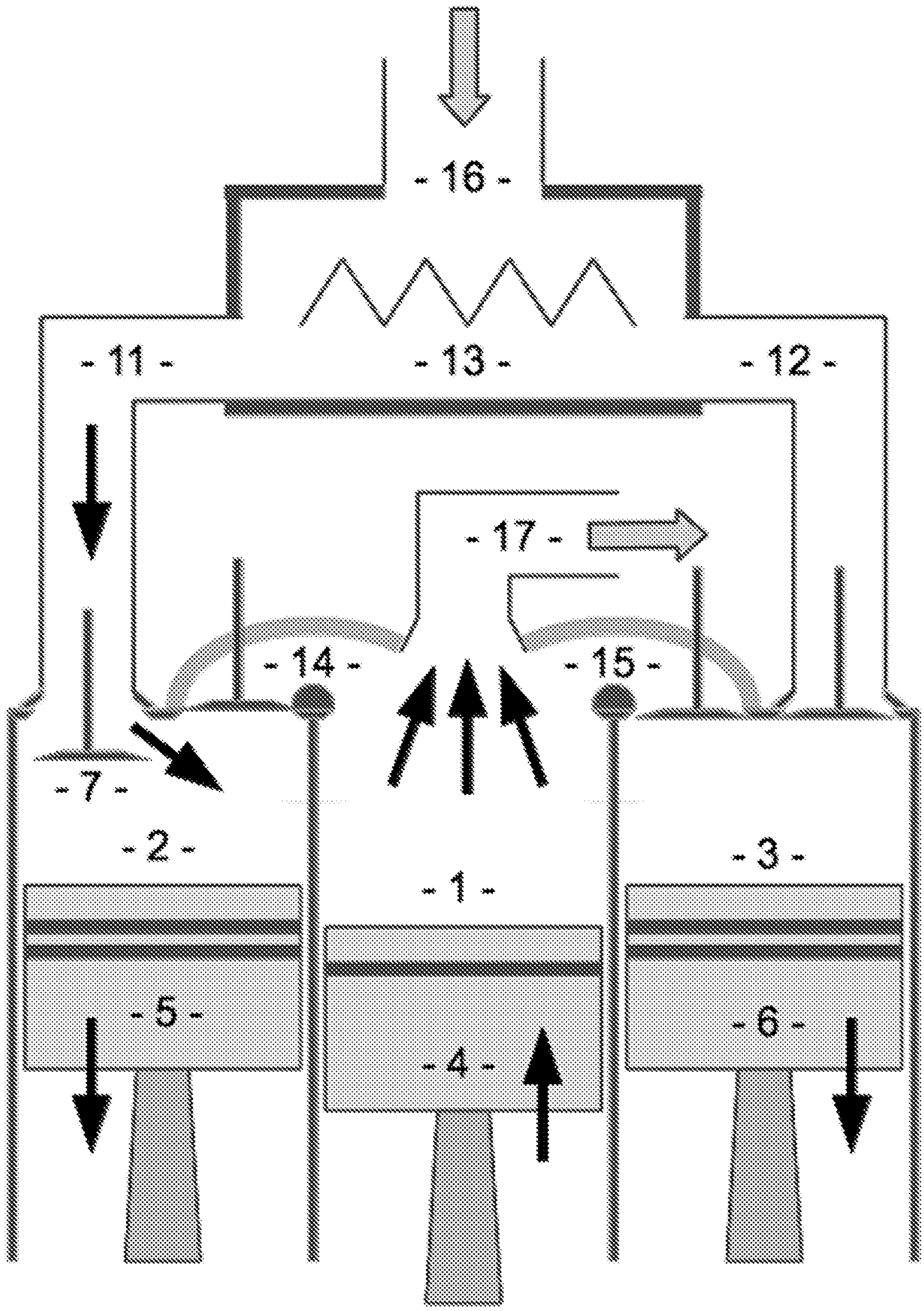

Figure 9a: 1:st stroke of 4 of design according to figure 8. Cylinder (1) venting remaining gases to the turbo. Cylinder (2) intake stroke. Cylinder (3) power stroke.

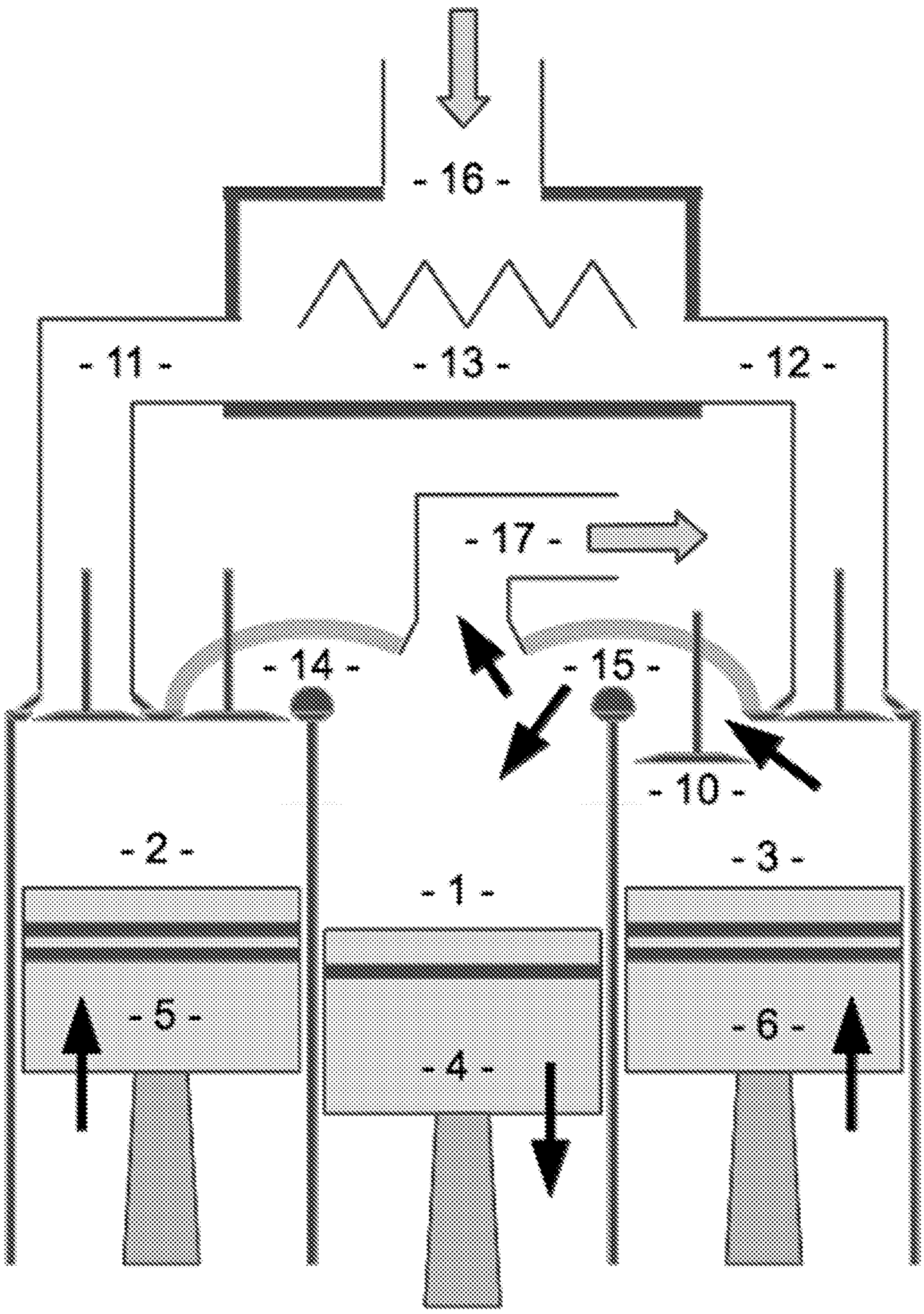

Figure 9b: 2:nd stroke of 4 of design according to figure 8. Cylinder (1) ca 50% of exhaust push piston (4), the rest is vented directly to turbo. Cylinder (2) compression stroke. Cylinder (3) exhaust stroke.

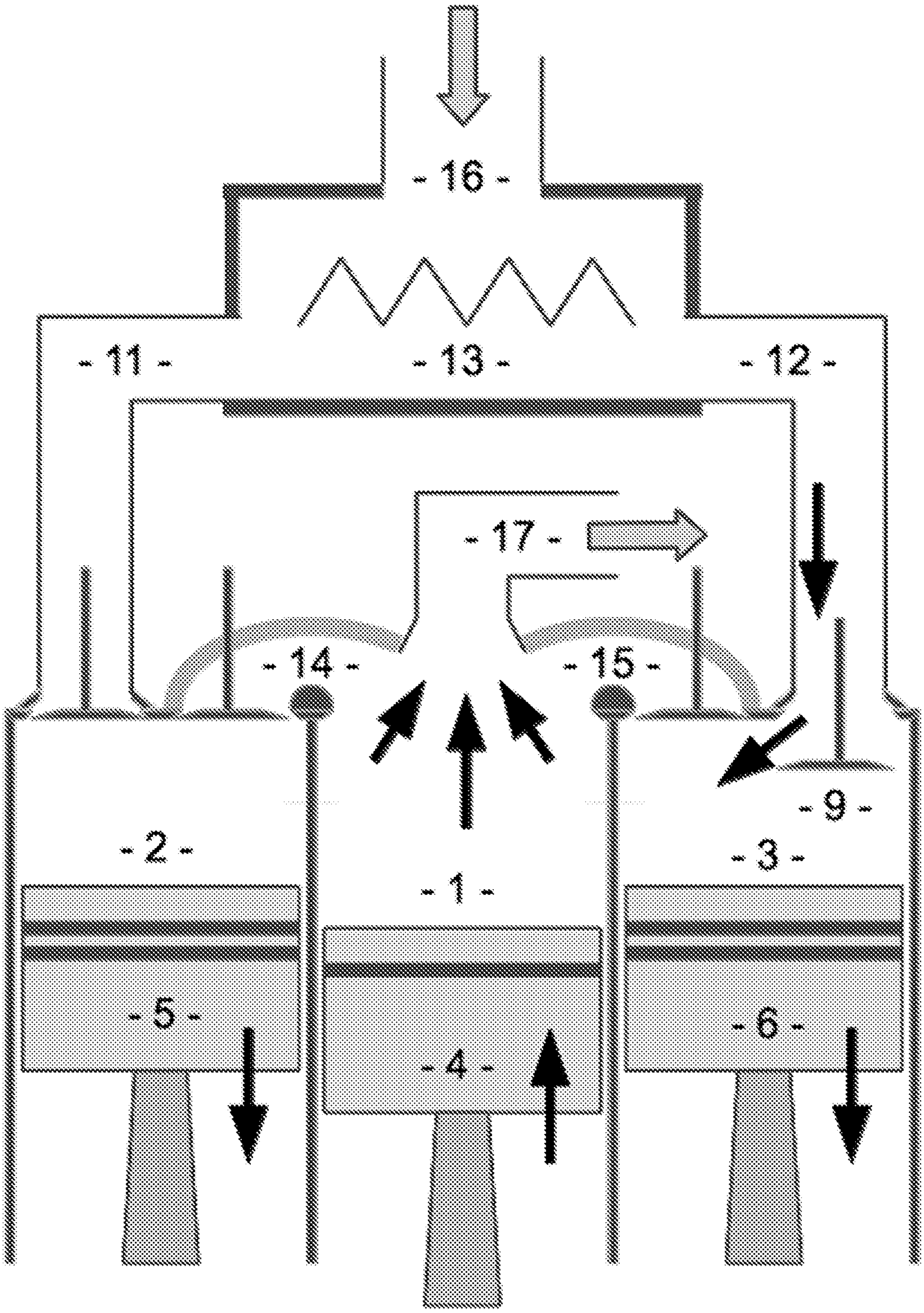

Figure 9c: 3:rd stroke of 4 of design according to figure 8. Cylinder (1) venting remaining gases to the turbo. Cylinder (2) power stroke. Cylinder (3) intake stroke.

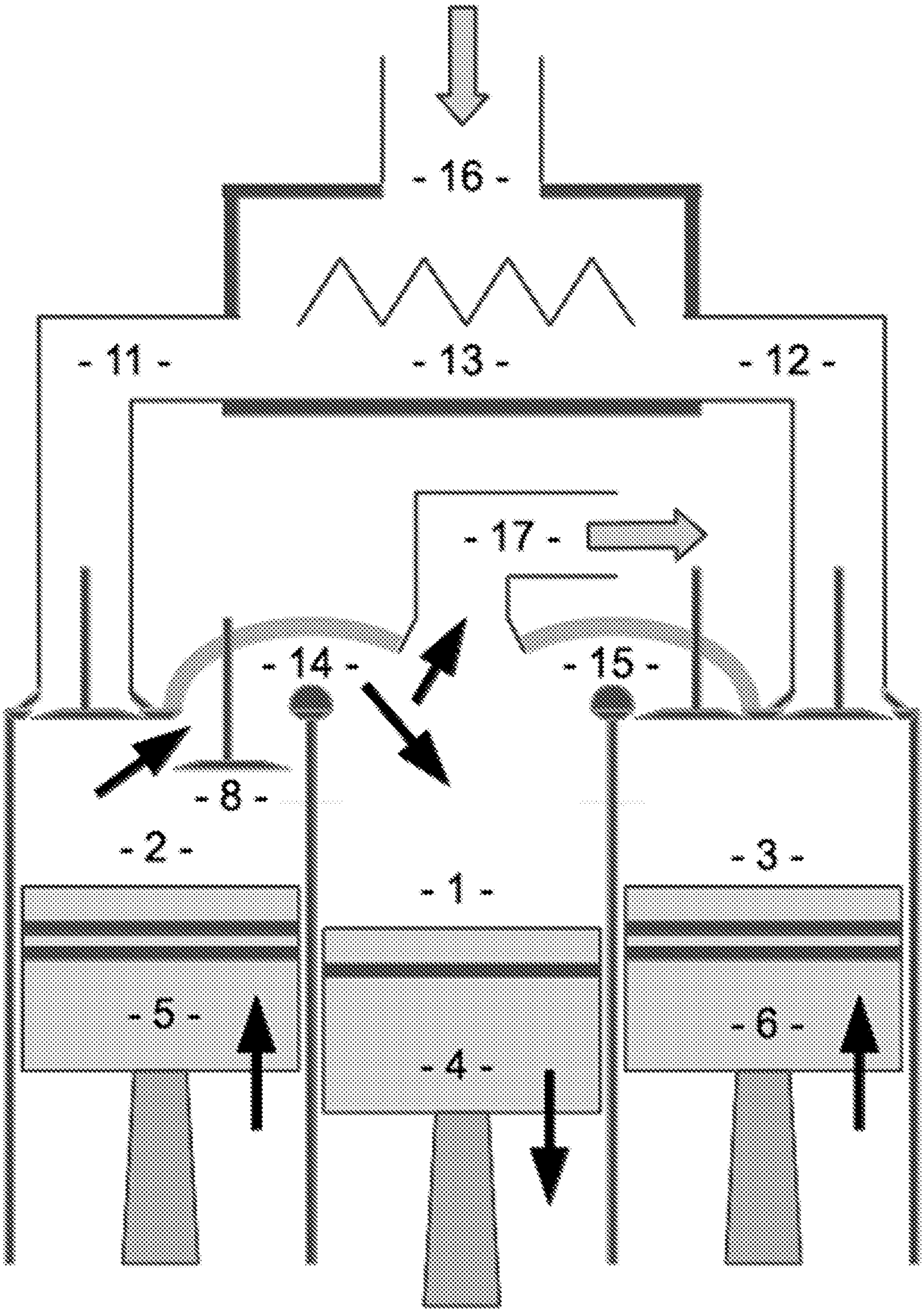

Figure 9d: 4:th stroke of 4 of design according to figure 8. Cylinder (1) ca 50% of exhaust push piston (4), the rest is vented directly to turbo. Cylinder (2) exhaust stroke. Cylinder (3) compression stroke.

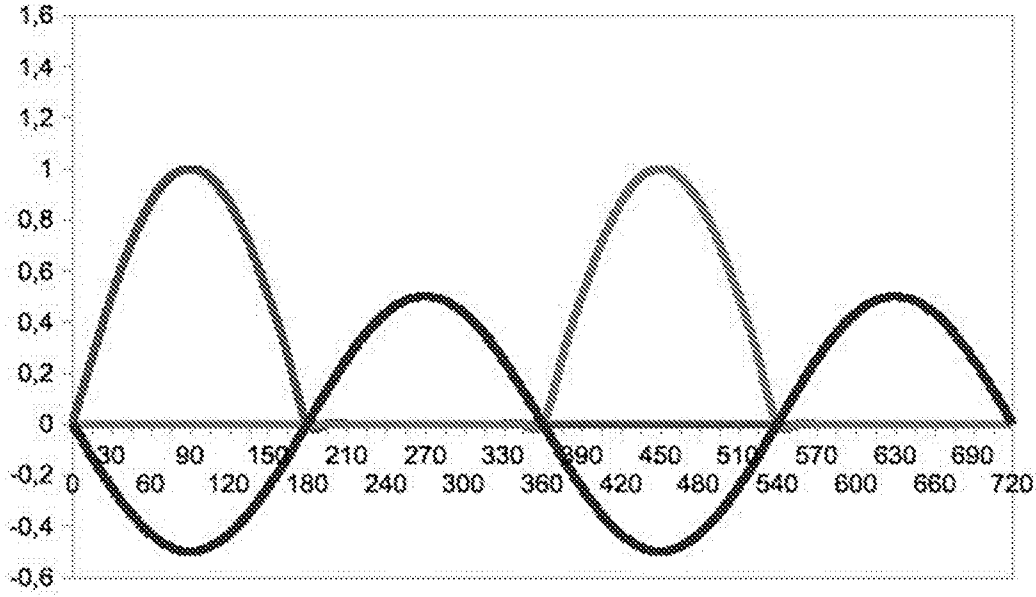

Figure 10a: Exhaust from design according to figure 8 (2 + 1 cylinder). Grey line – combustion cylinders. Black line – exhaust cylinder.

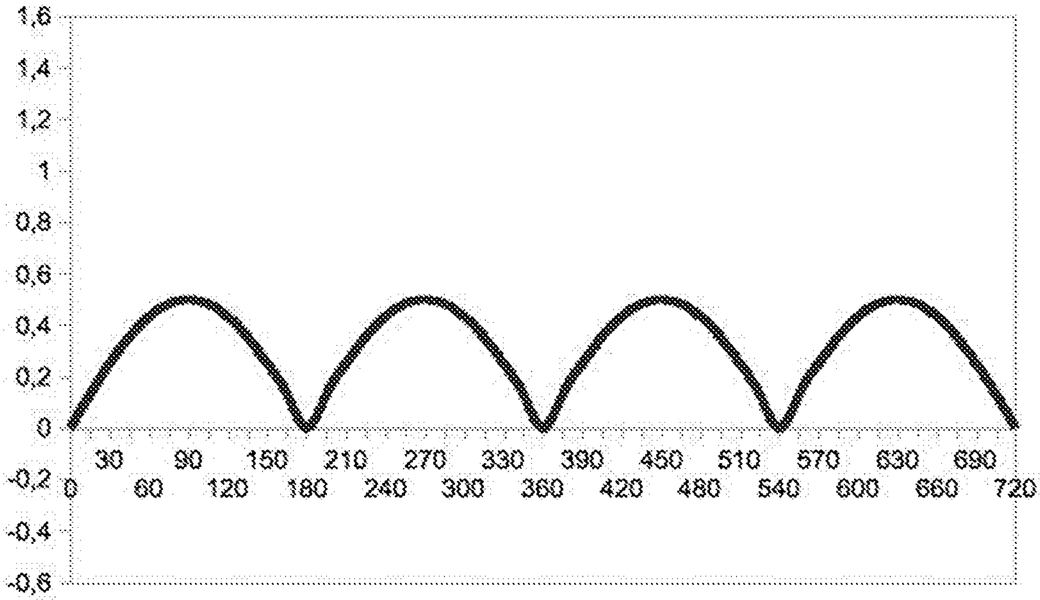

Figure 10b: Exhaust from design according to figure 8 (2 + 1 cylinder). Combined exhaust from combustion cylinders and exhaust cylinder.

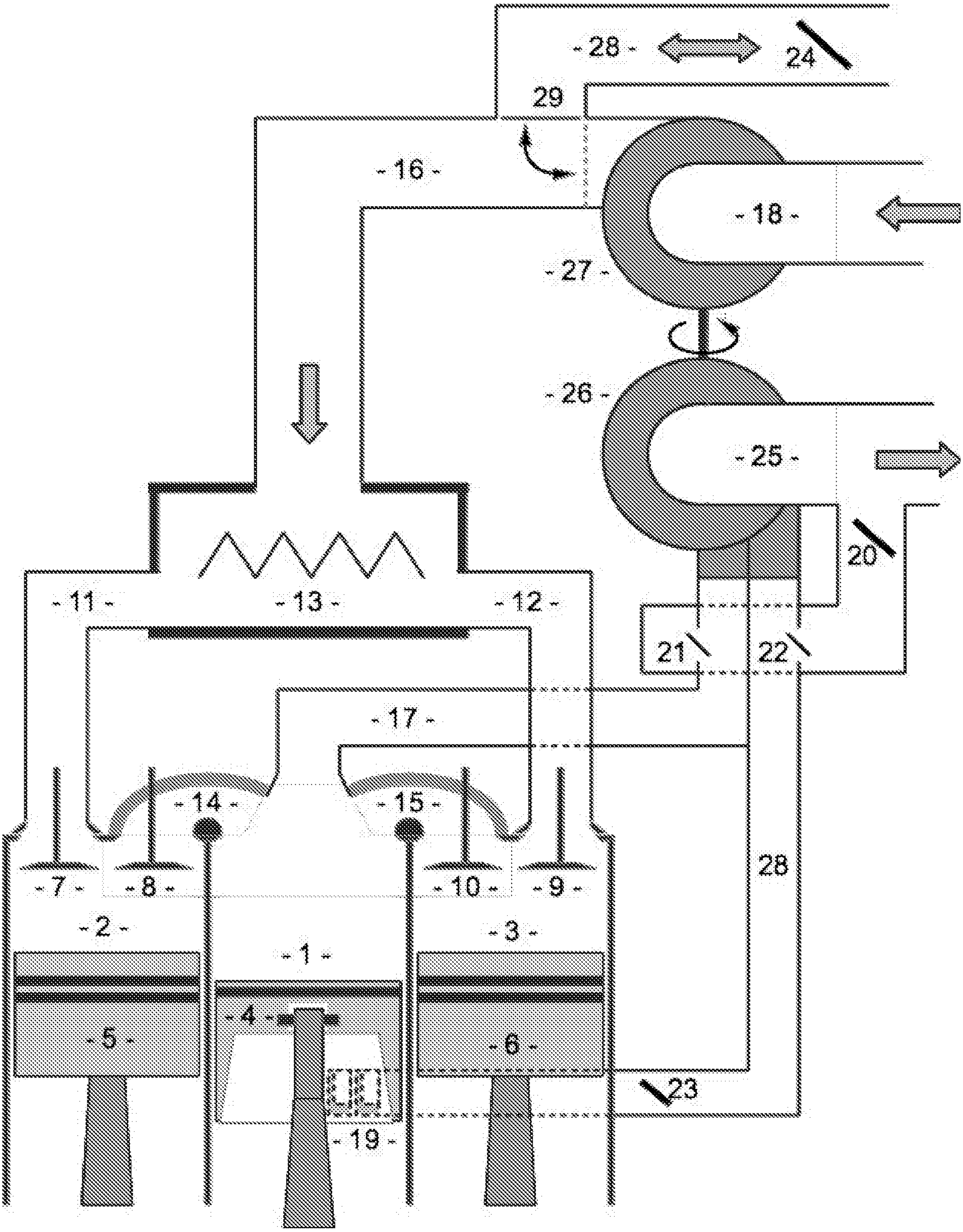

Figure 11: Variant of the design according to figure 8 (2 + 1 cylinder). This variant is adaptable to different rpm/workloads.

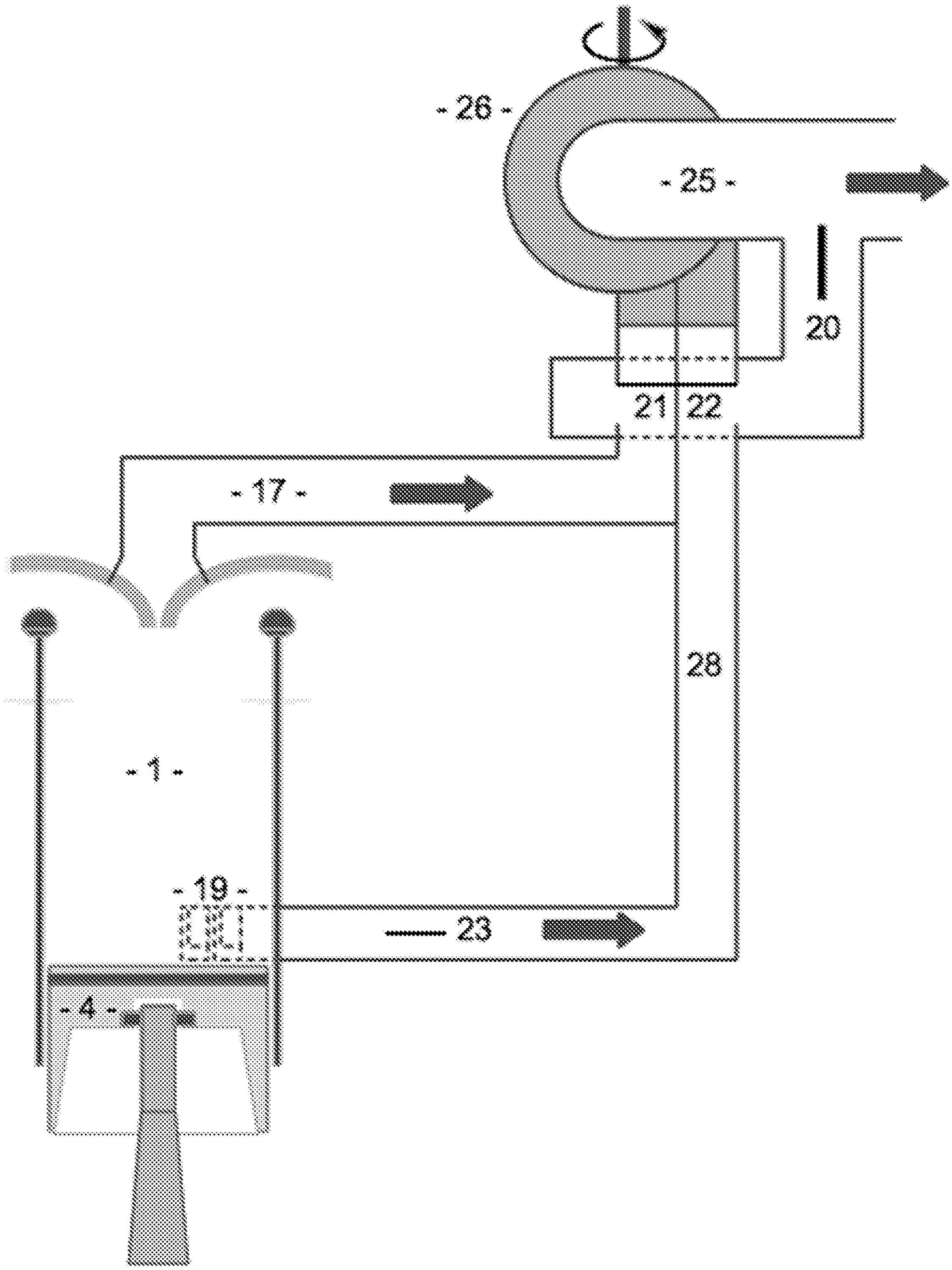

Figure 12a: Variant of figure 11 at idling conditions – no turbo. Valves 20, 21, 22 & 23 are open.

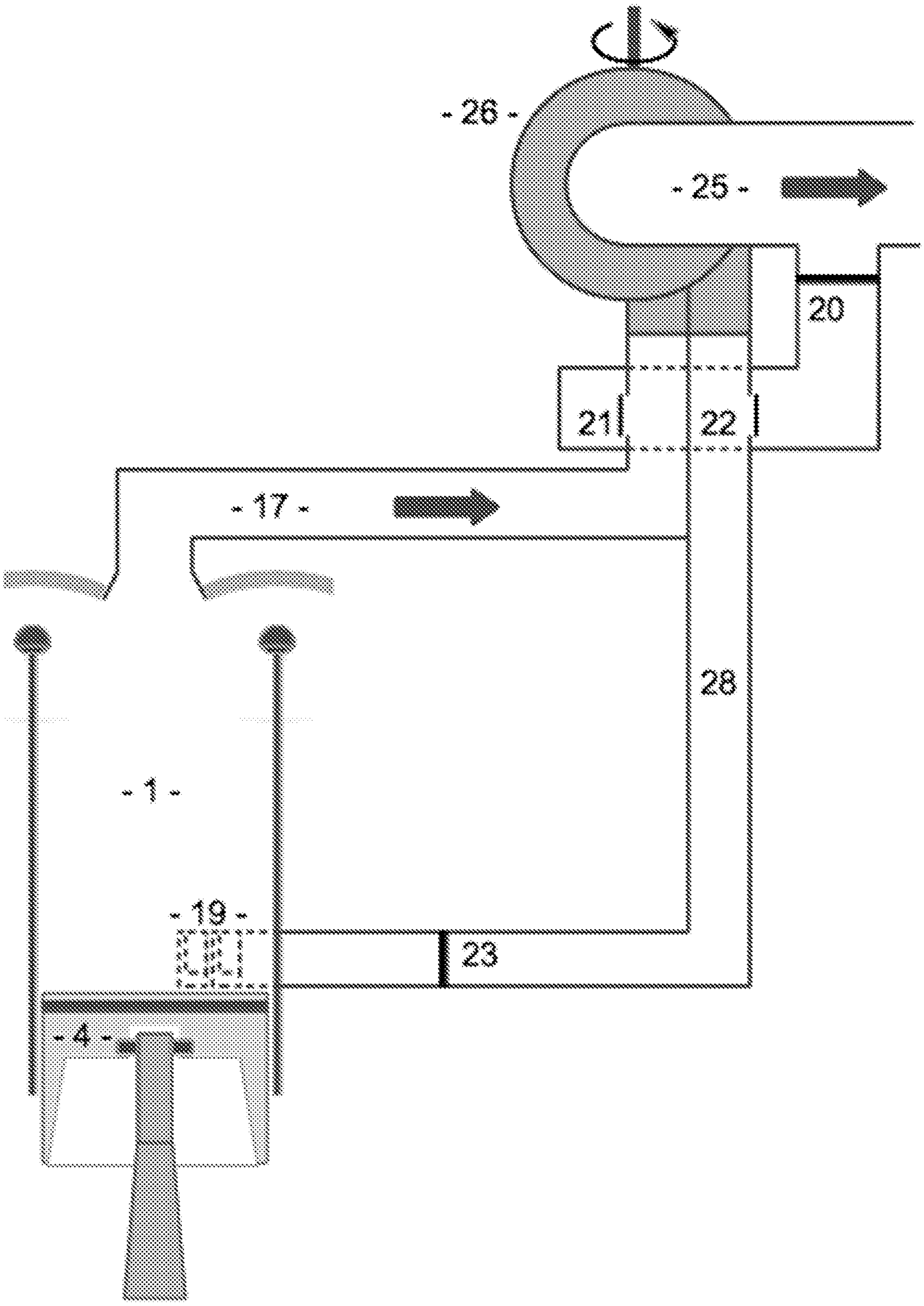

Figure 12b: Variant of figure 11 at low rpm/workload. Half of twin scroll turbo is used. Valves 20, 21, 22, 23 are closed.

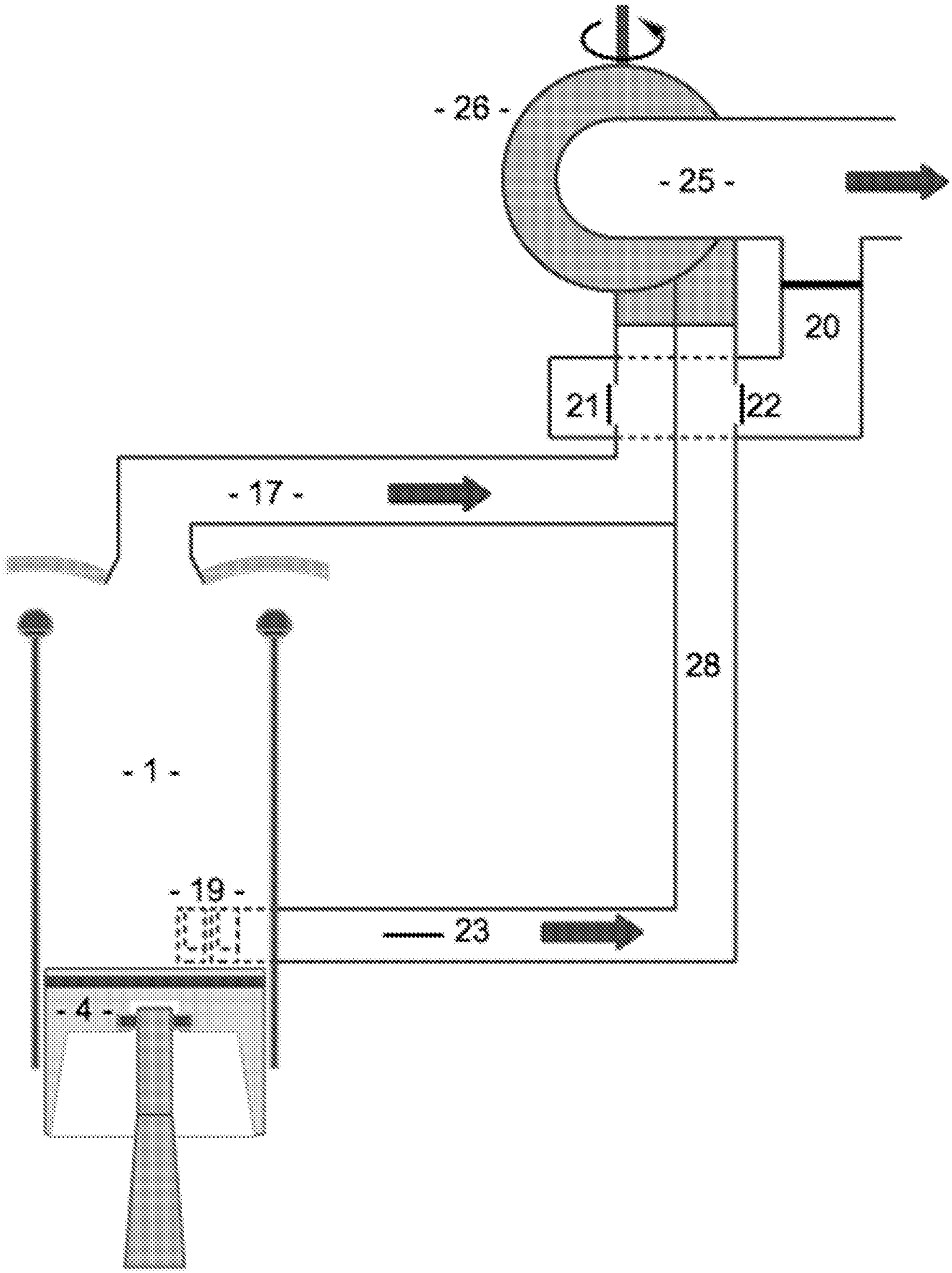

Figure 12c: Variant of figure 11 at medium rpm/workload. Twin scrolls in turbo are used. Valve 23 open, 20, 21 & 22 closed.

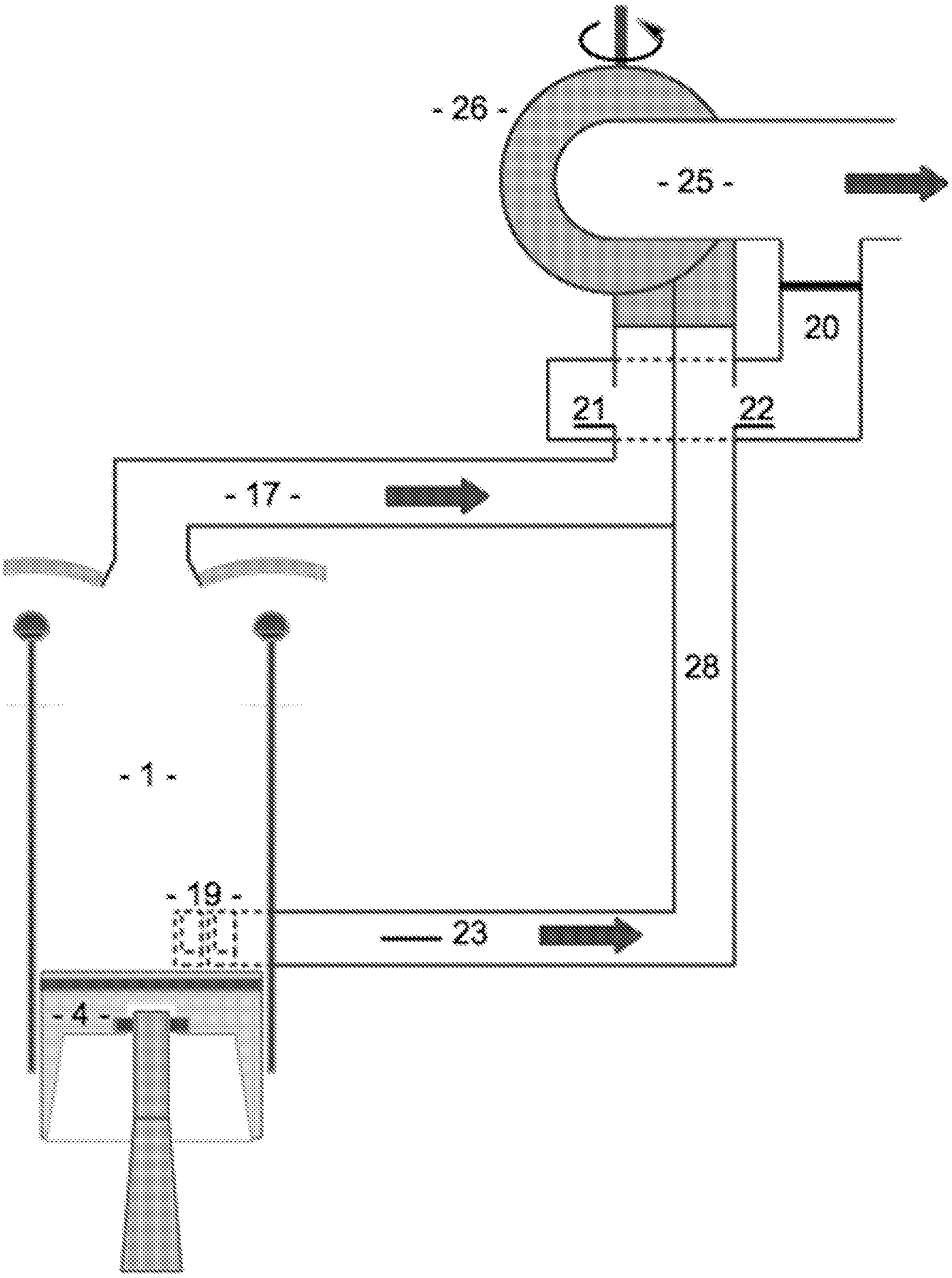

Figure 12d: Variant of figure 11 at high rpm/workload. Twin scrolls are used. Valves 21, 22, 23 open. Valve 20 closed.

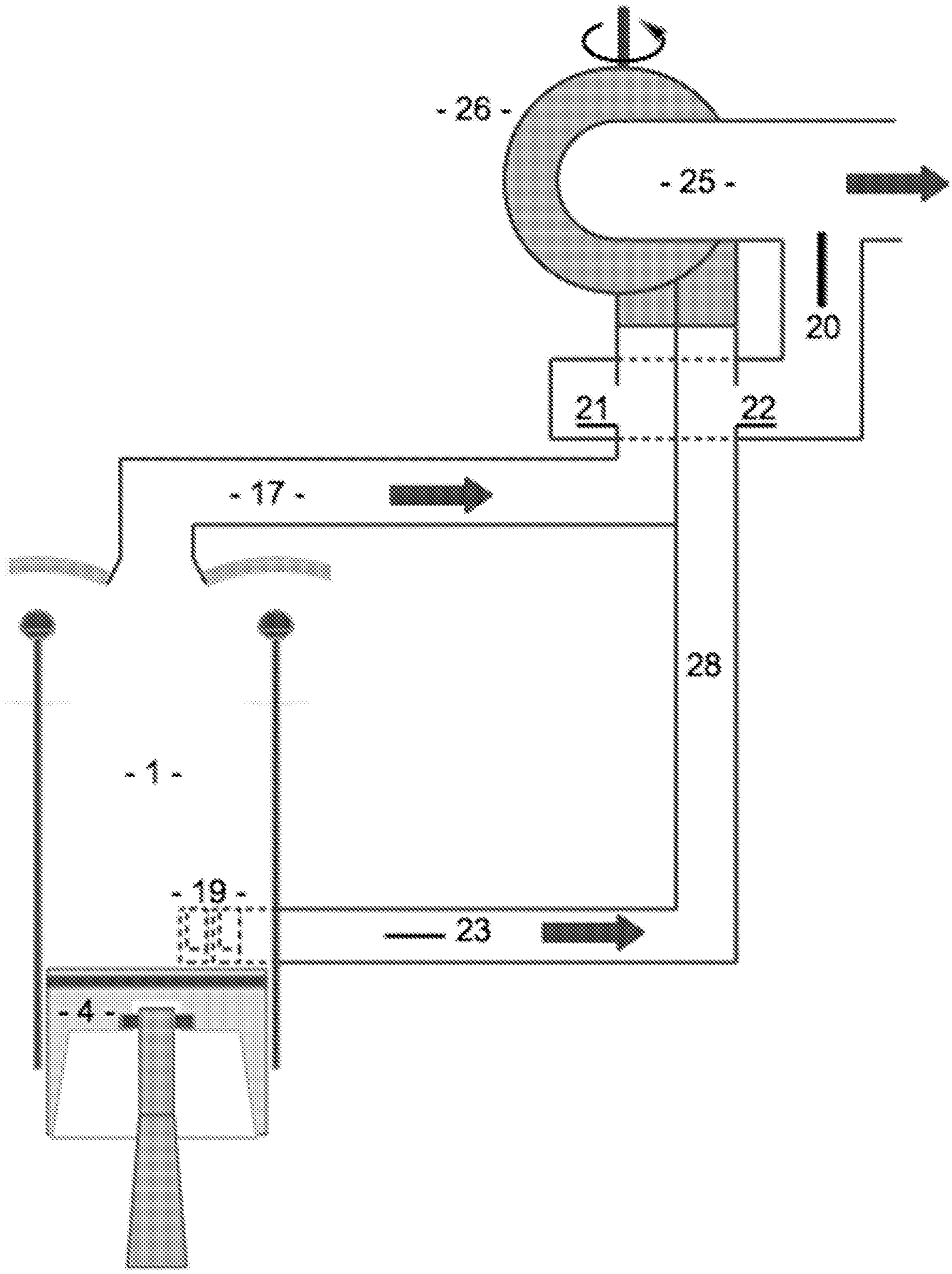

Figure 12e: Variant of figure 11 at overflow. Twin scrolls are used. Valves 20, 21, 22 & 23 open.

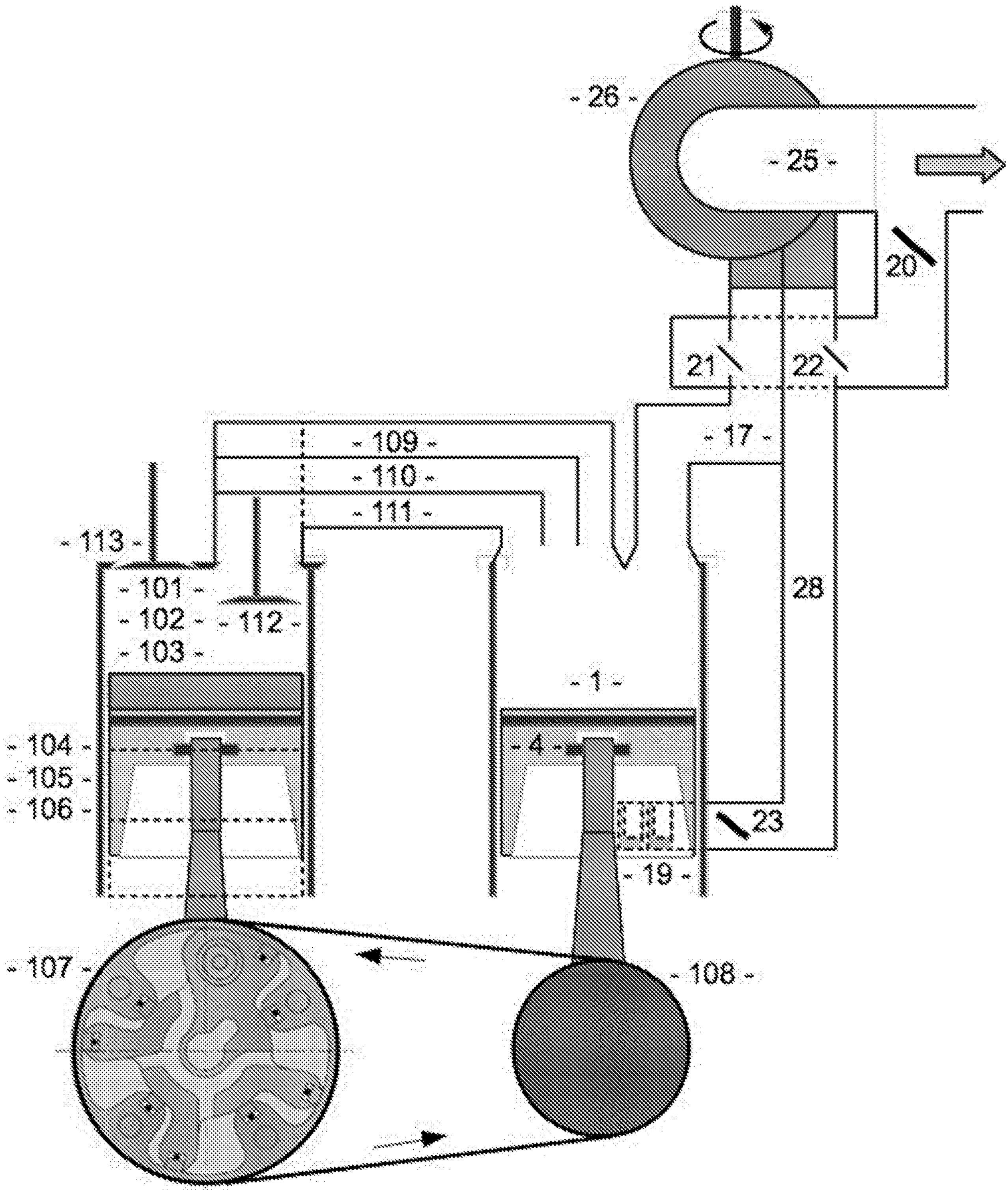

Figure 13: Variant with 3+1 cylinders. To the left are cylinders (101), (102) & (103), to the right is exhaust cylinder (1). Wheel (107) drives wheel (108) at a ratio of 1.5, to allow one exhaust cylinder to serve 3 combustion cylinders.

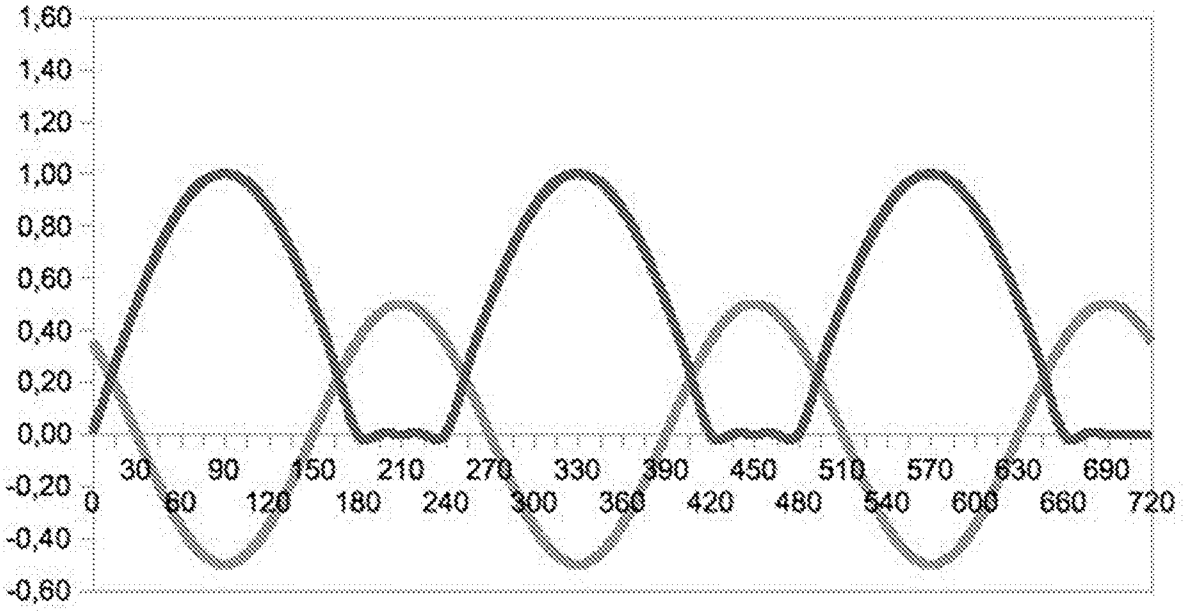

Figure 14a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift 0°. Black line – combustion cylinders. Grey line – exhaust cylinder.

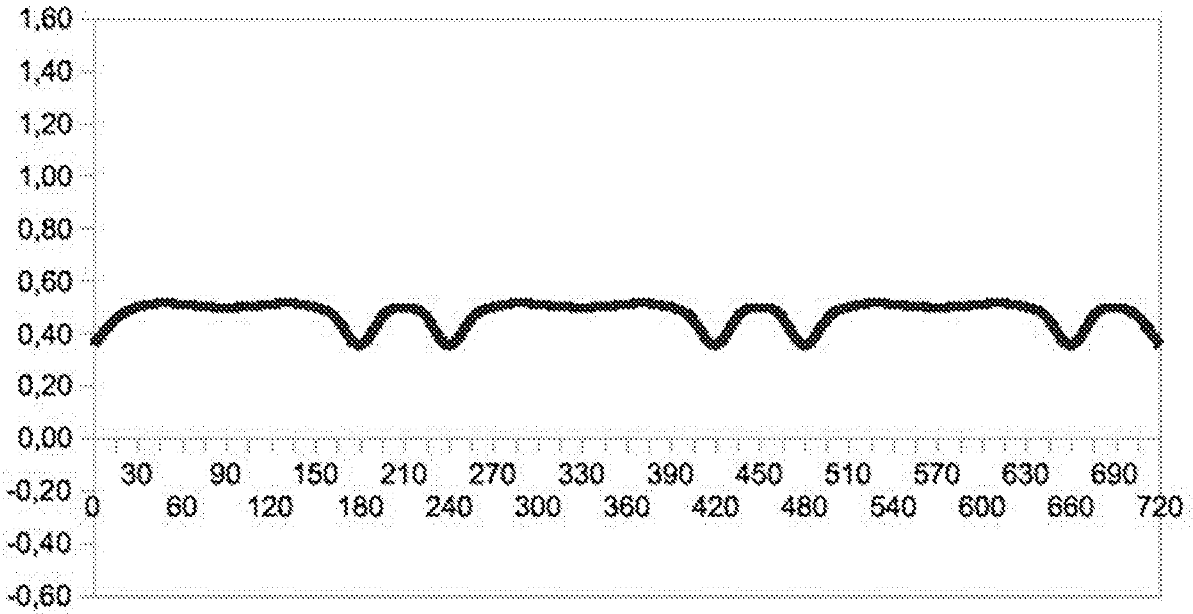

Figure 14b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift 0°. Combined exhaust from combustion cylinders and exhaust cylinder.

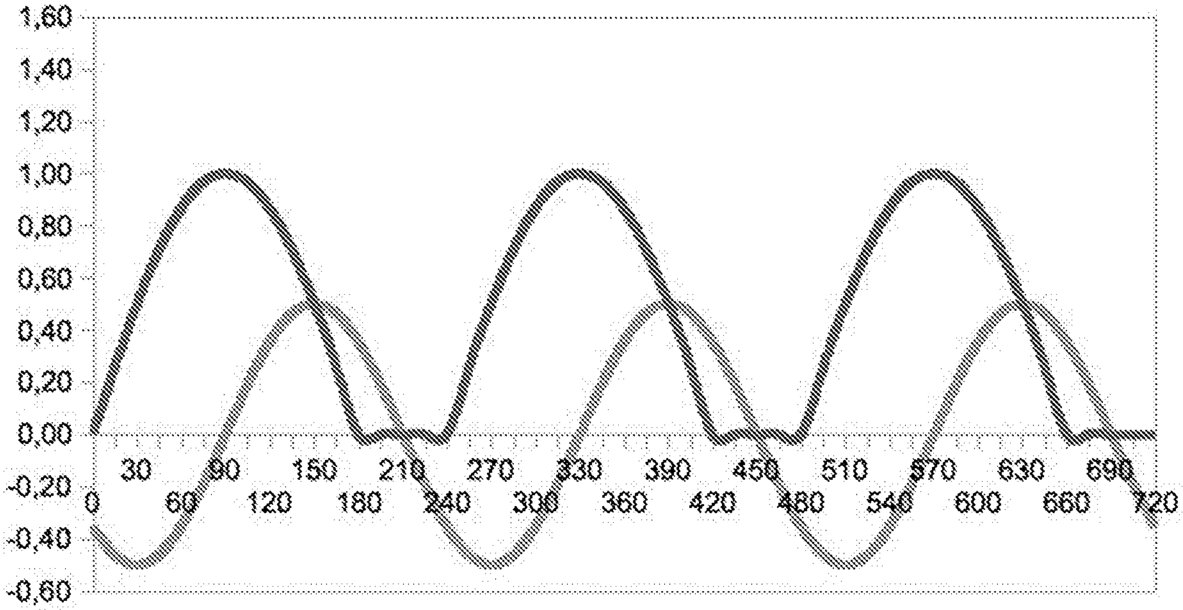

Figure 15a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -60°. Black line – combustion cylinders. Grey line – exhaust cylinder.

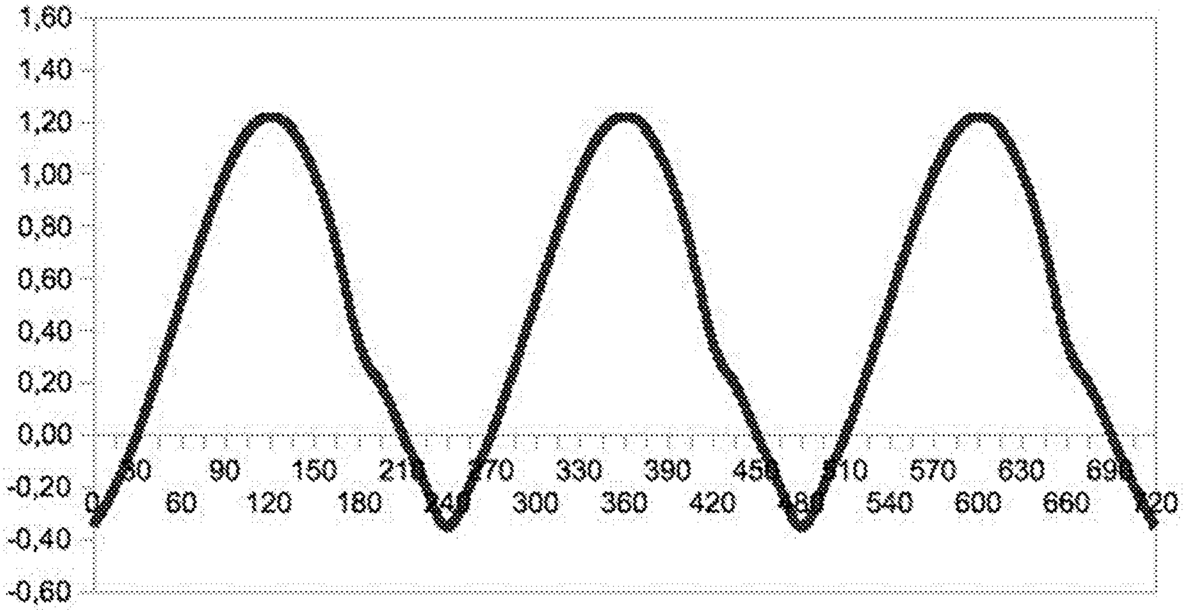

Figure 15b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -60°. Combined exhaust from combustion cylinders and exhaust cylinder.

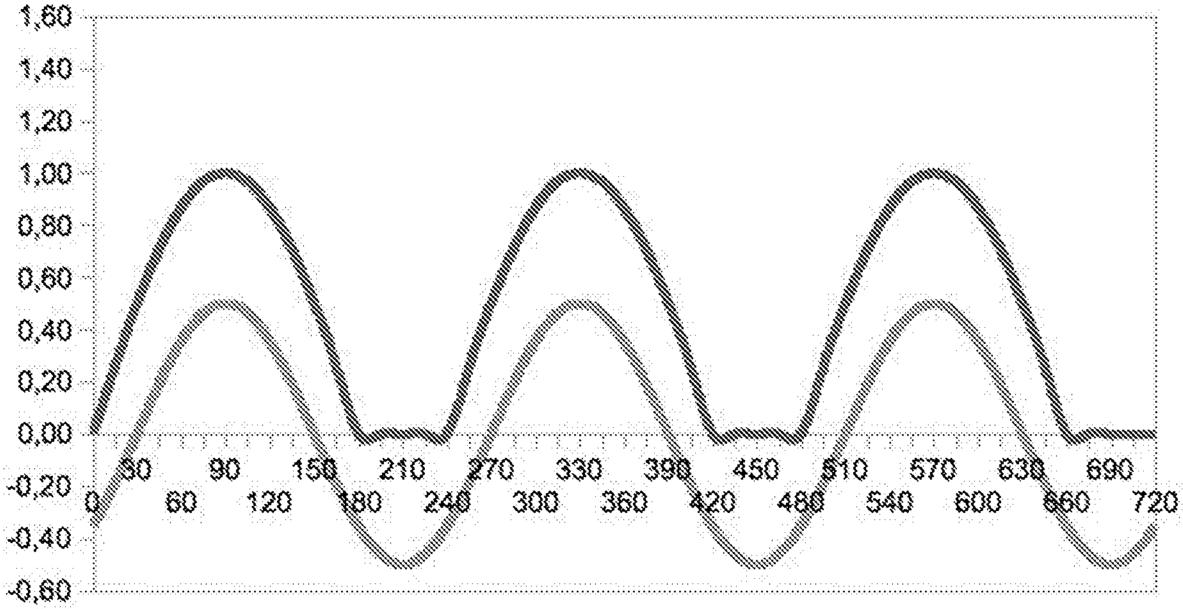

Figure 16a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -120°. Black line – combustion cylinders. Grey line – exhaust cylinder.

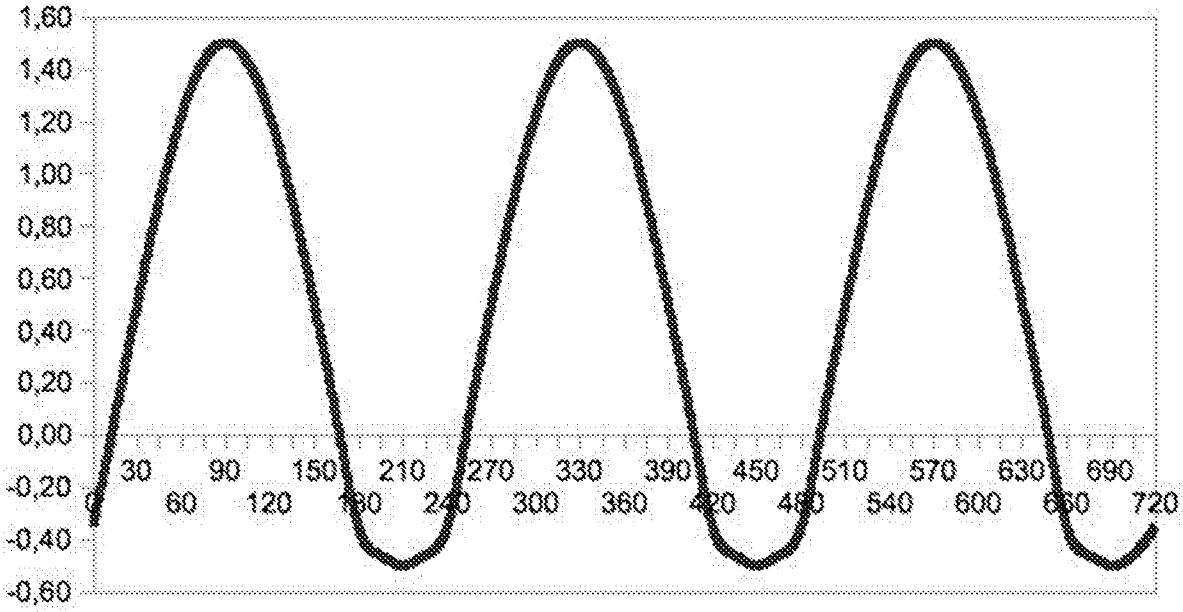

Figure 16b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -120°. Combined exhaust from combustion cylinders and exhaust cylinder.

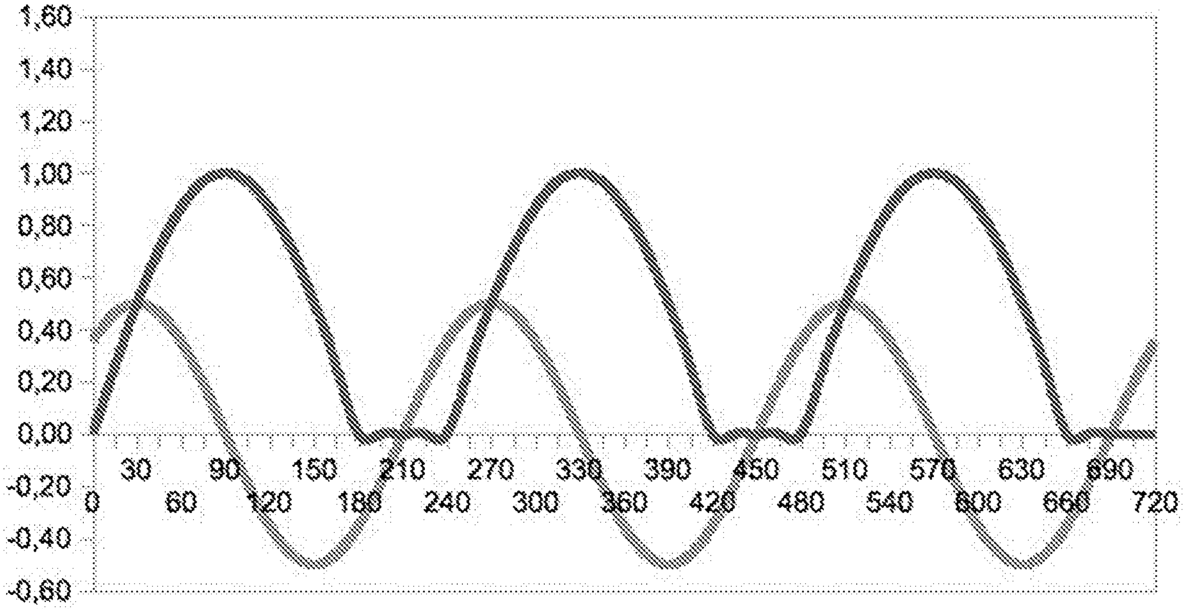

Figure 17a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -180°. Black line – combustion cylinders. Grey line – exhaust cylinder.

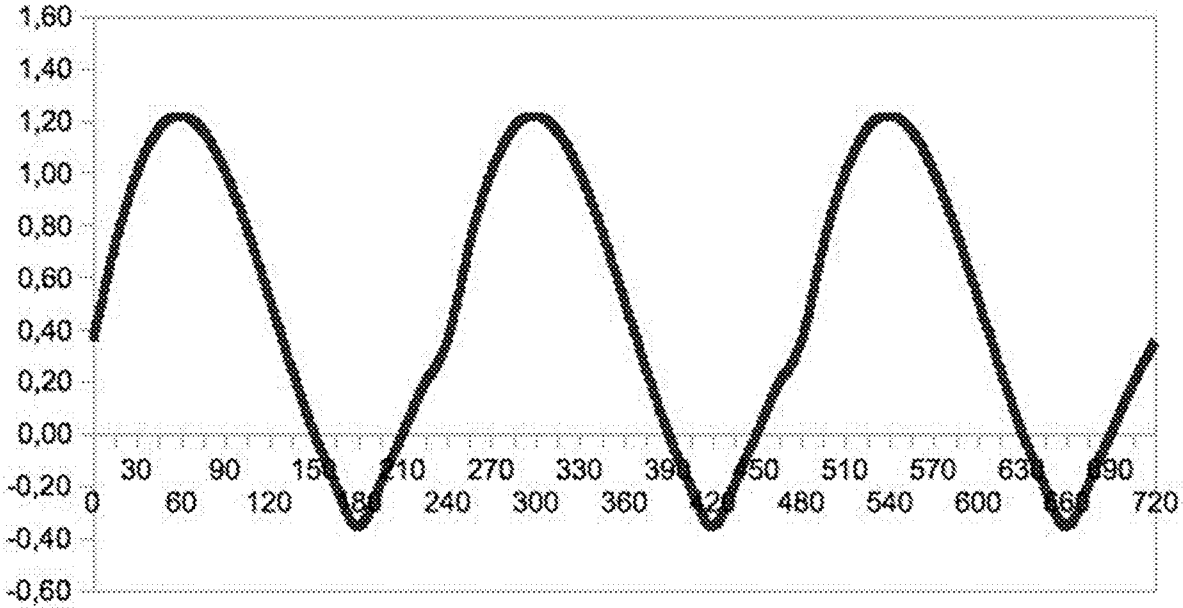

Figure 17b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -180°. Combined exhaust from combustion cylinders and exhaust cylinder.

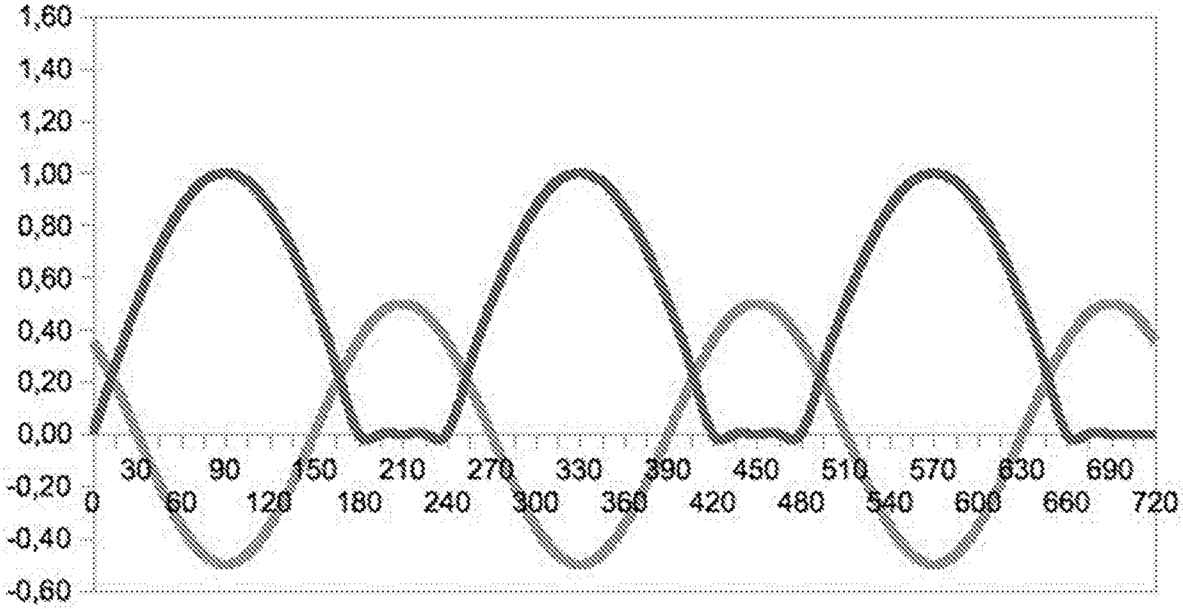

Figure 18a: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -240°. Black line – combustion cylinders. Grey line – exhaust cylinder.

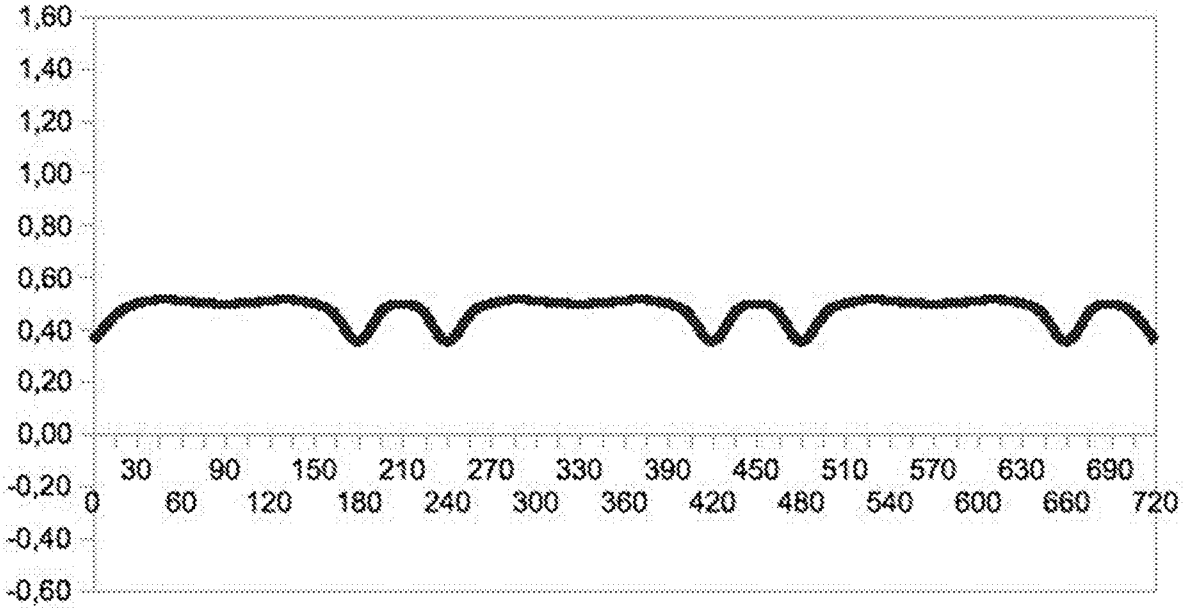

Figure 18b: Exhaust from design according to figure 13 (3 + 1 cylinder) at phase shift -240°. Combined exhaust from combustion cylinders and exhaust cylinder.

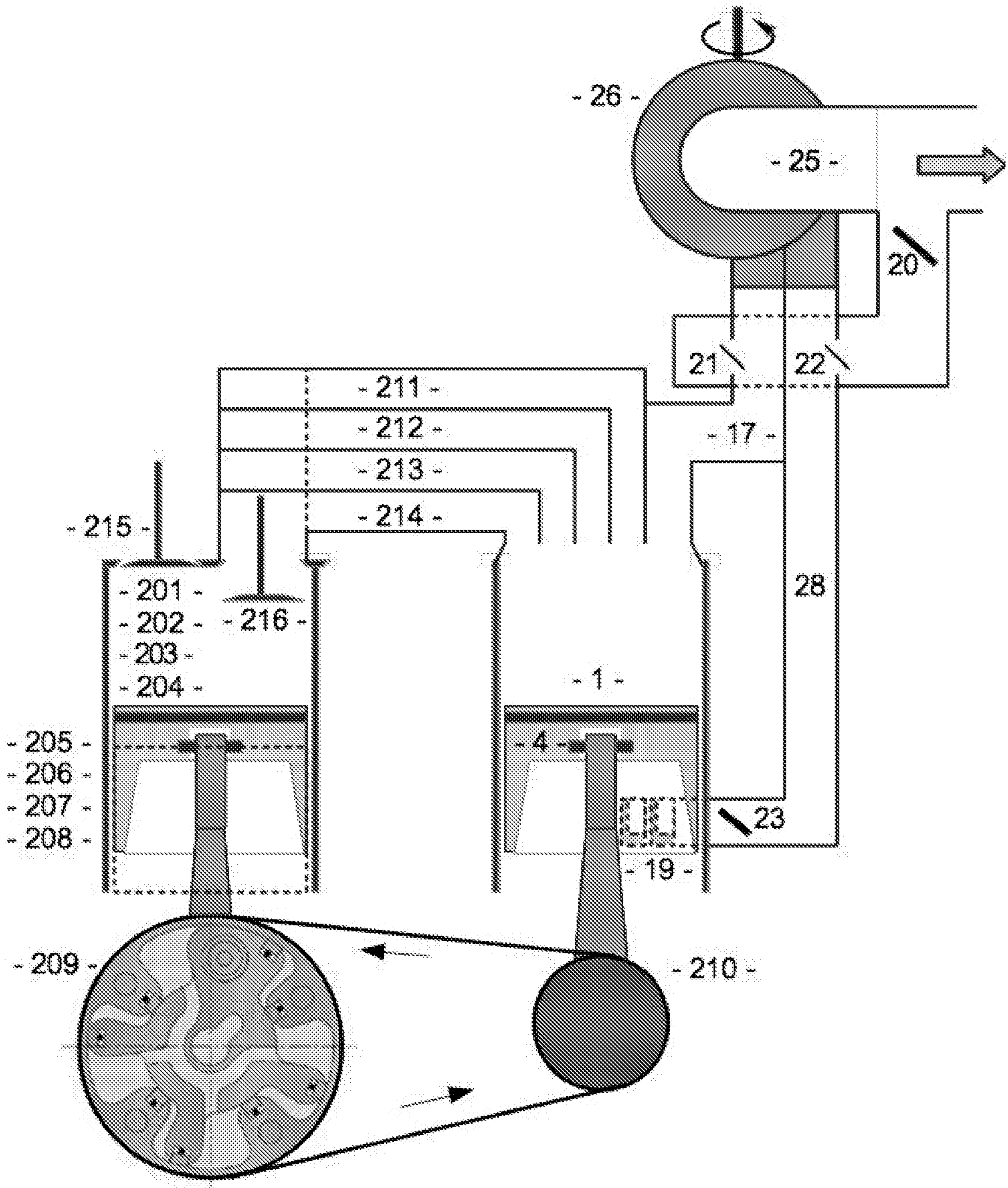

Figure 19: Variant with 4+1 cylinders. To the left are cylinders (201), (202), (203) & (204), to the right is exhaust cylinder (1). Wheel (209) drives wheel (201) at a ratio of 2, to allow one exhaust cylinder to serve 4 combustion cylinders. Phase shift is possible.

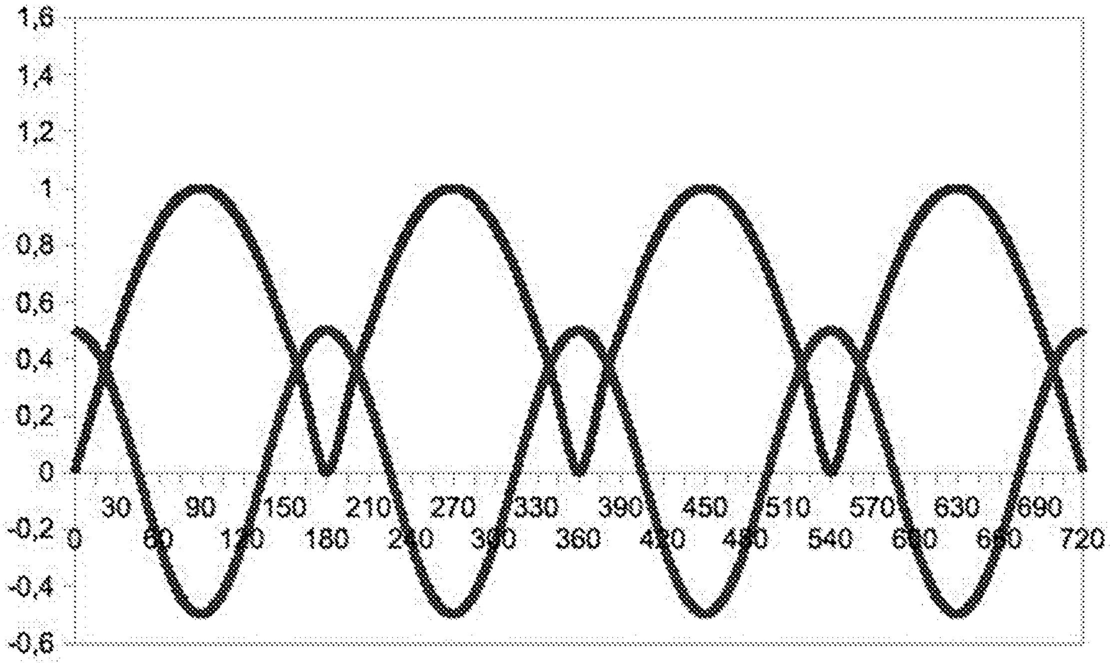

Figure 20a: Exhaust from design according to figure 19 (4 + 1 cylinder) at phase shift 0°. Upper line – combustion cylinders. Lower line – exhaust cylinder.

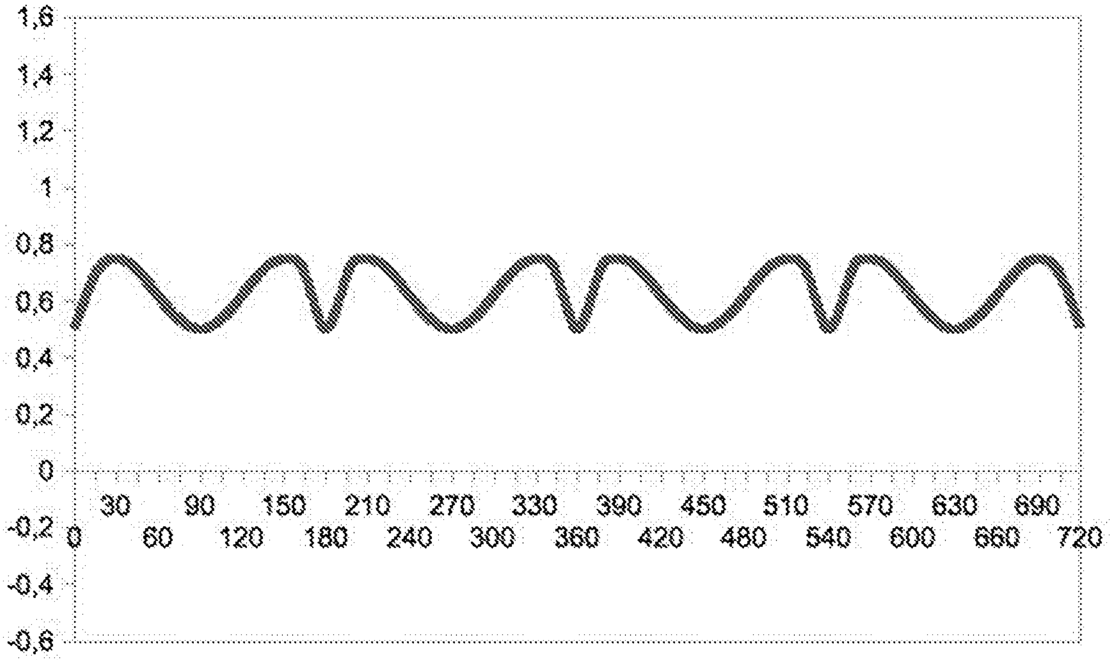

Figure 20b: Exhaust from design according to figure 19 (4 + 1 cylinder) at phase shift 0°. Combined exhaust from combustion cylinders and exhaust cylinder.

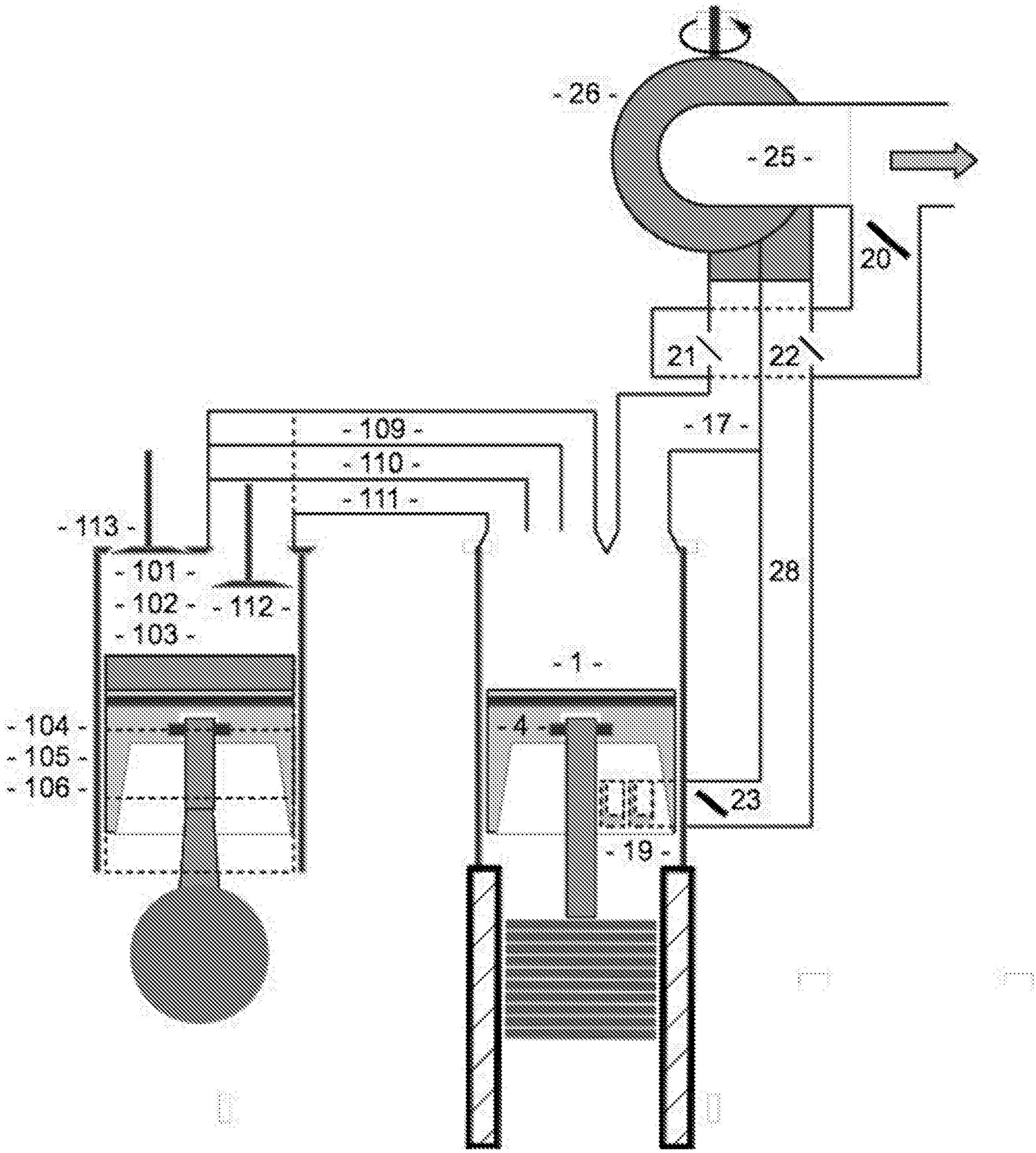

Figure 21: Free piston variant with 3+1 cylinders. This variant comprises 3 combustion pistons connected to a normal crankshaft and 1 exhaust piston connected to a linear engine/generator.

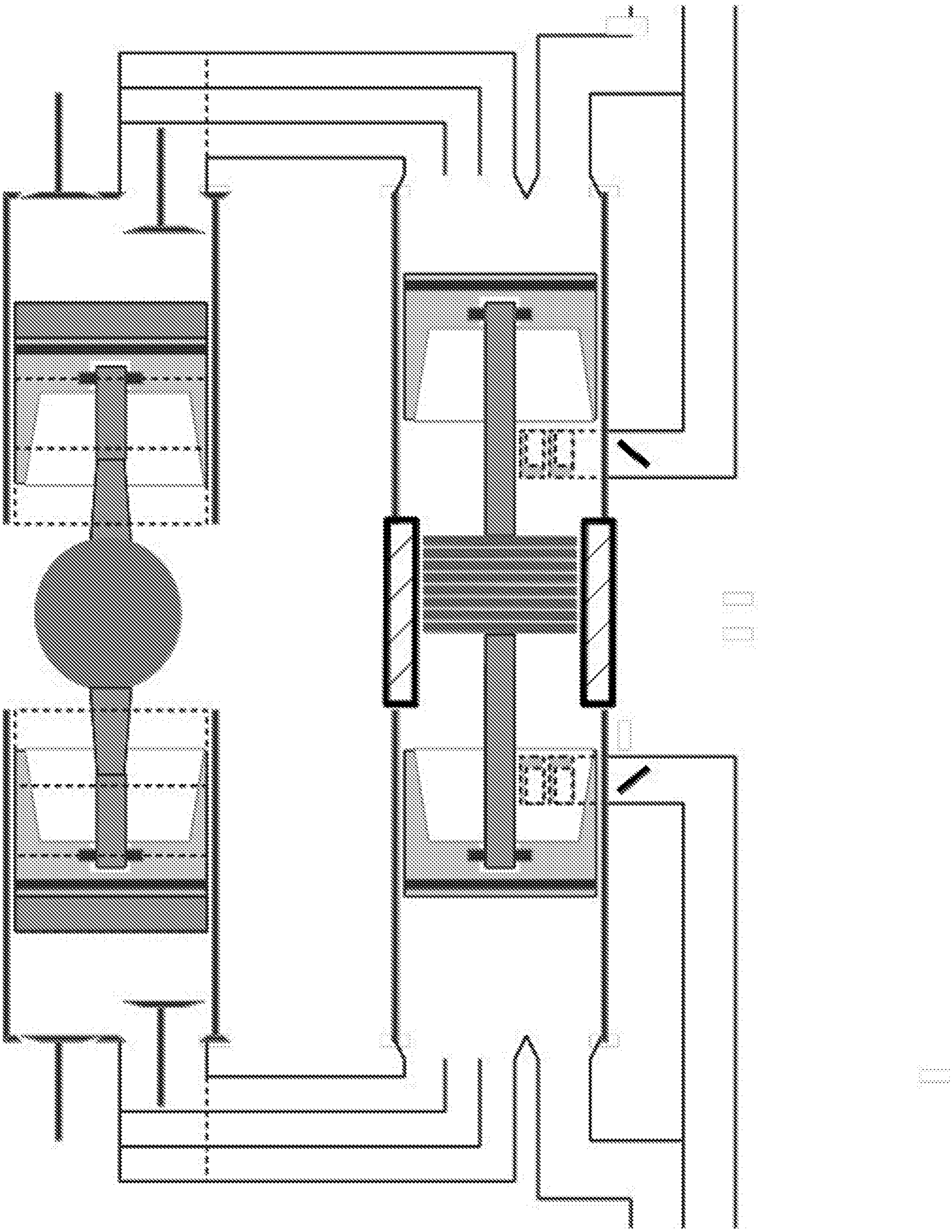

Figure 22: Free piston variant with 6+2 cylinders. This variant comprises 6 combustion pistons (left) connected to a normal crankshaft and dual exhaust pistons (right) connected to a linear engine/generator.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2018/051062

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: F02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 4409581 A1 (MAIER KARL), 28 September 1995 (1995-09-28); abstract; column 1, line 63 - column 2, line 12; column 2, line 35 - line 39; figure 1	1-3, 5-10, 18, 21
Y		11-17, 20
A	--	4, 19
Y	US 6553977 B2 (SCHMITZ GERHARD), 2 May 2002 (2002-05-02); abstract; column 8, line 10 - line 16; column 8, line 29 - line 31; column 9, line 16 - line 25; figures 1, 5-9 --	11-17, 20

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
03-12-2018	03-12-2018
Name and mailing address of the ISA/SE Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Authorized officer Marianne Dickman Telephone No. + 46 8 782 28 00

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 102010024006 A1 (PORSCHE AG), 15 December 2011 (2011-12-15); abstract; figures --	1
A	US 20140123958 A1 (DURRETT RUSSELL P ET AL), 8 May 2014 (2014-05-08); abstract; paragraph [0018]; figure 1 --	1
A	JP 59113239 A (SHIMIZU YOSHITAKA), 29 June 1984 (1984-06-29); figures; sammandrag från PAJ --	1, 13
A	DE 2947280 A1 (NOACK HEINZ), 27 May 1981 (1981-05-27); page 5; figures 1-2 --	1
A	US 20160222872 A1 (DURRETT RUSSELL P ET AL), 4 August 2016 (2016-08-04); abstract; paragraphs [0015], [0027]-[0030]; figures -- --------	1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2018/051062

Continuation of: second sheet
International Patent Classification (IPC)

F02B 41/06 (2006.01)
F02B 37/12 (2006.01)

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US	20160222872	A1	04/08/2016	CN	105840307	A	10/08/2016
				DE	102016100988	A1	04/08/2016
				US	9605708	B2	28/03/2017