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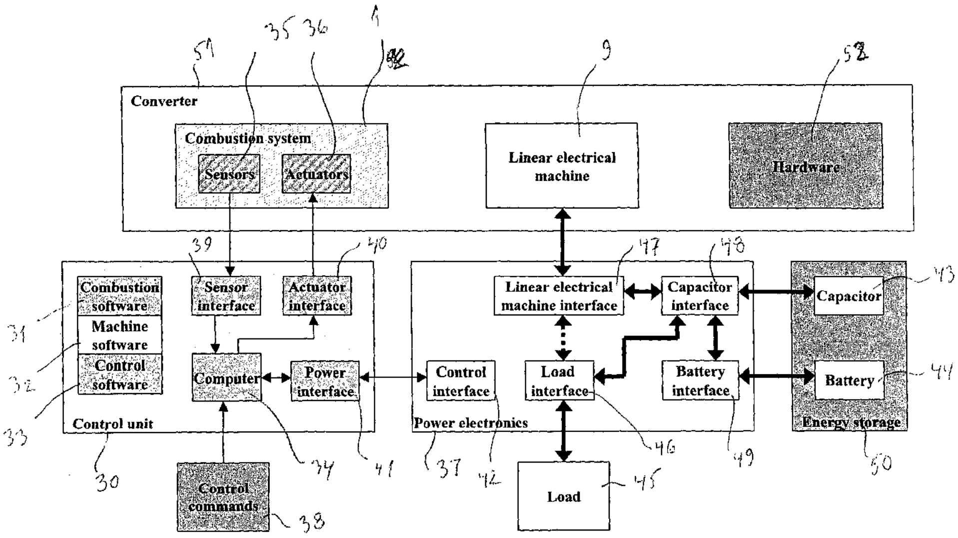

(57) **Abstract:** The invention relates to an energy converter, comprising a combustion system (1) comprising at least one piston (2, 3), at least one combustion chamber (6, 7) provided with at least one inlet (11, 13) and at least one outlet (10, 12), inlet and outlet valves (14, 15, 16, 17), of which at least one inlet valve or at least one outlet valve is controllable, means (18, 19) for supplying fuel and a medium containing oxygen into the combustion chamber (6, 7), an electric machine (9) arranged to interact directly or indirectly with the piston (2, 3) in an electromagnetic manner as to produce electrical energy from piston movements as well as to use electrical energy to affect the piston movements, and a control unit (30) that controls the combustion system (1) and the electric machine (9). According to the invention the energy converter is arranged to adapt its power output depending on the required load of the energy converter. The invention also relates to a method for operating an energy converter and a method for starting an energy converter.

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TITLE

Energy converter.

TECHNICAL FIELD

The present invention relates to an energy converter according to the preamble of claim 1, a method for operating an energy converter according to the preamble of claim 11, and a method of starting an energy converter according to the preamble of claim 16.

STATE OF THE ART

A free piston engine is characterised in that it does not have a crankshaft. Free piston engines can be of a single piston or dual piston layout. In a dual piston layout, there are separate combustion chambers and fuel injection for each piston. The pistons are attached to each other by a rod so that they move simultaneously. Free piston engines are well known in the art. A common way of attaining energy from a FPE is to mount an electrical generator to the interconnecting rod.

Also well known in the art is the so called HCCI combustion. When a homogeneous, diluted (air or residual gas fraction) fuel/air mixture is compressed in an engine at such a high temperature that it auto-ignites, the engine is said to operate on homogeneous charge compression ignition (HCCI).

US 6199519, for example, discloses a two-stroke, free piston engine with a linear electrical alternator/generator. The engine is driven in an oscillating mode with constant frequency. Fuel and air are introduced in a two-stroke cycle fashion without using valves. The engine operates in an HCCI (autoignition) mode and will shut off when not needed and run at essentially constant velocity and power when on. Regulation of the coil current can be used to regulate the piston velocity as to change the compression ratio if the fuel composition is changed. The engine/generator is particularly intended for charging batteries in hybrid automobile applications. To start the engine, the batteries are used to operate the linear alternator as a linear motor. The piston is oscillated in the cylinder, building to a higher compression each cycle until sufficient compression is developed for autoignition, at which time fuel is introduced to the engine and self powered operation will ensue.

WO 01/45977 describes a device including a free piston engine, an electromagnetic energy transducer, a combustion system and a control unit. The combustion system can include one or two active combustion chambers and operates in two strokes alternatively four strokes. The device makes it possible to determine the instantaneous position of the piston. By controlling the electrical power to and from the electromagnetic energy transducer, and in combination with spark plugs that also are controlled by the control unit, it is claimed to be possible to displace the piston to a desired position when a combustion is to be initiated by the spark plugs. It is also proposed to control and vary the compression depending on the instantaneous load on the combustion engine, e.g. by increasing the compression to obtain a higher power output. HCCI is mentioned as a possible combustion principle but there is nothing disclosed on how such a combustion could be controlled. Further, different storing devices, for storing at least a part of the combustion energy, such as capacitors, batteries and flywheels are discussed. Their use is however scarcely described.

Although the existing free piston engine energy converters do convert chemical energy via combustion to electric energy in a fairly good way when they are driven in a constant load situation, these solutions require large a large energy storage such as battery packs. Such equipment is expensive and lowers the efficiency of the system.

BRIEF DESCRIPTION OF THE INVENTION

One object of the invention is therefore to provide an energy converter that does not need a large energy storage. This object is achieved by means of a device according to claim 1.

As defined in claim 1, the invention is characterized in that the energy converter is arranged to adapt its power output depending on the required load of the energy converter. By doing so only a small energy storage is needed. This reduces both the cost and the weight of the energy converter compared to previous solutions. Further, the invention can be operated very efficiently with a very low fuel consumption and very low emissions.

Another object of the invention is to provide a method for operating an energy converter in an efficient way.

This object is accomplished by means of a method as defined in claim 11 and which is characterized in that that the power output of the energy converter is adapted to the required load of the energy converter.

Another object of the invention is to provide a method for starting an energy converter in an advantageous way.

This object is accomplished by means of a method as defined in claim 16, which is characterized in that that said method comprises storing, in said capacitor, electrical energy allowing said energy converter to be started within one stroke of said piston.

DESCRIPTION OF FIGURES

The invention will be described in greater detail below with reference to the accompanying figures of the drawings, in which

Fig. 1 is a schematic view of an energy converter according to a preferred embodiment of the invention,

Fig. 2 is a schematic view of a control unit and main power paths according to a preferred embodiment of the invention,

Fig. 3 shows simulation results from an example of a continuous operation of a preferred embodiment of the invention,

Fig. 4 shows further simulation results according to figure 3,

Fig. 5 shows simulation results from a first example of one-cycle operation of a preferred embodiment of the invention,

Fig. 6 shows further simulation results according to figure 5,

Fig. 7 shows simulation results from a second example of one-cycle operation of a preferred embodiment of the invention,

Fig. 8 shows further simulation results according to figure 7,

Fig. 9 shows simulation results from a cold start operation of a preferred embodiment of the invention,

Fig. 10 shows further simulation results according to figure 9,

Fig. 11 shows simulation results corresponding to operation at a high load of an energy converter according to the invention, and

Fig. 12 shows further simulation results corresponding to figure 11.

DESCRIPTION OF PREFERRED EMBODIMENT

HCCI combustion:

When a homogeneous, diluted (air or residual gas fraction) fuel/air mixture is compressed in an engine at such a high temperature that it auto-ignites, the engine is said to operate on homogeneous charge compression ignition.

Ignition points are provided by multiple exothermal centers (ETC) in the gas-mixture. Since HCCI has no flame-propagation, the combustion is instead kinetically controlled. To generate multiple ETCs, it is important to be able to control the homogeneity of temperature and composition in the gas-mixture. The lack of flame-propagation causes the temperature distribution in the combustion chamber after combustion, in contrast to normal flame propagation, to be almost homogeneous. This leads to reduction of NOx emissions from thousands of ppm to an order of ten ppm. The kinetically controlled combustion means that the heat release can be extremely rapid, which makes it theoretically possible to approach the ideal Otto-cycle (constant volume combustion). Only very lean or diluted fuel/air mixtures can be combusted this way, provided the compression temperature is high enough. The difficulty with HCCI is controlling the ignition delay in such a way that the combustion phasing is correct under varying speed and load conditions. Since HCCI combustion requires a high dilution of the air/fuel mixture, only the part load portion of the engine operational range can be valid for HCCI combustion (assuming a naturally aspirated engine). If high compression ratios are allowed, the HCCI combustion has the potential to exceed the Diesel engine in efficiency (40 - 45%) without the high NOx and particle emissions. Homogeneous charge compression ignition is not a new idea: As early as the 1940s, a kerosene driven auxiliary engine for a bicycle (Lohmann) was operated with this type of compression ignition and variable compression rate ($r_{c.eff.}$ = 8.5 - 12.5). During the 1950s, Alperstein, in the 1970s ATAC, and in the 1980s Smokey Yunick and South West Research Institute also operated an HCCI engine. The HCCI operation requires either a lean mixture (equivalence ratio, ϕ, below 0.5) or high amounts of residual gases (above 40%) to control combustion velocity. When a fuel with a high octane number is used, high compression temperatures are also required. For these reasons, only 2-stroke engines with high internal EGR such as Honda or engines with variable compression ratio like Lohmann have reached production. All attempts with conventional four-stroke homogeneous charge engines have failed due to the difficulty in controlling the auto-ignition process within the potential HCCI speed/load range and during transient engine operation. In the 1990s, the interest in HCCI combustion reawakened again. Today, due to advances made in engine control and variable engine systems, the chances of success are much greater.

One way of realizing a 4-stroke HCCI engine is to emulate the in-cylinder conditions of a 2-stroke engine by trapping large amounts of residual gases. This can be done by closing the exhaust valve early, as described by Kerkau *et al.*, Denbratt and Willand *et al.*. Another alternative is to manipulate the compression temperature by variable intake valve timing, Smith *et al.* and Aceves *et al.*, or by a combination of variable compression and variable intake valve timing, Denbratt.

An energy converter according to a preferred embodiment of the invention is shown in Fig. 1. The energy converter comprises a free piston combustion system 1 that comprises two pistons 2, 3 with separate cylinders 4, 5 and combustion chambers 6, 7. More precisely, the combustion system 1 comprises a first piston 2 arranged in a first cylinder 4 having a first combustion chamber 6 and also comprises a second piston 3 arranged in a second cylinder 5 and having a second combustion chamber 7.

The pistons are interconnected with a connecting rod 8. A linear electric machine 9 is positioned between the cylinders 4, 5. The rod 8 and the electric machine 9 can interact electromagnetically with each other and the electric machine 9 can operate both as a generator and a motor. Each combustion chamber 6,7 comprises ports 10, 11, 12, 13 with controllable inlet and outlet valves 14, 15, 15´, 16, 17, 17´ and a fuel injector 18, 19. More precisely, the first combustion chamber 6 is provided with a first outlet port 10 in which an outlet valve 14 is arranged and a first inlet port 11 in which an inlet valve 15 is arranged. Furthermore, the second combustion chamber 7 is provided with a second outlet port 12 in which a further outlet valve 16 is arranged, and a second inlet port 13 in which a further inlet valve 17 is arranged.

Preferably, the first combustion chamber 6 is provided with an additional inlet valve 15´, whereas the second combustion chamber 7 is provided with an additional inlet valve 17´.

The energy converter is further provided with e.g. sensors, actuators and a control unit (not shown) which are further described below.

The first outlet valve 14 is controlled by a first outlet valve control unit 20 and the first inlet valve 15 is controlled by a first inlet valve control unit 21. Furthermore, the second outlet valve 16 is controlled by a second outlet valve control unit 22, whereas the second inlet valve 17 is controlled by a second inlet valve control unit 23.

If the additional inlet valve 15′ is provided, it is suitably controlled by an additional inlet valve control unit 21′. In a similar manner, the additional inlet valve 17′ is controlled by a further inlet valve control unit 23′.

The control units 20, 21, 21′, 22, 23, 23′ are shown in Fig. 1 as separated units, but may be implemented as functions in a single control unit (as described below, with reference to figure 2) for controlling all the valves 14, 15, 15′, 16, 17, 17′.

Although the embodiment shown in Fig. 1 includes inlet and outlet valves 14, 15, 15′, 16, 17, 17′ which are all controllable, the invention is not limited to such an embodiment only. In fact, the invention can be implemented in a manner so that either one of the inlet valve 15 and outlet valve 14 (of the first combustion chamber 6) is controllable, or both. In a similar manner, either one of the second inlet valve 17 and the second outlet valve 16, or both, can be controlled. In embodiments of the invention in which not all valves are controllable, such valves can be in the form of a permanently open valve opening.

Figure 1 also shows schematically an example of a flow system for leading and handling of air and exhaust gas to and from one of the combustion chambers, in this case the first combustion chamber 6. A similar system (not shown) is arranged in connection to the second combustion chamber 7. The incoming air is led to a compressor 24, driven by a first electrical motor 25, and passes a first cooler 26 before it enters the first combustion chamber 6. The exhaust gas leaves the first combustion chamber 6 through the first outlet valve 14, via a turbine 27 connected to an electrical generator 28, and further to the surrounding atmosphere. Part of the exhaust gas flow, the so called EGR-flow, is led via a second cooler 29 back to the compressor 24 where it mixes with the incoming air. Of course this flow system may be designed in many different ways obvious for a person skilled in the art.

The energy converter according to a preferred embodiment of the invention also comprises a capacitor and a battery (not shown).

Figure 2 shows schematically a control unit 30 and main power paths according to the invention. The control unit 30 comprises various software modules such as combustion software 31, electric machine software 32 and control software 33. Furthermore, the control unit 30 comprises computer means 34, and interfaces for sending and/or receiving information from combustion sensors 35 and actuators 36, power electronics 37 and control commands 38. Said interfaces include a sensor interface 39 (for communicating with said sensors 35), an actuator interface 40 (for communicating with said actuators 36, and also the compressor 24/25) and a power interface 41 (for communicating with said power electronics 37). Such communication is indicated by thin arrows in Fig. 2.

The computer means 34 include a microprocessor, memory, input and output circuits/drivers, A/D and D/A converters etc (not shown) well known to a person skilled in the art. The control unit 30 can be connected to further electronic units (not shown) by means of a computer bus. The power electronics 37 comprises a control interface 42 for communication with the above-mentioned power interface 41 in the control unit 30 and interfaces for distributing power between the electric machine 9, the capacitor 43, the battery 44 and an external load 45. These interfaces include a load interface 46 (for cooperating with the load 45), a linear electrical machine interface 47 (for cooperating with the electric machine 9), a capacitor interface 48 for cooperating with the capacitor 43) and a battery interface 49 (for cooperating with the battery 44). The capacitor 43 and the battery 44 together form an energy storage unit 50, as indicated schematically in Fig. 2.

Furthermore, the main power paths in the power electronics 37 are indicated with bold arrows. Power may also be distributed for operation of e.g. the compressor (see Fig. 1). The power electronics 37 further comprises communication paths, e.g. between the control unit 30 and the electric machine 9 (not shown). Figure 2 also shows the principal content of the energy converting parts, shown schematically by reference numeral 51: the combustion system 1, including e.g. the flow system; the linear electrical machine 9; and miscellaneous hardware 52.

The combustion system comprises sensors 35 for e.g. pressure, temperature, knocking, air mass flow, piston position and piston acceleration, as well as actuators for controling e.g. fuel injection, valves and turbines.

The sensors 35 are connected to inputs on the control unit 30 and actuators 36 are connected to the output. For instance, the position sensor gives a signal corresponding to the relative position of the rod 8, i.e. the position of the pistons. Other parameters that could be inputted to the control unit 30, either directly through separate sensors or through the data bus, are engine temperature, cooling water temperature, vehicle speed, momentary current flow etc. These parameters are evaluated by the control unit and depending on predetermined limits, the control unit 30 controls the current flow through the electric machine 9.

The computer means 34 in the control unit 30 is provided with software that is arranged to simulate and predict the piston movement and the variations of pressure and temperature of the fuel/air-mixture in the combustion chambers.

The main function of the capacitor 43 is to act as an energy buffer between the engine strokes. The main function of the battery 44 is to charge the capacitor 43 at the start of the engine. The capacity of the capacitor 43 may be relatively small (e.g. 200 Ws) and the battery 44 can be an ordinary vehicle starting battery. Various types of capacitors and batteries may of course be used.

According to prior art, an FPE energy converter can be adapted to provide good combustion conditions, resulting in high efficiency and low emissions, by operating the engine at constant frequency and load. Energy is stored in a battery pack. When an FPE according to prior art is used in e.g. a vehicle, it will be dimensioned for providing the average power needed by the vehicle. This means that at times the power consumtion by the vehicle can be many times larger than the power output of the generator. This type of vehicle thus requires a large and heavy battery pack.

However, in vehicle applications it is desirable to have a small and light battery. This is not possible with the known FPE. Either a large battery pack is required or the FPE must be dimensioned so that it can deliver the maximal power required by the vehicle. Such an FPE is not an efficient choice.

To solve this problem, it is necessary to control the free piston energy converter so that it can vary its output power. This is a fundamental idea of the invention. According to the invention, this power variation can be done by varying the following parameters: the amount of fuel per stroke, the amount of air per stroke, the compression and the number of strokes per time unit, i.e. the operating frequency. At least one of these parameters can be controlled for providing said power variation in accordance with the invention.

The invention is not limited to using the above-mentioned parameters only. Additionally, the power variation can also be controlled by varying the following parameters: the EGR-flow via the second cooler 29, the inlet pressure (by means of the compressor 24) and the outlet back pressure (by means of the turbine 27).

The operating frequency is of great importance. The operation frequency of the combustion system is determined by its mass-spring characteristics: the oscillating mass, the stroke length, and the stiffness of the springs (air/combustion gases and/or a mechanical or hydraulic spring). To control engine power output in traditional crankshaft IC-engines, two measures are generally applied: control of load/amount of fuel per stroke, and control of engine speed/frequency. The oscillation frequency of a free piston engine is commonly regarded as being fixed by its lay-out. However, it can be varied by changing spring stiffness and stroke length.

Varying the stroke length has, however, a second effect: the amount of trapped air is also changed. Frequency and amount of air cancel each other out regarding power output. Therefore the main control of frequency is by varying the stiffness of the spring(s). This stiffness is strongly related to the charging pressure, i.e. the pressure of the incoming air, valve timing, i.e. the trapped amount of gas and maximum cylinder pressure in the combustion cycle. Also the variation of the charging pressure has two effects. In contrast to the variation of stroke length, they now go in the same direction: increased charging pressure increases the frequency and the amount of air. Charging pressure is therefore a strong control parameter for the power output. Even charging pressures below 1 bar abs. are interesting to control low loads, even though it costs extra fuel (pumping losses). With variable valve events, pumping losses can be avoided. The trapped gas mass can also be controlled by valve timing.

This means that one way of controlling the combustion system and thus the power output of the energy converter is by controlling the frequency by controlling the trapped gas mass. The trapped gas mass is controlled by charging pressure and valve timing. The control unit 30 (see Fig. 2) controls the opening times of the input and output valves 14, 15, 16, 17 (see Fig. 1). It further controls the compressor 24 that creates the pressure. Since the compressor 24 has a small time delay, this delay is taken into account when controlling the opening times for the valves.

HCCI combustion is characterized by a very fast heat release. The free piston movement is characterized by high piston speeds at the end of compression and beginning of expansion. These speeds are much higher than in a crankshaft engine, as the piston is not held by a crankshaft mechanism at top dead center. The combination of fast expansion and fast heat release fits very well together. The free piston engine needs a fast heat release to keep up with the expansion rate, and the HCCI combustion benefits from fast expansion after combustion completion.

Another advantage of the lack of a crankshaft mechanism is the automatic limitation of peak pressure. When the self-ignition starts relatively early during the compression stroke, the piston is slowed down by the combustion pressure, which reduces the compression ratio and starts the expansion stroke earlier. A late self-ignition has the opposite effect. Principally, one could say that the piston continues to compress the gases and increase gas temperature until self-ignition occurs. Then, the combustion pressure forces the piston back in the expansion stroke.

Additional variation of lambda or EGR will additionally increase the power range. Even the option of skip fire is possible when direct injection is applied (2N-stroke (N=1,2,3…)).

Gasoline, compared to diesel, requires/allows higher temperatures with HCCI, which results in higher peak pressures, which results in higher frequency and power density.

The piston 'speed range' of a free piston engine is relatively small compared to a crankshaft engine, i.e. the piston movement does not change much. This gives better conditions for optimising the combustion process and minimize emissions and fuel consumption. With a low friction free piston engine and an efficient generator the fuel consumption can be further decreased.

To be able to adapt the energy converter and the combustion system to varying loads, it is desirable to control the piston movement in each cycle, preferably both between and during the individual strokes. The HCCI combustion relies on self-ignition, which is very dependent on temperature, pressure and hence on compression ratio. The compression ratio is not geometrically determined but related to the piston speed at the end of compression. In the dual piston concept, the piston speed is dependent on the power from the previous stroke in the opposite cylinder, and the amount of power taken off by the electrical machine/generator. By varying the power taken off by the generator it is possible to even out cycle to cycle variations in the previous combustion and assure the correct compression ratio. To be able to do that, the piston speed must be determined and adjusted from cycle to cycle. This requires a fast and accurate speed determination and motor/generator response. Some recently invented electric machines provides this necessity. Examples of linear electric machines that may be suitable in this context are presented in WO 01/78218 and WO 01/78219.

The actual load requirements are analysed by the control unit 30. The control unit 30 may obtain information on the load requirements via a sensor at the load interface 46 that e.g. reads the required current or voltage, or by receiving control commands based on e.g. (change of) accelerator pedal position or vehicle driving conditions (previous, present, calculated future) or sensor signals for voltage drop or current interruption.

As mentioned previously, prior art FPE energy converters handle power peaks with batteries. A large batterypack is connected to the generator, which feeds the battery pack with a constant charge current. To save weight and cost, it is desirable to minimise the amount of batteries. A small battery pack can, on the other hand, not deliver the required current at power peaks. According to the invention, this problem is solved by adjusting the energy converter depending on the actual load. By adapting the combustion system to the load, the required current from the generator can be delivered. With the fast response time of the energy converter according to the invention, it is possible to use only a conventional starter battery as the battery pack.

In a preferred embodiment of the inventive energy converter, a capacitor or a super capacitor is used as the operational energy storage instead of a battery. A (super) capacitor makes it possible to store energy and obtain stored energy more quickly than by using a battery. Further, a (super) capacitor has a higher energy to weight factor than a battery and also a longer service life. However, a small battery will be needed to start the engine when it has been shut off for some time. The self discharge of capacitors appears presently to be too fast to make them suitable for use as a starter battery.

Operation of the invention

The operation of the invention will now be described with reference to figures 1 to 12.

The start behaviour (of which a cold start is a special case) of the FPE is preferably performed according to the following principal description.

1. The pistons start out from a position as far to the left as possible with reference to figure 1 (x = -half the stroke length).
2. The electric machine 9 (see also Fig. 1) accelerates the pistons 2, 3 to the right with both cylinders 4, 5 open (i.e. all valves 14, 15, 16, 17 are open).
3. The inlet valves of the second cylinder 5 are closed at an x-position (piston displacement) that gives a desired compression.

4. Fuel is fed to the second cylinder 5.
5. When the pistons 2, 3 reach their maximum x-value, i.e. a position as far to the right as possible with reference to figure 1, the combustion is initiated in the second cylinder 5.
6. During the expansion stroke part of the energy of the moving piston is taken up by the electric machine 9 and is stored in the capacitor 43. The remaining energy is used for compression in cylinder 6 and continuation of the operation.

In this way, the engine can be started in a fast and efficient way and reach working conditions in half a cycle.

The combustion system preferably comprises a NOx-trap and a catalytic converter for treating the exhaust gas (not shown). Exhaust gases from the cold start, before the engine is heated to working conditions, are preferably stored in the NOx-trap in a known fashion until the exhaust gases have reached the light-off temperature for the catalytic material.

This novel start behaviour is very quick and environmental friendly since it does not produce any excessive exhaust gases.

The electric machine 9 is controlled instantaneously so that the combustion is initiated in an optimal piston position. Valves, fuel injection and charging pressure are controlled so that a desired operation is achieved with regard to the required load. The electric machine 9 is controlled by the control unit 30 so that it instananeously can deliver desired force in desired direction. Further, the control unit 30 receives instantaneously information about the status of the electric machine 9. The electrical energy produced by the electric machine 9 is stored in the capacitor 43 (and in the battery 44 if necessary) and/or is transferred to the load 45, e.g. a driving mechanism for a car. During start and intensive controlling a high effect can be taken from the capacitor 43.

Continuous operation of the combustion system according to the invention may be performed in a 2-stroke or 4-stroke mode in accordance with traditional combustion engines. A 4-stroke mode is achieved by letting one of cylinders, temporarily or permanently, act as an gas(air)-spring with closed valves.

Simulation results from an example of a continuous operation of the energy converter is shown in figure 3 and 4 ("Type: Running. Case: 63 C, 1 bar.").

Previous FPE energy converters are run at a constant speed and power, and need large energy buffers such as batteries as a back-up for high-load situations. The energy converter according to the invention on the other hand can be controlled to deliver the required load by changing the operation mode of the combustion system. Mode-switches within continuous operation is described further below. The energy converter according to the invention makes it possible to run the converter in a novel and efficient way.

In situations where only a small amount of power output is needed the energy converter according to the invention can be operated in an intermittent mode, i.e. a mode in which the combustion system is alternatingly on and off and where only one or a few combustion cycles are performed each time the combustion system is on. Such an intermittent mode makes it possible to use a very small energy buffer. As the charging of the capacitor drops below a certain value, one or a few combustion cycles are performed for recharging. The energy converter according to the invention is thus capable of delivering energy continuously although the combustion system works intermittently. During intermittent operation the frequency of the combustion system, seen over a time period much longer than a few combustion cycles, is low compared to the continuous operation.

Simulation results from such an intermittent mode, a first example of one-cycle operation, is shown in figure 5 and 6 ("Type: Single stroke 1. Case: 63 C, 1 bar."). This first example inludes the following steps:

1. The pistons start out from a position as far to the left as possible with reference to figure 1 (x = -half the stroke length).
2. The electric machine 9 (see also Fig. 1) accelerates the pistons 2, 3 to the right with both cylinders 4, 5 open (i.e. all valves 14, 15, 16, 17 are open).
3. The valves of the second cylinder 5 are closed at an x-position (piston displacement) that gives a desired compression.
4. Fuel is fed to the second cylinder 5.
5. When the pistons 2, 3 reach their maximum x-value, i.e. a position as far to the right as possible with reference to figure 1, the combustion is initiated in the second cylinder 5.
6. During the expansion stroke the energy of the moving piston is taken up by the electric machine 9 and is stored in the capacitor 43. The valves 14, 15 of the first cylinder 4 are still open.
7. The pistons 2, 3 stay in their left waiting position as described in step 1 above.
8. The energy in the capacitor 43 is used by the load 45.
9. When it is time for recharging the capacitor 43 (step 6) steps 1 to 8 are repeated.

This means that in order to start in half a cycle, the invention comprises injection into the cylinder, at least one controllable valve for determining the amount of air, and the possibility of positioning the pistons at an end position, and also instantaneous control during the cycle.

Simulation results from a second example of one-cycle operation is shown in figure 7 and 8 ("Type: Single stroke 2. Case: 63 C, 1 bar."). This second example inludes the following steps:

1. The pistons 2, 3 start out from a position as far to the left as possible with reference to figure 1 (x = -half the stroke length).
2. The electric machine 9 accelerates the pistons 2, 3 to the right with both cylinders 4, 5 open (i.e. all valves 14, 15, 16, 17 are open).
3. The valves of the second cylinder 5 are closed at an x-position (piston displacement) that gives a desired compression.
4. Fuel is fed to the second cylinder 5.
5. When the pistons 2, 3 reach their maximum x-value, i.e. a position as far to the right as possible with reference to figure 1, the combustion is initiated in the second cylinder 5.
6. The valves 14, 15 of the first cylinder 4 close at a suitable point of time.
7. During the expansion stroke the energy of the moving piston is taken up by the electric machine 9 and the gas spring formed in the first cylinder 4. Energy is stored in the capacitor 43.
8. As the pistons 2, 3 have rebound off the gas spring in the first cylinder and are moving towards the second cylinder 5, the pistons 2, 3 are slowed down by the electric machine 9 which takes up and transfer the energy to the capacitor 43.
9. The pistons 2, 3 are brought back to a waiting position, either to the far left (as described above) or to the far right.
10. The energy in the capacitor 43 is used by the load 45.

11. When it is time for recharging the capacitor 43 (steps 7 and 8) steps 1 to 10 are repeated.

Compared to the first example of one-cycle operation, this second example allows for a higher combustion energy since (at least) two strokes are used for slowing down the pistons 2, 3.

The second example of one-cycle operation described above is also useful for starting a continuous operation. Such a starting process makes it possible to deliver output power after a very short time. As can be seen from figure 7 the electric machine 9 starts to deliver power after about 17 ms. If the energy converter has been shut off for some time it may be necessary to initially charge the capacitor 43 from the battery 44, typically this takes around 200 ms. This time delay can however be avoided by using the battery 44 to keep the capacitor 43 fully charged during the time the converter is shut off.

A cold start is a special case of starting process since a considerable compression is required to achieve the autoignition temperature. The principles of the second example ("Single stroke 2") described above is suitable for a cold start situation. Simulation results from such a cold start process is shown in figures 9 and 10 ("Type: Single stroke 2. Case: 63 C, 1 bar."). By choosing to close the valves of the second cylinder 5 (step 3) at a late stage, resulting in a smaller amount of gas entrapped in the second cylinder 5, it is possible to make the force of the electric machine 9 sufficient for compressing even cold gas sufficiently for ignition within one stroke.

The stopping procedure is performed in a similar way. When the combustion system is to be stopped, the fuel mixture is ceased. At the same time, the control unit 30 applies a current to the electric machine 9 in such a way that the force from the electric machine 9 to the rod is in the opposite direction to the movement of the rod. When the rod 8 reaches e.g. its central position, the current is released and the energy converter is stopped.

According to a further example, simulation results of an operating situation involving a relatively high power are described with reference to figures 11 and 12 ("Type: Running. 39 kW. High power with supercharging"). This situation corresponds generally to what is described with reference to figures 3 and 4, but involves a considerably higher power of the energy converter according to the invention and also considerably higher cylinder pressure and cylinder temperatures.

Additional explanation of figures 3-12

Figures 3 - 12 show examples of principal simulations of different running modes for an energy converter such as the preferred embodiment of the invention shown in figure 1. The pistons 2, 3 and the moving part of the electrical machine 9 are accelerated by the sum of the forces produced by the cylinder pressures and the electrical machine 9. In a continuos running mode these forces are balanced (as an average) and the pistons 2, 3 are oscillating between the left and right turning points. The parameter section shown first for every different mode is not necessary for the understanding the principles and is not explained further.

The first diagram (of three) for each running mode shows the piston displacement (expressed in centimeters), x, referring to the pistons´ 2, 3 central positions; the piston velocity (expressed in meters per second); and the force (El-force) (expressed in kilo-Newtons) produced by the electrical machine. To get high efficiency the electrical machine 9 is preferably only active when the piston velocity is high and the "El-force" is therefore, in these examples, zero around the turning points of the pistons. If the piston velocity and the "El-force" have the same signs the electrical machine 9 works as a motor which means that the pistons 2, 3 are accelerated by the electrical machine 9. If on the other hand, the piston velocity and the "El-force" have different signs the electrical machine 9 works as a generator which means that the pistons 2, 3 are retarded by the electrical machine 9. The energy converter produces power when the electrical machine 9 works as a generator. The second diagram for each running mode shows the cylinder pressure in the two cylinders. The control unit 30 has controlled the operation to get ignition (in these examples for the HCCI combustion) near the turning points of the pistons. The third diagram for each running mode shows the cylinder (combustion) temperatures in the two cylinders.

Figure 3 shows the piston displacement, the piston velocity, and the force produced by the electrical machine in a continuous running mode.

Figure 4 shows the cylinder pressures and the cylinder temperatures in a continuous running mode.

Figure 5 shows the piston displacement, the piston velocity, and the force produced by the electrical machine in a single stroke mode type 1. The pistons 2, 3 are first accelerated by the electrical machine 9 from their left position (minimal x value) to the right turning point where the combustion takes place in cylinder number 2. In the stroke from the right turning point the pistons 2, 3 are retarded and stopped by the electrical machine 9.

Figure 6 shows the cylinder pressures and the cylinder temperatures in a single stroke mode type 1. Note that the cylinder 4 is inactive (valves are open) in the whole cycle. Furthermore the valves are closed late (in this particular example) in the compression stroke for cylinder 5.

Figure 7 shows the piston displacement, the piston velocity, and the force produced by the electrical machine 9 in a single stroke mode type 2. The pistons 2, 3 are first accelerated by the electrical machine 9 from their left position (minimal x value) to the right turning point where the combustion takes place in the second cylinder 5. In the stroke from the right turning point the pistons 2, 3 are retarded by the electrical machine 9. In this single stroke mode the pistons 2, 3 has a left turning point where the first cylinder 4 acts as a gas spring. In the stroke from this left turning point the electrical machine 9 converts the remaining part of the movement to electrical energy and the pistons 2, 3 are stopped.

Figure 8 shows the cylinder pressures and the cylinder temperatures in a single stroke mode type 2. The first cylinder 4 is inactive (valves are open) in the stroke from the left start position to the right turning point. At the left turning point there is no combustion in the first cylinder 4 (gas spring). In the stroke from the left turning point the second cylinder 5 is inactive (valves are open).

Figure 9 shows the piston displacement, the piston velocity, and the force produced by the electrical machine in a single stroke mode type 2 at low temperature, cool start. The pistons 2, 3 are first accelerated by the electrical machine 9 from their left position (minimal x value) to the right turning point where the combustion takes place in the second cylinder 5. In the stroke from the right turning point the pistons 2, 3 are retarded by the electrical machine 9. In this single stroke mode the pistons has a left turning point where the first cylinder 4 acts as a gas spring. In the stroke from this left turning point the electrical machine 9 converts the remaining part of the movement to electrical energy and the pistons 2, 3 are stopped.

Figure 10 shows the cylinder pressures and the cylinder temperatures in a single stroke mode type 2 at low temperature, cool start. Note that the valves for the second cylinder 5 are closed late in the compression stroke to make it possible achieve the very high compression needed to reach the ignition temperature. The first cylinder 4 is inactive (valves are open) in the stroke from the left start position to the right turning point. At the left turning point there is no combustion in the first cylinder 4 (gas spring). In the stroke from the left turning point the second cylinder 5 is inactive (valves are open).

Figure 11 shows the piston displacement, the piston velocity, and the force produced by the electrical machine in a situation involving a high power of the energy converter according to the invention and in particular, a higher charging pressure from the compressor 24. The diagram according to figur 11 generally corresponds to figure 3 but involves a higher speed of the two pistons 2, 3 and a higher electric power of the electric machine 9.

Figure 12 shows the cylinder pressures and the cylinder temperatures in an operating condition according to figure 11, i.e. involving a high power of the energy converter.

In contrast to prior art FPEs, the starting process of the combustion system described here does not require an oscillation procedure. As described above the combustion system can be started within one stroke, even under cold-start conditions. Consequently, the energy converter according to the invention can give power output in a very short time. The very quick and simple starting and stopping procedures of the energy converter according to the invention makes it possible to run the converter in a novel way concerning start and stop. Previous FPE energy converters have relatively complicated starting and stopping procedures and need large energy buffers such as batteries as a back-up for the time required for the starting procedure. In contrast, the energy converter according to the invention can use its quick starting procedure to eliminate the need for such large energy buffers.

This is of particular interest in low load situations where the converter can be operated in the intermittent mode, e.g. one-cycle operation, or even be shut off. One example is when the converter is used in a hybride vehicle that runs in a city where low load situations arise at traffic lights, in case of traffic jam etc. The engine may in such a case switch to one-cycle mode which might be close to being shut off depending on the status and capacity of the battery and how much energy is needed for lights, radio etc. The time period between the strokes may of course be varied. Another example is when the converter is used in a reserve power application. Since the invention makes it possible to obtain power as quickly as in the order of a period of net frequency (20 ms for 50 Hz) the very large back-up system of batteries/capacitors in traditional reserve power plants can be dramatically decreased. Naturally, if the invention is used in such an emergency application the capacitor should be kept fully charged during the time the converter is not in use.

The load control of the energy converter according to the invention is very flexible. Firstly, a number of different combustion modes can be selected:

· Intermittent mode (e.g. one-cycle operation)
· 2-stroke mode
· 4-stroke mode, 6 -stroke etc.

Secondly, the combustion principle can be selected:

· Compression ignited combustion
· Spark ignited combustion (provided that the combustion system is provided with spark plugs)

Thirdly, one may select with or without skip-fire, by elimination of fuel injection and/or spark ignition.

A fourth selection is possible since the following traditional combustion control methods may be selected within a certain running mode:

· Ignition timing by spark ignition
· Ignition timing for compression ignition
· Pressure charge level (by using a pressurized air tank buffer)
· Late or early fuel injection, or a combination of both, with one or multiple fuel injections at each timing
· Different valve actuation selection such as:
    · Late or early intake valve closing
    · Late or early exhaust valve closing
· EGR level control by e.g. positive or negative valve overlap

All the above selections can be changed from cycle-to-cycle as the energy converter according to the invention has the ability to prepare shift operation mode within one piston stroke, achieved by the within-one-stroke control ability of the electric machine and by the fuel and valve actuators.

The selection of combustion mode depends on the outer requirements. Examples of such requirements are:

- Cold start
- Warm start
- Instantaneous load level requirement
- Phase position requirements in relation to other co-operated converters
- Load level requirement predictions for the nearest set of strokes (by derivative or control unit history self learning functions)
- Instantaneous combustion system emission requirement
- Emission requirement prediction for the nearest sets of combustion strokes
- Emission system status (e.g. NOx-trap status, oxygen storage status etc)

Depending on the combination of these requirements different combustion mode settings can be used. One, out of several different combustion mode settings, that exhibits the best fit to the running demands can be selected from cycle to cycle.

In this way both the stationary and transient output torque of the energy converter according to the invention can be optimized for minimum fuel consumption and emission levels, without need for any additional load leveling capacitor or battery.

An energy converter according to the invention has several advantageous effects: a very high efficiency, a very low fuel consumption, it produces very small amounts of emissions and it eliminates/decreases the need for large battery stacks. The latter contributes to the efficiency, as there are energy losses associated with battery systems, and it also makes the energy converter system relatively cheap and light, as batteries generally are costly and heavy.

The invention can be used to avoid the traditionally negative consequences of misfire in the combustion chamber. Normally, unburnt fuel leaves the engine via the exhaust pipe. By using the sensors to detect the misfire, the control unit to take adequate actions (such as keeping the valves closed) and the electric machine to aid in the following compression in the other combustion chamber, the unburnt fuel can be kept in the combustion chamber until the piston returns the next time.

An FPE normally needs to be balanced. In order to do this two energy converters may be arranged after each other with the rods in a line. Each converter may have the general design outlined in figure 1. Balance can be achieved by operating the two rods totally in anti-phase, controlled by communication between the control units of the converters. The individual phase position of the two rods can be adjusted by redistributing the effect output within one stroke with maintained conditions at the end positions of the pistons. Two energy converters arranged in a line may have one cylinder and thus one combustion chamber in common.

A system comprising more than one energy converter may be arranged offset in phase so that power is delivered contineously or almost contineously from the electric machines. Such an arrangement decreases the need for capacitors.

The energy converter may be used as an engine brake. A control command from e.g. the brake pedal to the control unit can be used to initiate a procedure where the combustion process is stopped and the braking energy is used to move the rod/pistons to compress only air in the cylinders. By closing and opening valves and releasing the compressed air at adequate moments the energy converter will aid in the braking process. The compressed air may be stored in a pressure vessel for use as a compliment to charging.

As mentioned previously, the invention is preferably applied in hybride vehicle and reserve power plant applications. Other preferred applications are as APUs (Auxiliary Power Unit) in marine vehicles and as main engines and APUs in work machines such as wheel loaders, articualted haulers, excavators etc.

The invention is not limited to the what is described above but may be modified within the patent claims.

The number and position of the valves may be modified and inlet ports may be used as outlet ports and vice versa.

Even though the invention is described for a dual piston layout, it can also be utilised for a single piston layout well known to the person skilled in the art.

The expression "instantaneous" is in this context meant to be a time period that is short compared to a combustion cycle.

Although HCCI combustion is very well suited for the energy converter according to the invention, conventional spark ignition is on some occasions favourable and could be applied for different reasons: to start the engine at very low temperatures, to create the initial conditions for HCCI, or for example for mode transitions. Of course, spark ignition can also be used for longer periods in cases where this is benificial for the performance of the energy converter.

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CLAIMS

1. An energy converter, comprising
- a combustion system (1) comprising at least one piston (2, 3), at least one combustion chamber (6, 7) provided with at least one inlet (11, 13) and at least one outlet (10, 12), inlet and outlet valves (14, 15, 16, 17), of which at least one inlet valve or at least one outlet valve is controllable, means (18, 19) for supplying fuel and a medium containing oxygen into the combustion chamber (6, 7),
- an electric machine (9) arranged to interact directly or indirectly with the piston (2, 3) in an electromagnetic manner as to produce electrical energy from piston movements as well as to use electrical energy to affect the piston movements, and
- a control unit (30) that controls the combustion system (1) and the electric machine (9),
c h a r a c t e r i z e d i n
that the energy converter is arranged to adapt its power output depending on the required load of the energy converter.

2. An energy converter according to claim 1,
c h a r a c t e r i z e d i n
that the energy converter is arranged to supply the control unit (30) with information on the required load.

3. An energy converter according to claim 1 or 2,
c h a r a c t e r i z e d i n
that the electric machine (9) and at least one of the valves (14, 15, 16, 17) is arranged to be controllable within a time period that is significantly shorter than a combustion cycle of said combustion chamber (6, 7).

4. An energy converter according to any of the above claims,
c h a r a c t e r i z e d i n
that the combustion chamber (6, 7) is provided with at least one fuel injector (18, 19).

5. An energy converter according to any of the above claims,
c h a r a c t e r i z e d i n
that the combustion system is arranged for a compression ignition combustion principle.

6. An energy converter according to any of the above claims,
c h a r a c t e r i z e d i n
that the combustion chamber (6, 7) is provided with at least one spark plug.

7. An energy converter according to any of the above claims,
c h a r a c t e r i z e d i n
that the energy converter is used for propulsion of a vehicle or in a power plant application.

8. An energy converter according to any of the above claims,
c h a r a c t r e r i z e d i n
that said control unit (30) is adapted for controlling at least one of the following operating parameters:
- the amount of fuel per stroke,
- the amount of air per stroke,
- the compression and
- the number of strokes per time unit, i.e. the operating frequency,

in order to to adapt said power output depending on said required load.

9. An energy converter according to claim 8,
c h a r a c t e r i z e d i n

that said control unit (30) is adapted for controlling said frequency by controlling the charging pressure.

10. An energy converter according to any of the preceding claims,
c h a r a c t e r i z e d i n that said combustion system (1) comprises a free piston engine.

11. Method for operating an energy converter, said energy converter comprising:
- a combustion system (1) comprising at least one piston (2, 3), at least one combustion chamber (6, 7) provided with at least one inlet (11, 13) and at least one outlet (10, 12), inlet and outlet valves (14, 15, 16, 17), of which at least one inlet valve or at least one outlet valve is controllable, means (18, 19) for supplying fuel and a medium containing oxygen into the combustion chamber (6, 7),
- an electric machine (9) arranged to interact directly or indirectly with the piston (2, 3) in an electromagnetic manner as to produce electrical energy from piston movements as well as to use electrical energy to affect the piston movements, and
- a control unit (30) that controls the combustion system (1) and the electric machine (9),
- a control unit that controls the combustion system (1) and the electric machine (9), said method being
c h a r a c t e r i z e d i n
that the power output of the energy converter is adapted to the required load of the energy converter.

12. Method according to claim 11,
c h a r a c t e r i z e d i n
that the power output is controlled by varying the amount of fuel per stroke and/or the amount of the oxygen containing medium per stroke.

13. Method according to claim 11 or 12,
c h a r a c t e r i z e d i n

that the combustion system comprises a charging compressor (24) and that the power output is controlled by varying the charging pressure.

14. Method according to any one of claims 11 to 13, c h a r a c t e r i z e d i n that the power output is controlled by selecting different combustion modes.

15. Method according to claim 14, c h a r a c t e r i z e d i n that the different combustion modes comprises: intermittent mode, preferably one-cycle operation, 2-stroke mode, 4-stroke mode and 6-stroke mode.

16. Method of starting an energy converter, said energy converter comprising:

- a combustion system (1) comprising at least one piston (2, 3), at least one combustion chamber (6, 7) provided with at least one inlet (11, 13) and at least one outlet (10, 12), inlet and outlet valves (14, 15, 16, 17), of which at least one inlet valve or at least one outlet valve is controllable, means (18, 19) for supplying fuel and a medium containing oxygen into the combustion chamber (6, 7),
- an electric machine (9) arranged to interact directly or indirectly with the piston (2, 3) in an electromagnetic manner as to produce electrical energy from piston movements as well as to use electrical energy to affect the piston movements,
- a control unit (30) that controls the combustion system (1) and the electric machine (9), and
- a capacitor (43) electrically connected to the electric machine (9),

c h a r a c t e r i z e d i n that said method comprises storing, in said capacitor (43), electrical energy allowing said energy converter ~~is~~ to be started within one stroke of said piston (2, 3).

1/12

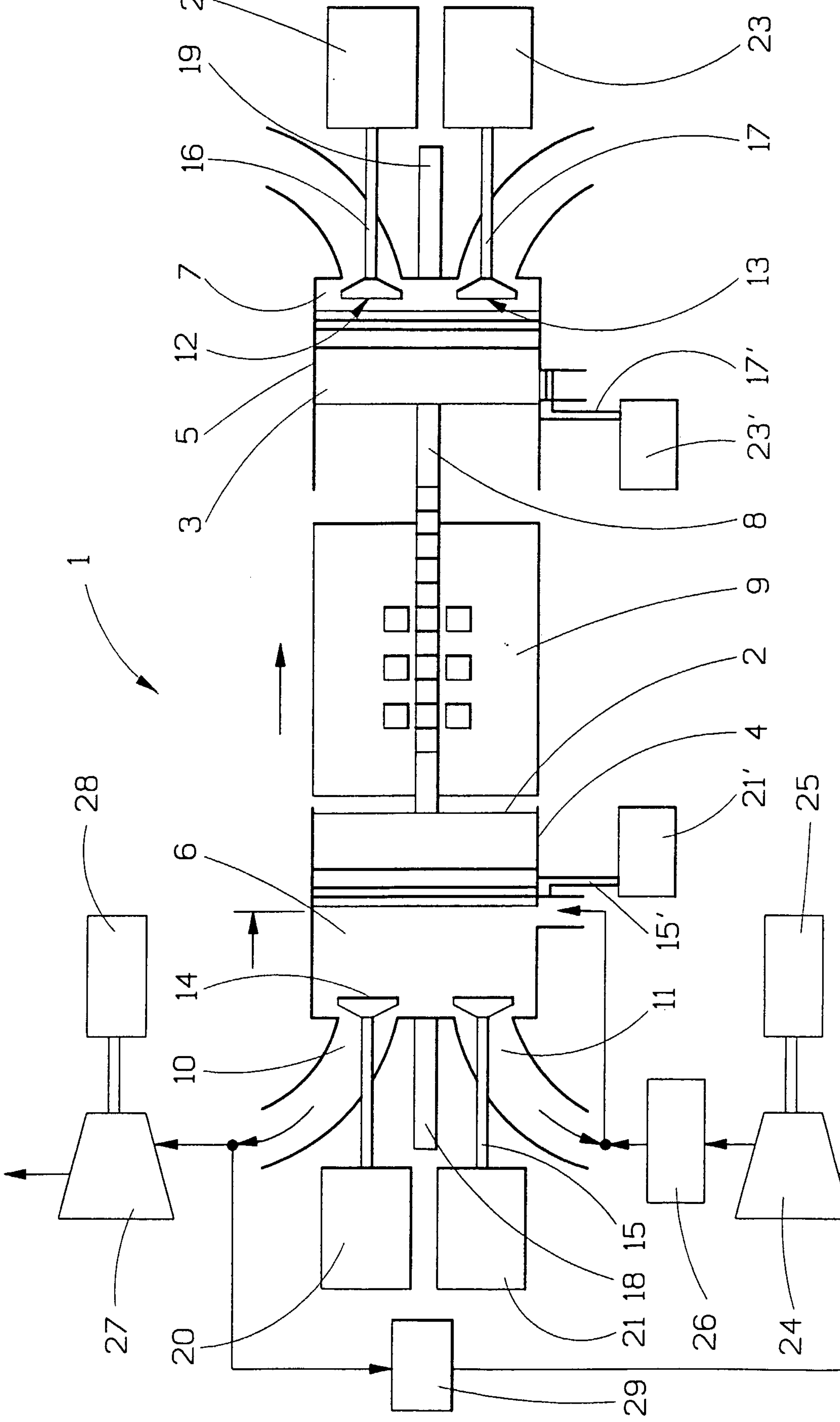

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
15'
16
17
17'
18
19
20
21
21'
22
23
23'
24
25
26
27
28
29

FIG.1

2/12

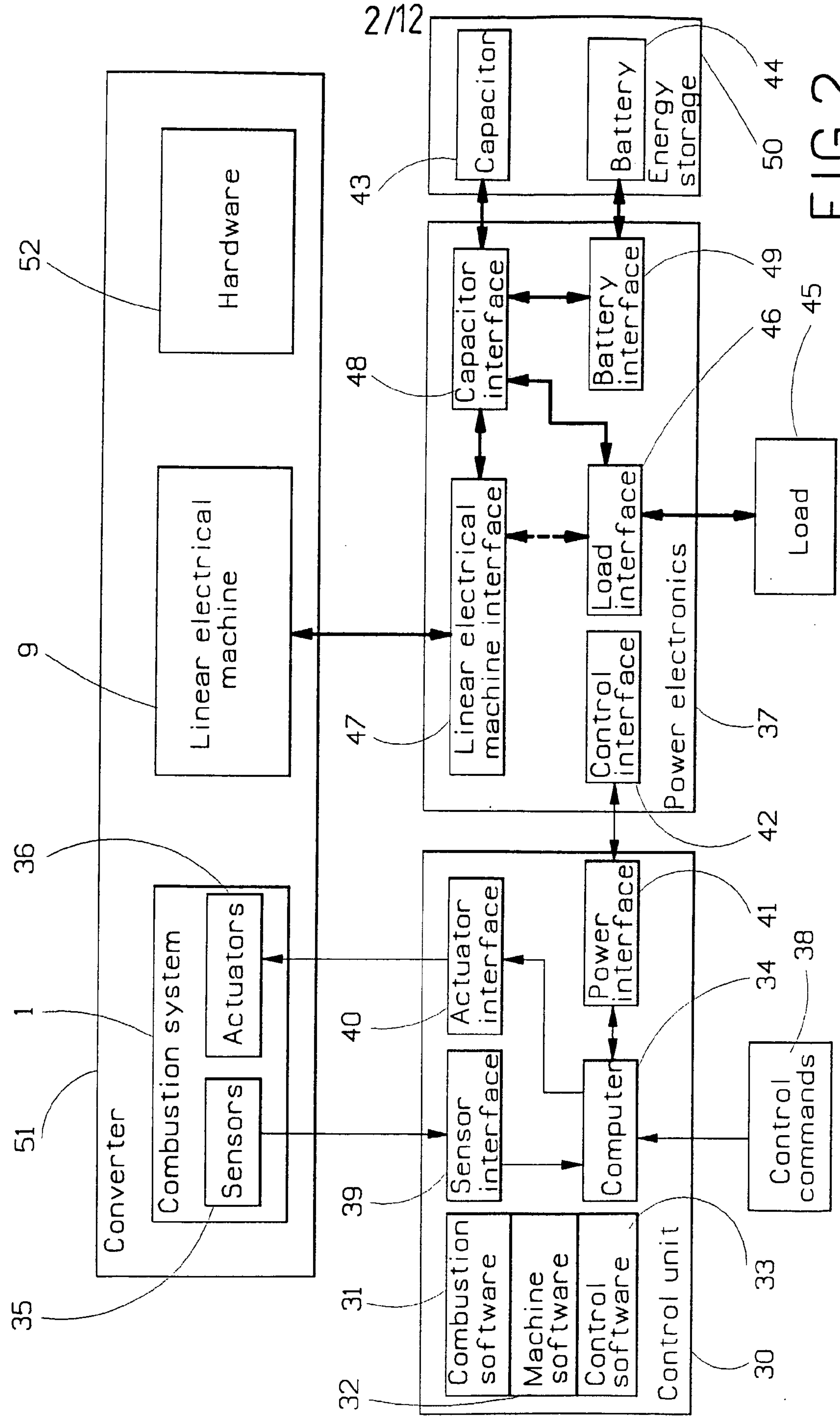

Converter
Combustion system
Sensors
Actuators
Linear electrical machine
Hardware
Control unit
Combustion software
Machine software
Control software
Sensor interface
Actuator interface
Computer
Power interface
Control commands
Power electronics
Linear electrical machine interface
Control interface
Load interface
Capacitor interface
Battery interface
Load
Capacitor
Battery
Energy storage
1
9
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52

FIG.2

Type: Running 12 kW

Power:	11.56 [kW]
Cycle_energy:	182.8 [J]
Frequency:	63.2 [Hz]
Efficiency:	48.6 [%]
Indicated_effic.:	52.8 [%]
Fuel amount:	57.0 [%]
El-force:	-2663.0 [N]

p_atm:	1.0 [bar]	compression:	14.5 [-]
T_atm:	63.0 [C]	valve_intake:	10.0 [% of stroke]
p_0:	1.0 [bar]	valve_exhaust:	10.0 [% of stroke]
T_0:	63.0 [C]	El_efficiency:	92.2 [%]
p_ign:	38.8 [bar]	Moving mass:	4.0 [kg]
T_ign:	627.0 [C]	Diameter:	80.0 [mm]
p_max:	55.3 [bar]	Maximal stroke:	50.0 [mm]
T_max:	1399.0 [C]	Actual stroke:	43.8 [mm]

t_comb:	1.0 [ms]
heat_loss:	0.00025 [W / K*Pa*m2*s]
friction:	60.0 [N]

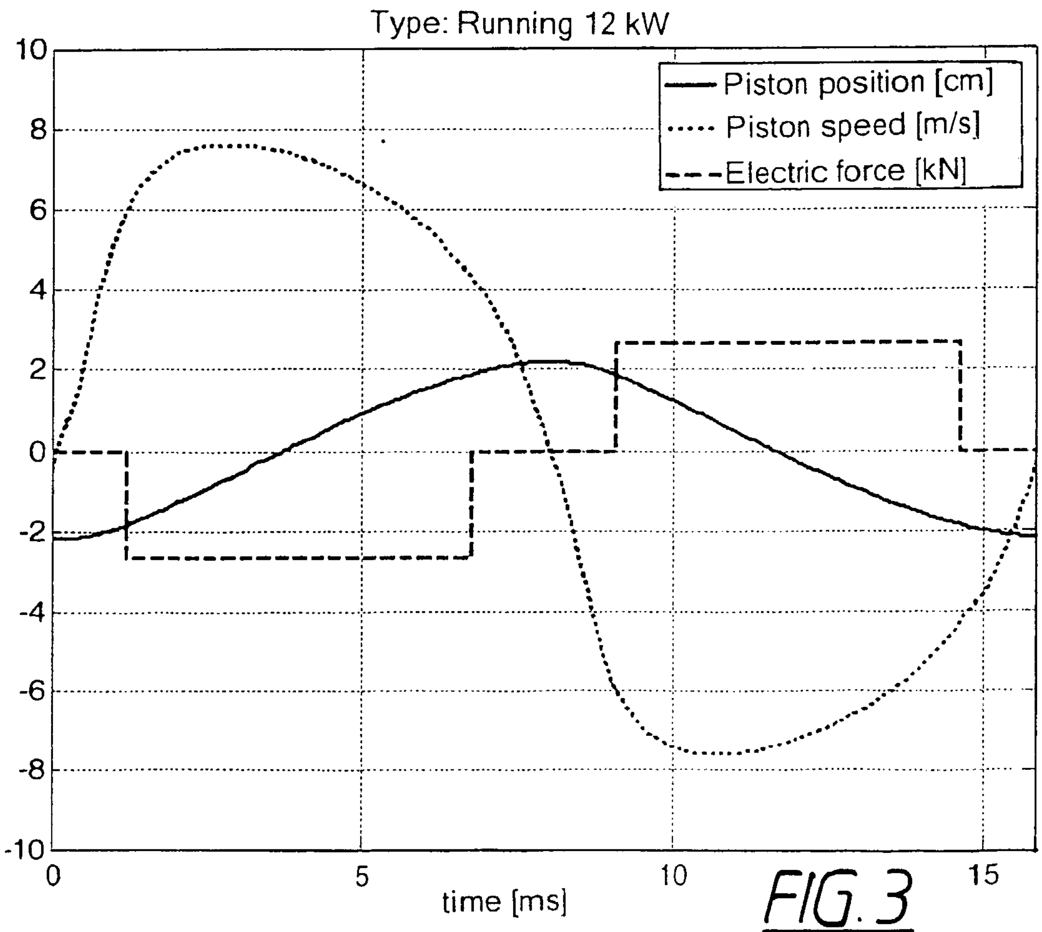


FIG. 3

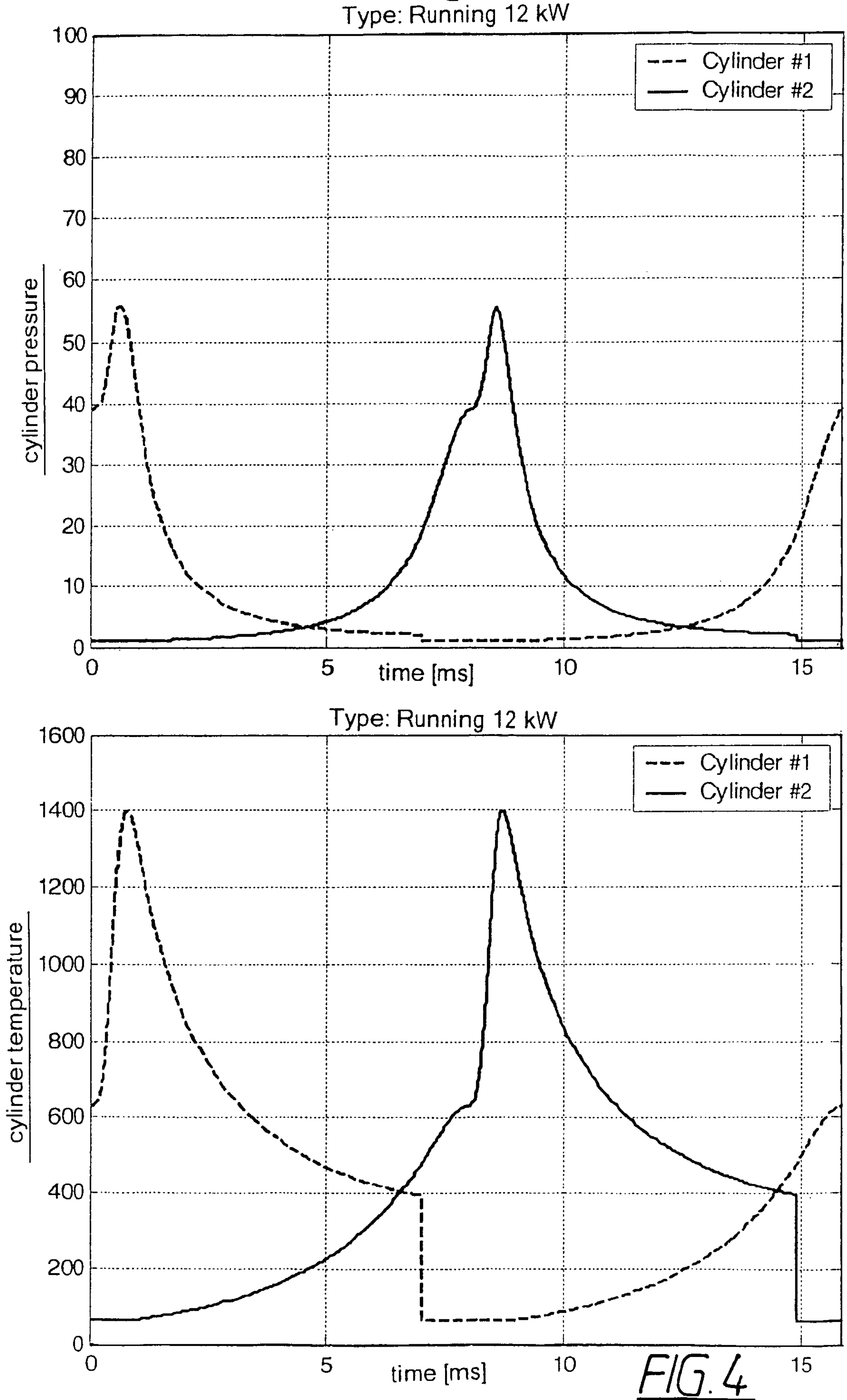

Type: Running 12 kW
Cylinder #1
Cylinder #2
cylinder pressure
time [ms]
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
Type: Running 12 kW
Cylinder #1
Cylinder #2
cylinder temperature
time [ms]
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15

FIG. 4

Type: Single stroke, method 1

Cycle_energy:	18.4	[J]
Cycle_time:	30.1	[ms]
Efficiency:	24.6	[%]
Indicated_effic.:	40.9	[%]
Fuel amount_start:	30.0	[%]
El-force_start:	1380.0	[N]
El-force:	-2663.0	[N]

p_atm:	1.0	[bar]	compression:	14.5	[-]
T_atm:	63.0	[C]	valve_intake_start:	60.0	[% of stroke]
p_0:	1.0	[bar]	valve_exhaust:	10.0	[% of stroke]
T_0:	63.0	[C]	El_efficiency:	92.2	[%]
p_ign:	38.8	[bar]	Moving mass:	4.0	[kg]
T_ign:	627.0	[C]	Diameter:	80.0	[mm]
p_max:	38.7	[bar]	Maximal stroke:	50.0	[mm]
T_max:	851.0	[C]	Actual stroke:	43.8	[mm]

t_comb:	1.0	[ms]
heat_loss:	0.00025	[W / K*Pa*m2*s]
friction:	60.0	[N]

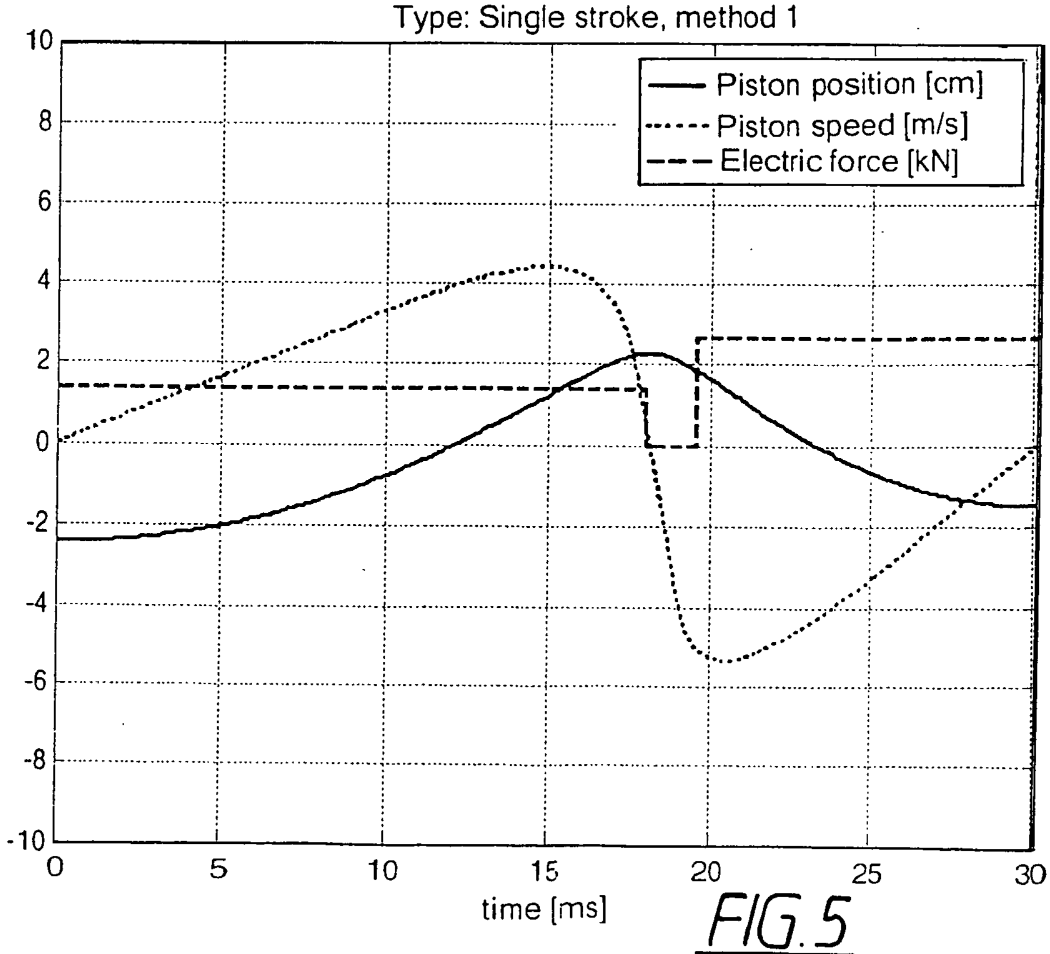


FIG.5

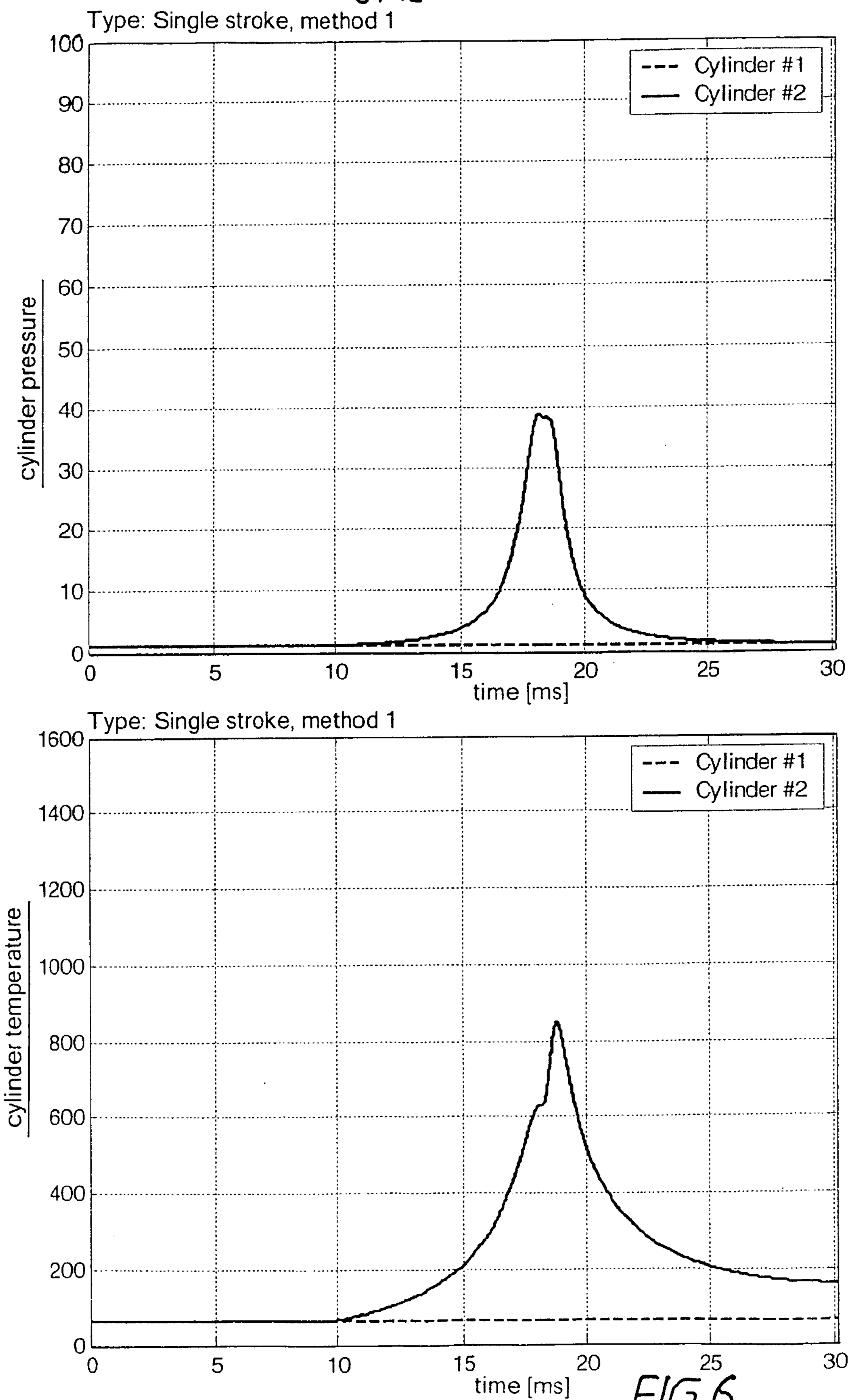

Type: Single stroke, method 1
cylinder pressure
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
time [ms]
Cylinder #1
Cylinder #2
Type: Single stroke, method 1
cylinder temperature
0
200
400
600
800
1000
1200
1400
1600
0
5
10
15
20
25
30
time [ms]
Cylinder #1
Cylinder #2

FIG.6

Type: Single stroke, method 2

Cycle_energy: 73.8 [J]
Cycle_time: 36.4 [ms]
Efficiency: 39.3 [%]
Indicated_effic.: 50.2 [%]
Fuel amount_start: 57.0 [%]
El-force_start: 1850.0 [N]
El-force: -2400.0 [N]

p_atm: 1.0 [bar]
T_atm: 63.0 [C]
p_0: 1.0 [bar]
T_0: 63.0 [C]
p_ign: 38.8 [bar]
T_ign: 627.0 [C]
p_max: 55.3 [bar]
T_max: 1394.0 [C]

compression: 14.5 [-]
valve_intake_start: 10.0 [% of stroke]
valve_exhaust: 10.0 [% of stroke]
El_efficiency: 92.2 [%]
Moving mass: 4.0 [kg]
Diameter: 80.0 [mm]
Maximal stroke: 50.0 [mm]
Actual stroke: 43.8 [mm]

t_comb: 1.0 [ms]
heat_loss: 0.00025 [W / K*Pa*m2*s]
friction: 60.0 [N]

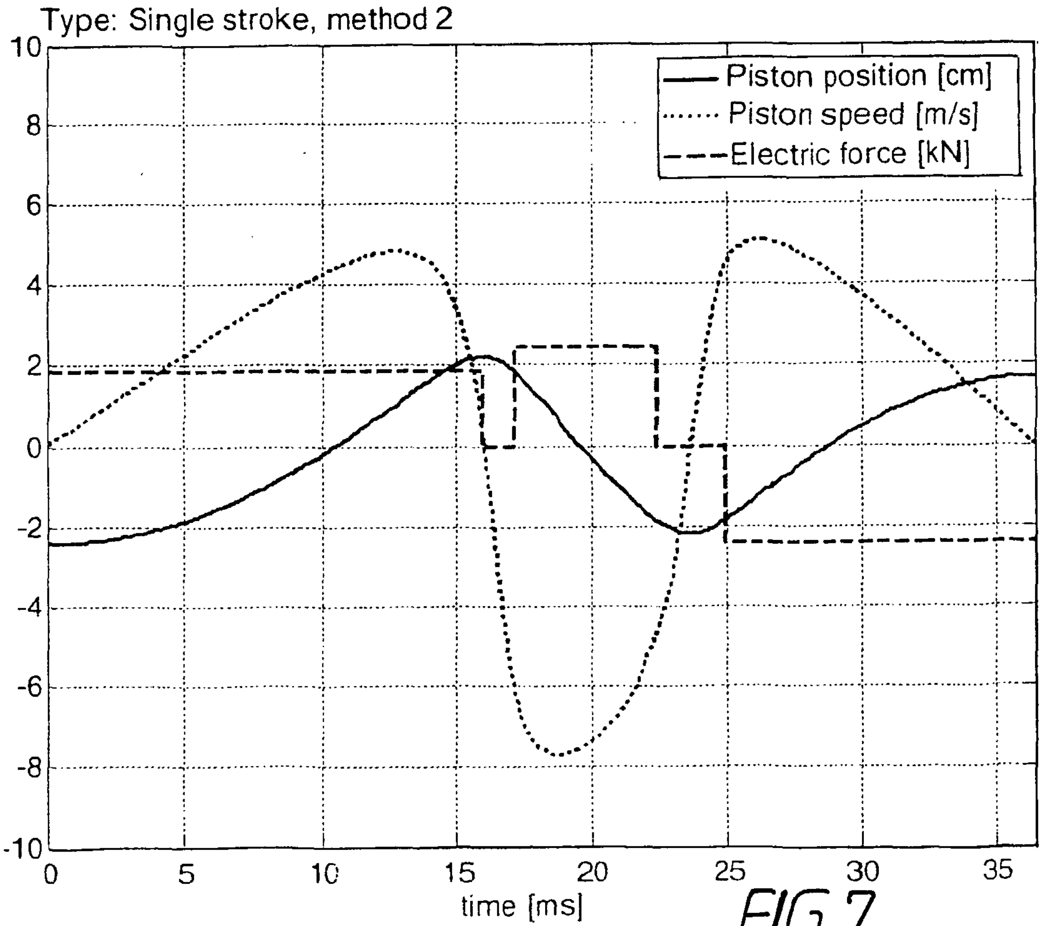
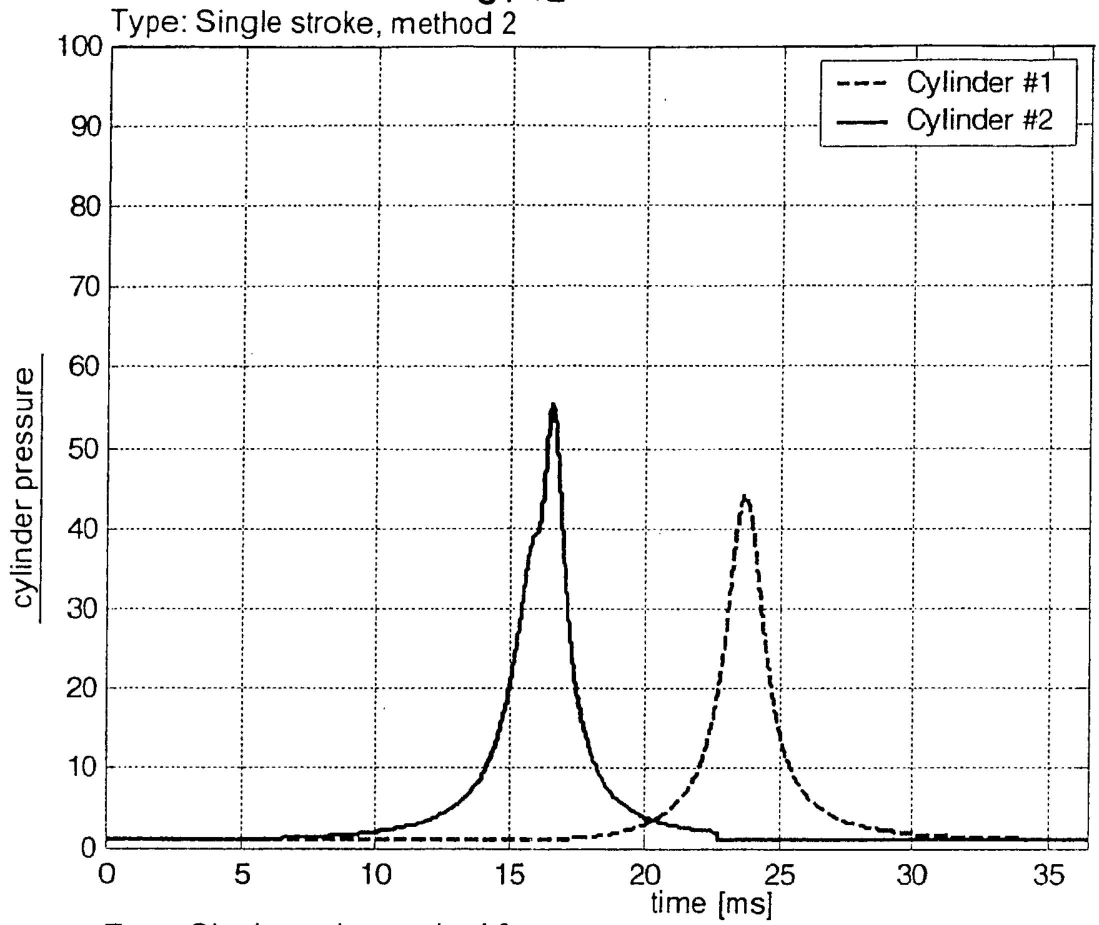


FIG.7


Type: Single stroke, method 2
Cylinder #1
Cylinder #2
cylinder pressure
time [ms]
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35

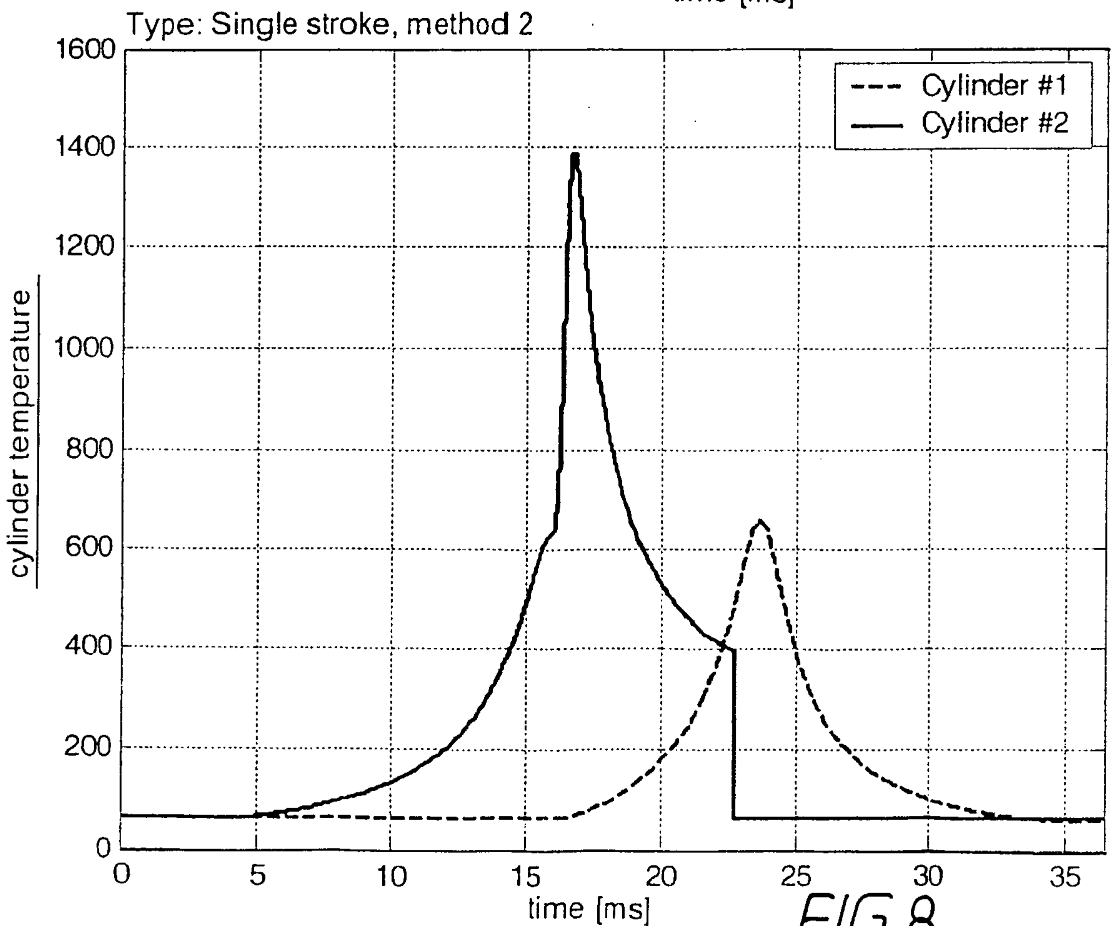

Type: Single stroke, method 2
Cylinder #1
Cylinder #2
cylinder temperature
time [ms]
0
200
400
600
800
1000
1200
1400
1600
0
5
10
15
20
25
30
35

FIG.8

Type: Single stroke, method 2. Cold start -30°C

Cycle_energy:	61.8 [J]
Cycle_time:	32.9 [ms]
Efficiency:	30.7 [%]
Indicated_effic.:	43.1 [%]
Fuel amount_start:	57.0 [%]
El-force_start:	2500.0 [N]
El-force:	-2500.0 [N]

p_atm:	1.0 [bar]	compression:	33.9 [-]
T_atm:	-30.0 [C]	valve_intake_start:	59.0 [% of stroke]
p_0:	1.0 [bar]	valve_exhaust:	10.0 [% of stroke]
T_0:	-30.0 [C]	El_efficiency:	92.2 [%]
p_ign:	125.7 [bar]	Moving mass:	4.0 [kg]
T_ign:	627.0 [C]	Diameter:	80.0 [mm]
p_max:	146.2 [bar]	Maximal stroke:	50.0 [mm]
T_max:	834.3 [C]	Actual stroke:	47.3 [mm]

t_comb:	1.0 [ms]
heat_loss:	0.00025 [W / K*Pa*m2*s]
friction:	60.0 [N]

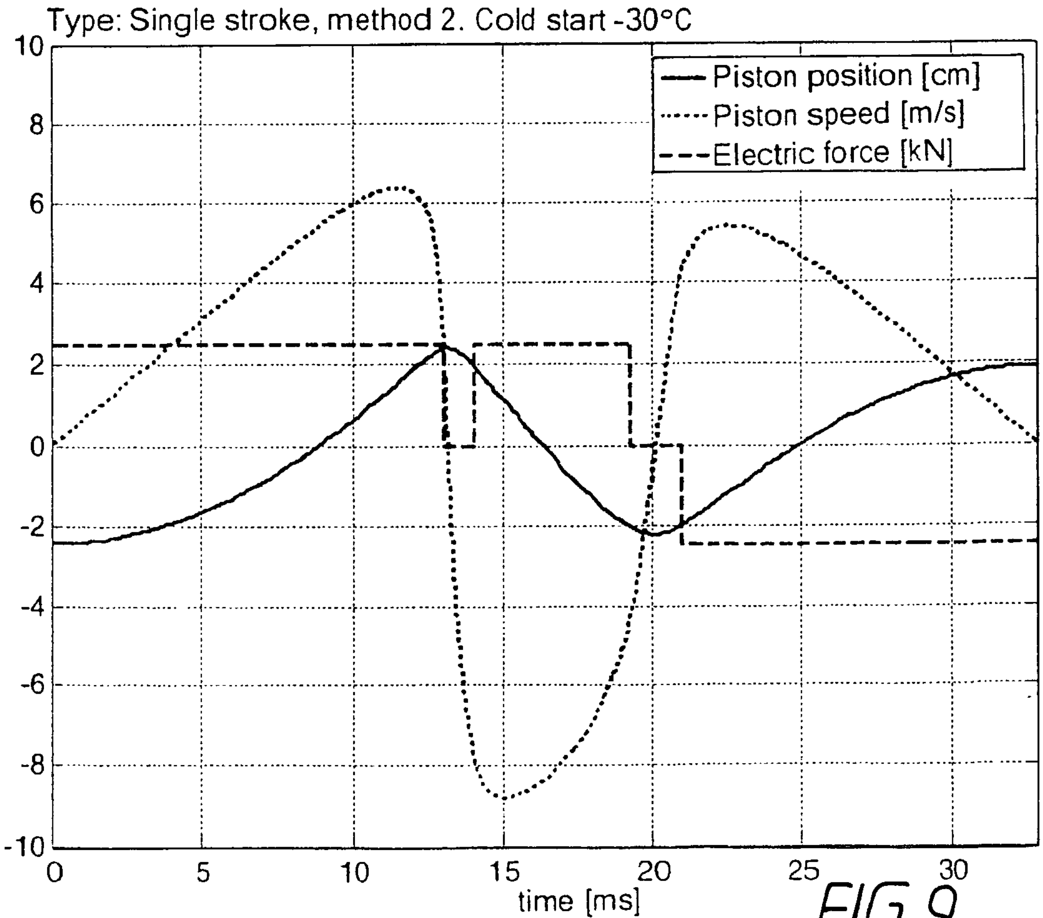


FIG. 9

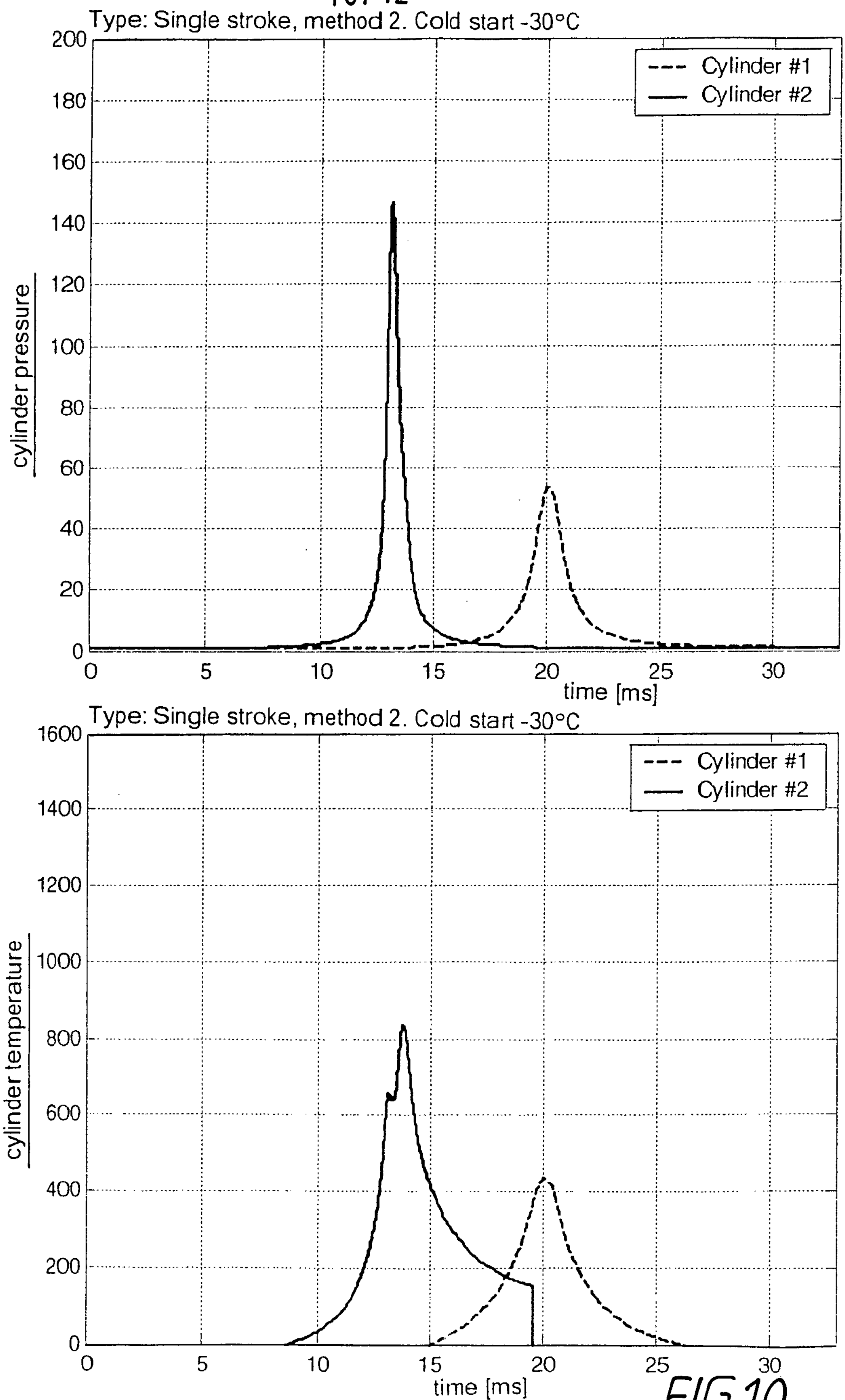

Type: Single stroke, method 2. Cold start -30°C
Cylinder #1
Cylinder #2
cylinder pressure
200
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
time [ms]
Type: Single stroke, method 2. Cold start -30°C
Cylinder #1
Cylinder #2
cylinder temperature
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
time [ms]

FIG.10

Type: Running. 39 kW. High power with supercharging.

Power:	39.13 [kW]
Cycle_energy:	427.9 [J]
Frequency:	91.4 [Hz]
Efficiency:	52.0 [%]
Indicated_effic.:	56.4 [%]
Fuel amount:	60.0 [%]
El-force:	-5897.0 [N]

p_atm:	1.0 [bar]	compression:	14.2 [-]
T_atm:	50.0 [C]	valve_intake:	10.0 [% of stroke]
p_0:	2.0 [bar]	valve_exhaust:	10.0 [% of stroke]
T_0:	50.0 [C]	El_efficiency:	92.2 [%]
p_ign:	75.8 [bar]	Moving mass:	4.0 [kg]
T_ign:	587.0 [C]	Diameter:	80.0 [mm]
p_max:	134.4 [bar]	Maximal stroke:	50.0 [mm]
T_max:	1527.5 [C]	Actual stroke:	43.7 [mm]

t_comb:	0.5 [ms]
heat_loss:	0.00025 [W / K*Pa*m2*s]
friction:	60.0 [N]

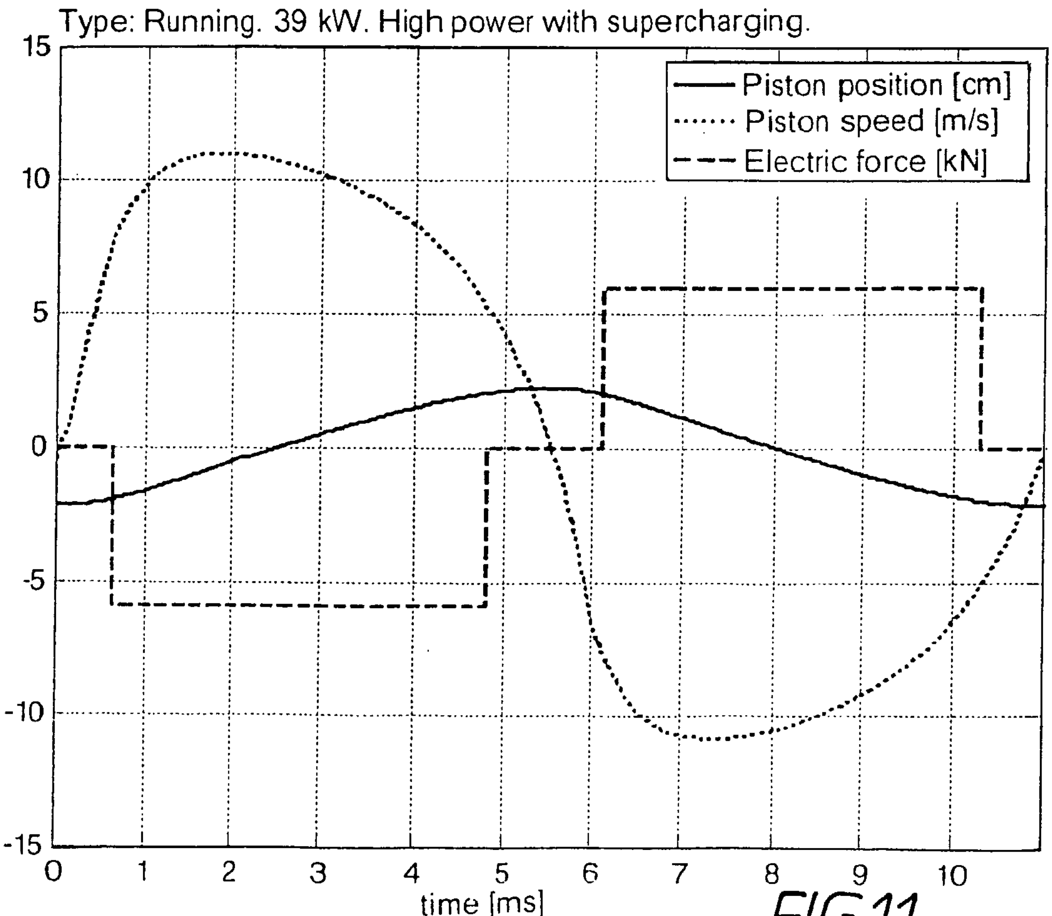


FIG.11

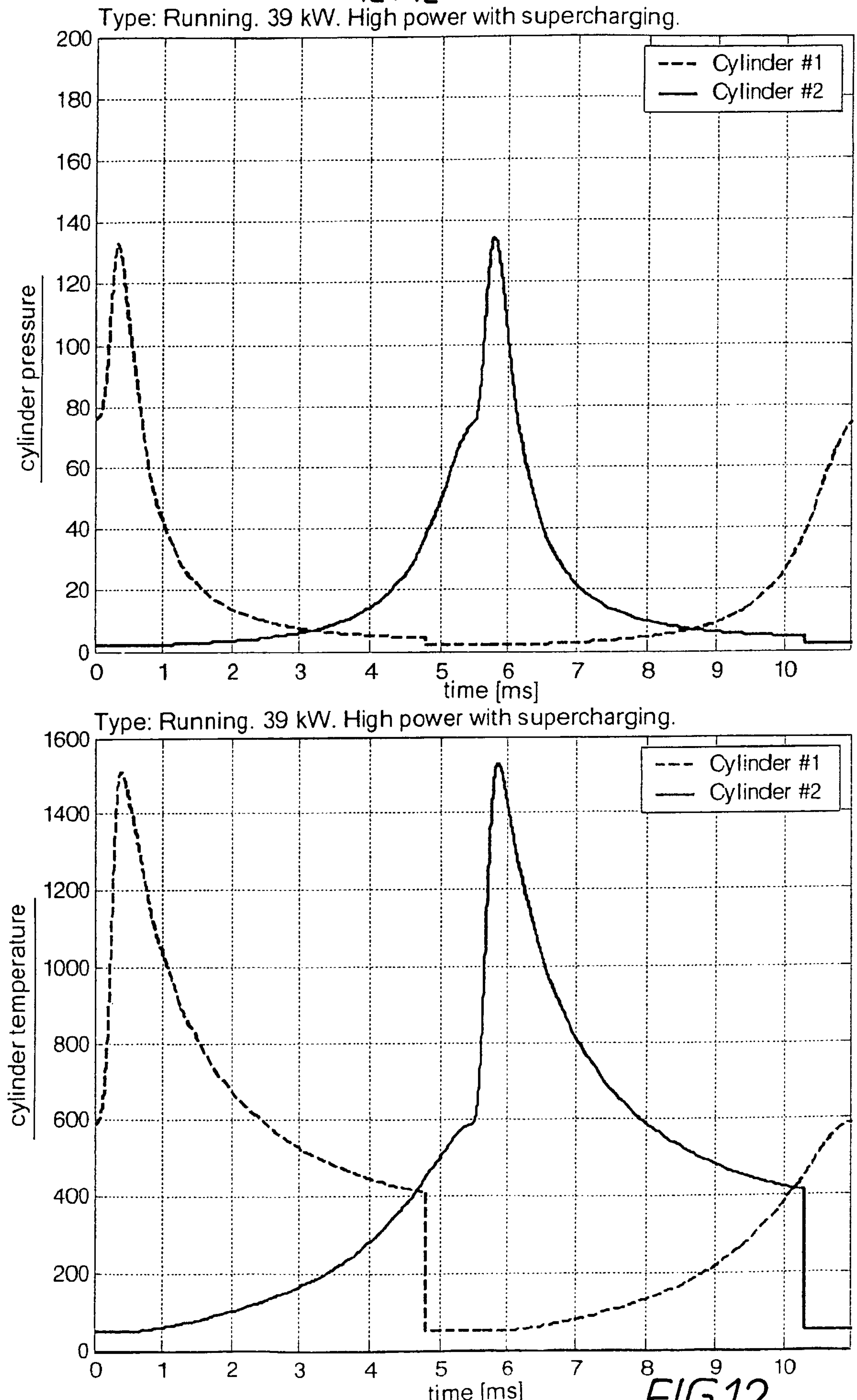

Type: Running. 39 kW. High power with supercharging.
Cylinder #1
Cylinder #2
cylinder pressure
time [ms]
0
20
40
60
80
100
120
140
160
180
200
0 1 2 3 4 5 6 7 8 9 10
Type: Running. 39 kW. High power with supercharging.
Cylinder #1
Cylinder #2
cylinder temperature
time [ms]
0
200
400
600
800
1000
1200
1400
1600
0 1 2 3 4 5 6 7 8 9 10

FIG.12

INTERNATIONAL SEARCH REPORT

International Application No
PCT/SE 03/01441

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F02B71/04

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 7 F02B

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

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

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

	Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
2	A	WO 00 55482 A (PINSKY FELIX ILIICH ;PINSKY TIMUR FELIXSOVICH (RU)) 21 September 2000 (2000-09-21) the whole document ---	1-16
5	A	DE 37 27 335 A (BIEBER GEROLD ING GRAD) 25 February 1988 (1988-02-25) the whole document ---	1-16
2	A	DE 38 43 207 A (HINGER KLAUS JUERGEN PROF DR I) 7 June 1990 (1990-06-07) the whole document ---	1-16
2	A	DE 199 43 993 A (VOLKSWAGENWERK AG) 15 March 2001 (2001-03-15) the whole document ---	1-16

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 December 2003	08. 01. 2004

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/SE 03/01441

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

	Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/SE 03/01441

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