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(71) Applicant (for all designated States except US): **PONTI MOTORS S.r.l.** [IT/IT]; Frazione Cerbara, Via Carlo Marx. 1, I-06012, Citta di Castetlo, Perugia (IT).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **CIACCINI, Marco** [IT/IT]; Via Verna, 6, I-06018, Umbertide, Perugia (IT).

(74) Agent: **LEIHKAU, Steffen**; c/o Jacobacci & Partners S.p.A., Via Senato, 8, I-20121 Milano (IT).

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(54) Title: METHOD FOR OPERATING A INTERNAL COMBUSTION ENGINE AND A INTERNAL COMBUSTION ENGINE

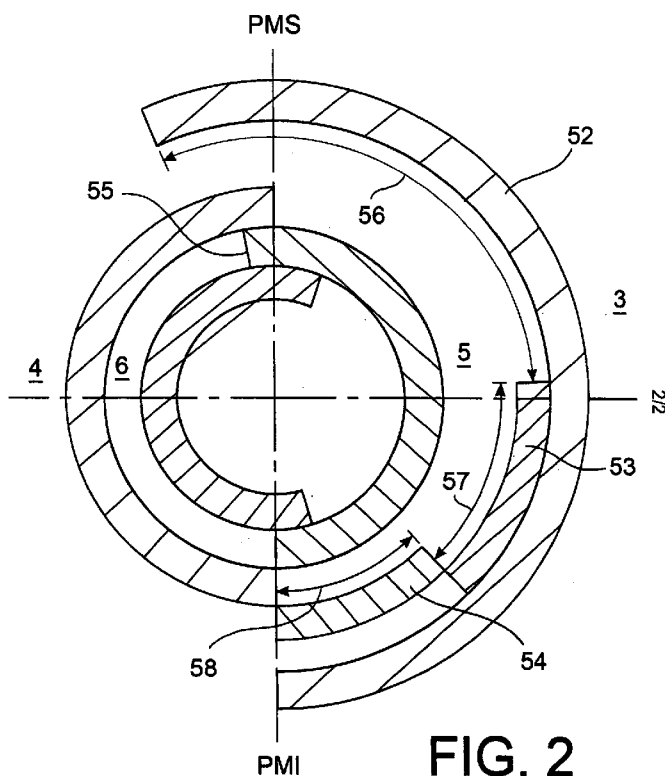


FIG. 2

(57) Abstract: A method for operating an internal combustion engine (1) of the type comprising a system (7) for feeding fuel to the explosion chamber and a system (8) for generating water vapour (V) and feeding the water vapour (V) to the explosion chamber, having the steps of generating water vapour (V)1 feeding (52) comburent air into the explosion chamber during the suction step (3), feeding (53) at least part of the water vapour generated in the explosion chamber during the suction step (3), feeding (54) fuel into the explosion chamber during the suction step (3), wherein the vapour (V) generated and fed into the explosion chamber is dry and overheated water vapour.



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DESCRIPTION**“METHOD FOR OPERATING AN INTERNAL COMBUSTION ENGINE AND
INTERNAL COMBUSTION ENGINE”**

[0001] The object of the present invention is a method for operating an internal
5 combustion engine of the type comprising at least one cylinder-piston unit defining
an explosion chamber and wherein the piston is cyclically movable between a top
dead centre TDC and a bottom dead centre BDC, determining a suction step, a
compression step, a combustion and expansion step and an exhaust step in a
sequence, as well as a system for feeding fuel to the explosion chamber, a system
10 for feeding water vapour to the explosion chamber and a system for feeding
comburent air to the explosion chamber.

[0002] A further object of the present invention is an internal combustion chamber
designed for implementing the above method.

[0003] From the theoretical point of view, it is known to combine the principle of the
15 internal combustion engine (according to which the chemical combustion reaction
generates combustion gases that exert a pressure on a piston, transforming
chemical energy into mechanical energy) with the principle of the steam engine
(according to which the thermal expansion of the water vapour exerts a pressure
on a piston, transforming the thermal energy into mechanical energy) in order to
20 transform also a part of the heat produced by the combustion reaction into
mechanical energy.

[0004] In order to reduce fuel consumption and noxious emissions of existing
combustion engines, the idea of feeding water or water vapour directly into the
explosion chamber of the internal combustion engine has been developed, so that
25 the combustion occurs in direct contact with the vapour and the pressure
generated by the thermal expansion of the water vapour acts together with the
pressure generated by the combustion gases on the same piston.

[0005] However, to date it has not been possible to tune the fuel inlet, vapour and
water inlet times, and determine and provide the amounts of vapour, air and fuel
30 and the characteristics of the vapour itself so as to ensure a reliable operation of
the engine and obtain the desired reductions of fuel consumption and polluting
emissions.

[0006] The object of the present invention therefore is to propose a method for
operating an internal combustion engine of the type specified above, having such

features as to ensure a reliable engine operation and reduce, at the same time, both fuel consumption and polluting emissions, in particular nitrogen oxides, carbon dioxide and fine powders.

[0007] This and other objects are achieved by a method for operating an internal

5 combustion engine of the type comprising at least one cylinder-piston unit defining an explosion chamber and wherein the piston is cyclically movable within the cylinder between a top dead centre TDC and a bottom dead centre BTM, determining a suction step, a compression step, a combustion and expansion step and an exhaust step of the explosion chamber in a sequence, as well as a system
10 for feeding fuel to the explosion chamber, a system for feeding the water vapour to the explosion chamber, a plant for feeding comburent air to the explosion chamber and a fuel ignition device,

such method comprising the steps of:

- 15 - setting the piston in a cyclical movement between the top dead centre TDC and the bottom dead centre BDC;
- generating water vapour;
- feeding comburent air into the explosion chamber during the suction step;
- feeding at least part of the water vapour generated into the explosion chamber during the suction step;
- 20 - feeding fuel into the explosion chamber during the suction step;
- following the suction step, compressing the mixture of comburent air, water vapour and fuel during the compression step;
- igniting the fuel when the piston is close to the top dead centre, in a transition step between the compression step and the subsequent expansion step, so that
- 25 the combustion gases and the thermal expansion of the vapour exert a pressure on the piston during the expansion step;
- during the exhaust step, venting from the cylinder explosion chamber the gases present therein,

characterised by generating and feeding dry and overheated water vapour into
30 the explosion chamber.

Water vapour with these features combines particularly well the opposite needs for compressibility (during the compression step), thermal capacity (for actively cooling the explosion chamber, reducing the formation of nitrogen oxides) and thermal expansion (for increasing the engine power).

[0008] According to a further aspect of the invention, the step of feeding the comburent air to the explosion chamber comprises:

- an initial step of feeding only air without feeding the generated water vapour and the fuel;

5 - a subsequent step of concurrent feeding of air and of the water vapour generated without feeding fuel;

- a final step of concurrent feeding of air and fuel without feeding vapour.

[0009] Thanks to this particular definition of the injection steps of air, vapour and fuel in the explosion chamber of the cylinder, such arrangement and partial mixing
10 of the three components is obtained that the subsequent compression step is not opposed and hindered and thus, a reliable operation of the engine itself is ensured.

[0010] To better understand the invention and appreciate its advantages, some exemplary non-limiting embodiments thereof will now be described with reference to the figures, wherein:

15 [0011] - figure 1 shows a schematic view of an engine with a fuel feeding system and a water vapour feeding system according to an embodiment of the invention;

[0012] - figure 2 shows a schematic view of the steps of a method for operating an internal combustion engine according to an embodiment of the invention;

[0013] - figure 3 shows a schematic view of a system for controlling the engine in
20 figure 1 according to an embodiment of the invention.

[0014] With reference to figure 1, an internal combustion engine 1 comprises at least one cylinder-piston unit 2 defining an explosion chamber and wherein the piston is cyclically movable within the cylinder between a top dead centre TDC and a bottom dead centre BTM, determining a suction step 3, a compression step 4, an
25 expansion step 5 and an exhaust step 6 of the explosion chamber, as well as a system 7 for feeding fuel to the explosion chamber, a system 8 for generating water vapour and feeding the water vapour to the explosion chamber, a system 9 for feeding comburent air to the explosion chamber and a fuel ignition device 10.

[0015] The system for generating and feeding water vapour 8 may comprise a
30 water tank 11 connected by a water pump 12 and a water conduit 13 to a vapour generator 14.

[0016] The water flow from tank 11 to the vapour generator 14 is indicated by arrow A.

[0017] The vapour generator 14 comprises a heat exchanger designed for placing

the water in thermal exchange connection with a flow of exhaust gases vented by the cylinder-piston unit 2 and/or in thermal exchange connection with a motor block that forms the cylinder of the cylinder-piston unit 2, so as to overheat water and transform it into vapour.

5 [0018] For example, vapour generator 14 may comprise a reaction chamber that receives the water to be vaporised, as well as a branching conduit 15 of a header 16 of the exhaust gases of the cylinder-piston unit 2, extended through the interior of the reaction chamber.

10 [0019] A vapour outlet of the vapour generator 14 is connected by a vapour conduit 22 to a vapour injection unit 23 designed for injecting vapour V produced by the vapour generator 14 into the explosion chamber of the cylinder-piston unit 2.

[0020] To eject the produced excess vapour R1 not injected in the cylinder-piston unit 2 there may be provided a vapour ejection conduit 25 with a vapour ejection valve 24 that connect the vapour injection unit 23 to a vapour condenser 26
15 intended for cooling and expanding vapour in order to recover it into liquid water. The vapour condenser 26 is in turn connected by a recirculation conduit 27 to water tank 11 for reintroducing condensate R2 again thereto.

[0021] To adjust the features of the water vapour generated in vapour generator 14, in particular temperature and pressure, there may be provided:

20 [0022] – an exhaust gas flow valve 18 located in the exhaust header 16 upstream of the vapour generator 14 and designed for controlling the rate of the exhaust gas flow in input to the vapour generator 14;

[0023] – an exhaust gas obstruction valve 19 located downstream of the vapour generator 14 and designed for controlling the rate of the exhaust gas flow in output
25 from the vapour generator 14 towards an exhaust tube 20 downstream of the exhaust header 4;

[0024] – a vapour adjustment valve 21 located in the vapour conduit 22 between the vapour generator 14 and the vapour injection unit 23 and designed for allowing only water vapour having the desired features (in particular, temperature and
30 pressure) to the vapour injection unit 23.

[0025] The above valves 18, 19, 21 and the vapour injection unit 23 are controlled by a vapour control unit 17 that comprises a microprocessor and a memory and that is in signal connection with a plurality of sensors of engine 1 that shall be described hereinafter.

[0026] According to an embodiment, the vapour feeding system 8 further comprises an end system 28 for vapour recovery, arranged in the proximity of an exhaust terminal 29 and designed for capturing the final condensates R3 present therein and reintroducing them back into the water tank 11.

5 [0027] The fuel feeding system 7 may comprise a fuel tank 28 connected by a fuel conduit 29 and a fuel pump 30 with a fuel injection unit 31 designed for injecting the fuel into the explosion chamber of the cylinder-piston unit 2.

[0028] A fuel recirculation conduit 35 may be provided for ejecting and recirculating fuel in excess not injected in the cylinder-piston unit 2 which connects the fuel
10 injection unit 33 to the fuel tank 30.

[0029] The fuel injection unit 31 is controlled by a fuel control unit 34 that comprises a microprocessor and a memory and that is in signal connection with a plurality of sensors of engine 1 that shall be described hereinafter.

[0030] The vapour control unit 17 and the fuel control unit 34 may be two separate
15 control units, two separate control units connected in signal communication or, as an alternative, combined in a single central engine controller.

[0031] Besides the vapour feeding and the fuel feeding, the engine control system also pilots and regulates the air feeding and the fuel-air mixture ignition.

[0032] According to a preferred embodiment, the engine control system with the
20 vapour control unit 17 and the fuel control unit 34 is in signal connection with:

- an RPM sensor 36 which detects the number of revolutions of engine 1;
- a position sensor 37 which detects the instant when the top dead centre TDC is reached;
- an air flowmeter 38 which detects the amount of air sucked by engine 1;
- 25 – an engine temperature sensor 39 which detects the operating temperature of engine 1;
- a fuel pressure sensor 40 which detects the fuel injection pressure;
- a vapour pressure sensor 41 which detects the pressure of the generated vapour;
- 30 – a vapour temperature sensor 51 which detects the temperature of the generated vapour;
- an exhaust gas temperature sensor 42 which detects the temperature of exhaust gases, for example in the exhaust header 16;
- an exhaust gas combustion sensor 43 which provides an Air Fuel Ratio based on

the composition of exhaust gases, for example based on oxygen concentration;

- an accelerator sensor 44 which detects the engine power demand by the user;
- an engine knock temperature sensor 45 which detects the thermo-mechanical efficiency in the explosion chamber of the cylinder-piston unit;

5 – an exhaust gas pressure sensor 46 which detects the pressure of exhaust gases in the exhaust header 16;

- an air vacuum sensor 47 which detects the vacuum in the air flow sucked by the engine;

10 – an air temperature sensor 48 which detects the temperature of the air sucked by the engine;

- an engine coolant temperature sensor 49 which detects the temperature of the engine coolant;

- an atmospheric pressure sensor 50 which detects the atmospheric pressure outside the engine,

15 and regulates, based on the parameters provided by the above sensors and by the fuel injection unit 33 and the vapour injection unit 23, the amounts (duration and pressure) of fuel and vapour injected in the explosion chamber.

[0033] Moreover, in piloted ignition engines, the control system determines and regulates, through an ignition device 10, for example an ignition coil, the explosion
20 time or in other words, the ignition angle.

[0034] According to an aspect of the invention, the method for operating the internal combustion engine 1 comprises the steps of:

- setting the piston in a cyclical movement between the top dead centre TDC and the bottom dead centre BDC;
- 25 – generating water vapour V;
- feeding comburent air 52 into the explosion chamber during the suction step 3;
- feeding at least part of the water vapour generated 53 in the explosion chamber during the suction step 3;
- feeding fuel 54 into the explosion chamber during the suction step 3;
- 30 – subsequent to the suction step 3, compressing the mixture of comburent air, water vapour and fuel during the compression step 4;
- igniting 55 the fuel when the piston is close to the top dead centre, in a transition step between the compression step 4 and the subsequent expansion step 5, so that the combustion gases and the thermal expansion of the vapour exert a

pressure on the piston during the expansion step 5;

- during the exhaust step 6, venting from the explosion chamber the gases present therein,

wherein the vapour generated and fed to the explosion chamber is dry and
5 overheated water vapour having titre 1 (with reference to a substantially pure water vapour).

The overheated vapour phase can for example be provided based on the temperature and pressure of the vapour itself, for example 14 bar and 200 °C corresponds to a saturated vapour and 14 bar and 210 degrees corresponds to a
10 dry and overheated vapour.

[0035] A dry and overheated water vapour, thanks to its specific volume, to its thermal capacity and to its distance from the saturation and condensation point, combines particularly well the opposite needs for compressibility (during the compression step), thermal capacity (for actively cooling the explosion chamber,
15 reducing the formation of nitrogen oxides) and thermal expansion (for increasing the engine power during the expansion).

[0036] Advantageously, the water vapour is generated and injected in the explosion chamber in a temperature range from 150°C to 800°C, preferably from 250°C to 350°C, as well as at a pressure from 1.5 bar to 60 bar, preferably from 10
20 bar to 30 bar, even more preferably about 15 bar.

[0037] The present invention further provides, preferably, for the possibility of injecting the generated water vapour in indirect injection engines for an injection time adjustable over a range of 0 to 90 degrees.

[0038] In direct injection gasoline engines, the generated water vapour may be
25 injected for an injection time adjustable over a range of 90 to 195 degrees. Moreover, the vapour injection may be carried out upstream of the valves in direct injection.

[0039] In direct injection diesel engines, the generated water vapour may be injected for an injection time adjustable over a range of 180 to 270 degrees (the
30 above indications refer to an engine cycle expressed in 360° and corresponding to a piston movement from top dead centre TDC – to bottom dead centre BDC – from bottom dead centre BDC – to top dead centre TDC)

[0040] According to a further aspect of the invention, in particular with reference to indirect injection engines, the step of feeding the comburent air 52 to the explosion

chamber comprises:

- an initial step 56 of feeding only air without feeding the generated water vapour and the fuel;
- a subsequent step 57 of concurrent feeding of air and of the water vapour generated without feeding fuel;
- a subsequent final step 58 of concurrent feeding of air and fuel without feeding vapour.

[0041] Thanks to this particular definition of the sequence of injection steps of air, vapour and fuel in the explosion chamber of the cylinder-piston unit, such arrangement and partial mixing of the three components is obtained that the subsequent compression step is not opposed and hindered and thus, a reliable operation of the engine itself is ensured.

[0042] According to an embodiment, the vapour feeding (or injection) step 53 begins after the start of the air feeding (or injection) step 52 and the fuel feeding (or injection) step 54 begins after the start of the vapour feeding step 53, wherein preferably the entire vapour feeding step 53 takes place during the air feeding step 52, the entire step fuel feeding step 54 takes place during such air feeding step 52.

[0043] The beginning of the fuel feeding step 54 may be overlapped to the end of the vapour feeding step 53 for an interval of around 0 degrees to around 1 degree of the engine cycle.

[0044] Alternatively, the fuel feeding step 54 begins after the end of the vapour feeding step 53.

[0045] According to an embodiment, the air feeding step 52 is started in advance relative to the top dead centre TDC and extends up to 90 degrees of the engine cycle from the top dead centre TDC, whereas the vapour feeding step 53 preferably takes place in an interval shorter than or equal to, 45 degrees of the engine cycle.

[0046] The fuel feeding step 54 preferably takes place in an interval shorter than or equal to, 45 degrees of the engine cycle.

[0047] According to an even further aspect of the invention, the method comprises the step of piloting pressure, the start time and the duration of the vapour feeding 53 and fuel feeding 54 steps so as to determine an Air Fuel Ratio (AFR) comprised within the range from 9:1 to 22:1, preferably from 13:1 to 18:1, even more preferably of about 18:1. Within the scope of the present description, by $AFR = 1$ it

is meant the theoretical air fuel ratio for a complete combustion, and by $AFR = X : 1$ it is meant a situation wherein the comburent contents is X times higher than that theoretically required for a complete combustion.

5 [0048] These air fuel ratios are possible thanks to the controlled cooling of the explosion chamber by the water vapour fed and allow considerably reducing the formation of fine powders, nitrogen oxides and sulphur dioxide, as well as decreasing the formation of carbon dioxide thanks to an almost complete combustion.

10 [0049] According to an important aspect of the invention, the amount of vapour to be injected in the explosion chamber is determined, through the control system 17, 34 described above, according to the engine operating temperature, in particular the amount of vapour injected in the explosion chamber is increased as the engine temperature increases and decreased as the engine temperature sensed, for example by the engine temperature sensor 39 described above, is decreased.

15 [0050] According to a preferred embodiment, the ratio between the vapour amount and the amount of fuel injected in the explosion chamber is increased as the engine temperature increases and decreased as the engine temperature is decreased.

20 [0051] By way of a non limiting example, an amount of vapour may be injected with cold engine (expressed as injection time) substantially equal to the amount (expressed as injection time) of fuel injected (at low engine speeds) up to injecting an amount of vapour around three times higher than the amount of fuel injected (at high engine speeds) with hot engine, that is, at T approximately equal to 600°C – 900°C.

25 [0052] Since the energy contribution offered by vapour is directly dependent on the combustion temperatures, an adjustment of the vapour amount based on the engine temperature combines in a synergic manner the effect of a controlled engine cooling and that of an increase of mechanical work carried out by the engine, the burnt fuel being equal.

30 [0053] According to an embodiment, the amount of water vapour injected in the explosion chamber is regulated by the control system, in particular by the vapour control unit 17, based on the air fuel ratio (AFR, or also called Lambda ratio) really seen and previous measured and/or calculated, for example by the exhaust gas combustion sensor 43.

[0054] In particular, as the air fuel ratio increases, the amount of vapour injected in the explosion chamber increases, or in other words, the duration of vapour injection is increased, the vapour pressure being equal.

[0055] The adjustment of the vapour amount and thus, of the vapour injection time at each engine cycle may further take place based on the number of revolutions detected by the RPM sensor 36, as well as on the power demand detected by the accelerator sensor 44 and on the vapour features detected based on the vapour temperature and pressure detected, for example, by the vapour temperature sensor 51 and the vapour pressure sensor 41.

10 Adjustment of vapour amount injected – Example 1:

AFR=12:1;

RPM=2000;

air suction throttle valve opening TPS=23%; vapour pressure VAP=12BAR;

vapour injection time =7ms.

15 Adjustment of vapour amount injected – Example 2:

AFR=16:1;

RPM=2000;

air suction throttle valve opening TPS=23%; vapour pressure VAP=12BAR;

vapour injection time =16ms.

20 [0056] According to an embodiment, the amount of fuel injected in the explosion chamber is regulated by the control system, in particular by the fuel control unit 34, based on the air fuel ratio (AFR, or also called Lambda ratio) really seen and previously measured and/or calculated, for example by the exhaust gas combustion sensor 43.

25 [0057] The adjustment of the fuel amount and thus, of the fuel injection time at each engine cycle may further take place based on the number of revolutions detected by the RPM sensor 36, as well as on the power demand detected by the accelerator sensor 44 and on the amount of air loaded into the explosion chamber.

Adjustment of fuel amount injected – Example 1:

30 AFR=12:1;

RPM=2000;

air suction throttle valve opening TPS=23%; air load = 650 milligrams;

fuel injection time =4ms.

Adjustment of fuel amount injected – Example 2:

AFR=13:1;

RPM=2000;

air suction throttle valve opening TPS=23%; air load = 950 milligrams;

- 5 fuel injection time =9ms.

Adjustment of fuel amount injected – Example 3:

AFR=16:1;

RPM=2000;

air suction throttle valve opening TPS=23%; air load = 950 milligrams;

- 10 fuel injection time =14ms.

Adjustment of fuel amount injected – Example 4:

AFR=18:1;

RPM=2000;

air suction throttle valve opening TPS=23%; air load = 650 milligrams;

- 15 fuel injection time =7ms.

[0058] According to an embodiment, the ignition time is regulated by the control system based on the air fuel ratio (AFR, or also called Lambda ratio) really seen and previously measured and/or calculated, for example by the exhaust gas combustion sensor 43.

- 20 [0059] The adjustment of the ignition time at each engine cycle may further take place based on the number of revolutions detected by the RPM sensor 36, as well as on the vapour injection time or, in other words, on the amount of vapour injected into the explosion chamber at each engine cycle.

- 25 [0060] In particular, other conditions being equal, as the amount of vapour injected increases at each engine cycle it may be advantageous to advance the ignition timing relative to the top dead centre to obtain an extended combustion step along with a controlled cooling of the combustion environment by the injected vapour.

Adjustment of ignition time – Example 1

AFR=18:1;

- 30 RPM=2000;

air suction throttle valve opening TPS=23%;

vapour injection time =9ms.

ignition advance relative to TDC = 14 degrees.

Adjustment of ignition time – Example 2

12

AFR=18:1;

RPM=2000;

air suction throttle valve opening TPS=23%;

vapour injection time =18ms.

- 5 ignition advance relative to TDC = 22 degrees.

Adjustment of ignition time – Example 3

AFR=13:1;

RPM=2000;

air suction throttle valve opening TPS=23%;

- 10 vapour injection time =18ms.

ignition advance relative to TDC = 40 degrees.

Adjustment of ignition time – Example 4

AFR=13:1;

RPM=2000;

- 15 air suction throttle valve opening TPS=23%;

vapour injection time =4ms.

ignition advance relative to TDC = 12 degrees.

- [0061] According to an embodiment, the method comprises the step of measuring pressure and temperature within the combustion chamber and regulating the air suction, the vapour injection and the fuel injection of a subsequent engine cycle also based on the pressure and temperature measured in the previous engine cycle.

- [0062] From the description provided herein, the man skilled in the art may certainly appreciate how the method and the engine according to the present invention obtain a reliable and safe operation of the engine and at the same time a considerable increase of the engine thermo-dynamic yield that leads to an increase of the performance of the engine itself, a reduction of fuel consumption with the same mechanical work carried out and a reduction of polluting agents produced during the combustion process.

- [0063] Thanks to the method and to the engine according to the present invention, it is possible to use water vapour in a synergic manner both as a means for transforming the thermal energy produced by the combustion into mechanical energy, and as a means for regulating ("cooling") in a controlled manner the combustion temperature itself which, in turn, allows regulating and reducing in a

targeted and selective manner the levels of the main pollutants, such as for example SO_x, NO_x, CO and fine powders.

5 [0064] Thanks to the controlled cooling of the engine it is possible to load more comburent air into the explosion chamber and as a consequence, a gain is obtained in engine volumetric efficiency compared to the engines of the prior art.

[0065] The method and the engine according to the present invention refer, in particular but not only, to explosion engines for motor traction, operating machines, for transport and lifting, turbines, generators, pumps, compressors, etcetera.

10 [0066] These engines include, for example, gasoline-, diesel-, liquefied gas-, natural gas –fueled engines, and so on.

[0067] It is clear that a man skilled in the art may make several changes and adjustments to the method and to the engine according to the present invention in order to meet specific and incidental needs, all falling within the scope of protection of the invention as defined in the following claims.

CLAIMS

1. Method for operating an internal combustion engine (1) of the type comprising at least one cylinder-piston unit (2) defining an explosion chamber and wherein the piston is cyclically movable within the cylinder between a top dead centre (TDC) and a bottom dead centre (BTM), determining a suction step (3), a compression step (4), an expansion step (5) and an exhaust step (6) of the explosion chamber in a sequence, as well as a system (7) for feeding fuel to the explosion chamber, a system (8) for generating water vapour (V) and feeding the water vapour (V) to the explosion chamber, a system (9) for feeding comburent air to the explosion chamber and a fuel ignition device (10),
said method comprising the steps of:
- setting the piston in a cyclical movement between the top dead centre (TDC) and the bottom dead centre (BDC);
 - generating water vapour (V);
 - feeding comburent air (52) into the explosion chamber during the suction step (3);
 - feeding (53) at least part of the water vapour generated in the explosion chamber during the suction step (3);
 - feeding fuel (54) into the explosion chamber during the suction step (3);
 - subsequent to the suction step (3), compressing the mixture of comburent air, water vapour and fuel during the compression step (4);
 - igniting (55) the fuel when the piston is close to the top dead centre (TDC), in a transition step between the compression step (4) and the subsequent expansion step (5), so that the combustion gases and the thermal expansion of the vapour exert a pressure on the piston during the expansion step (5);
 - during the exhaust step (6), venting from the explosion chamber the gases present therein,
- characterised in that** the vapour (V) generated and fed into the explosion chamber is dry and overheated water vapour.
2. Method according to claim 1, wherein said water vapour is generated and injected in the explosion chamber in a temperature range from 150°C to 800°C, preferably from 250°C to 350°C.
3. Method according to claim 1 or 2, wherein said water vapour is generated and injected in the explosion chamber in a pressure range from 1.5 bar to 60 bar, preferably from 10 bar to 30 bar, even more preferably around 15 bar.

4. Method according to any one of the previous claims, wherein the step of feeding the comburent air (52) to the explosion chamber comprises:
- an initial step (56) of feeding only air without feeding the generated water vapour and without feeding the fuel;
 - 5 - a subsequent step (57) of concurrent feeding of air and of the water vapour generated without feeding fuel;
 - a subsequent final step (58) of concurrent feeding of air and fuel without feeding vapour.
- 10 5. Method according to any one of the previous claims, wherein the vapour feeding step (53) begins after the start of the air feeding step (52) and the fuel feeding step (54) begins after the start of the vapour feeding step (53), and wherein preferably the entire vapour feeding step (53) and the entire fuel feeding step (54) take place during the air feeding step (52).
- 15 6. Method according to any one of the previous claims, wherein the beginning of the fuel feeding step (54) is overlapped to the end of the vapour feeding step (53) for an interval from 0 degrees to 1 degree of the engine cycle.
- 20 7. Method according to any one of the previous claims, wherein said air feeding step (52) is started in advance relative to the top dead centre (TDC) and extends up to 90 degrees of the engine cycle from the top dead centre (TDC), whereas the vapour feeding step (53) takes place in an interval shorter than or equal to, 45 degrees of the engine cycle.
8. Method according to the previous claim, wherein the fuel feeding step (54) takes place in an interval shorter than or equal to, 45 degrees of the engine cycle.
- 25 9. Method according to any one of the previous claims, comprising the step of piloting pressure, the start time and the duration of the vapour feeding (53) and fuel feeding (54) steps so as to determine an Air Fuel Ratio comprised within the range from 13:1 to 22:1, preferably from 16:1 to 20:1, even more preferably of about 18:1.
- 30 10. Method according to any one of the previous claims, wherein the amount of vapour injected in the explosion chamber is regulated based on the engine operating temperature.
11. Method according to any one of the previous claims, wherein the ratio between the vapour amount and the amount of fuel injected in the explosion chamber is increased as the engine temperature increases and decreased as the engine temperature is decreased.

12. Method according to the previous claim, comprising the steps of:

- measuring pressure and temperature inside the explosion chamber;
- regulating the air suction, the vapour injection and the fuel injection of a subsequent engine cycle based on the pressure and on the temperature measured in the previous engine cycle.

13. Method according to any one of the previous claims, wherein the amount of water vapour injected in the explosion chamber is regulated based on the air fuel ratio measured and/or calculated in advance.

14. Method according to the previous claim, wherein as the air fuel ratio increases, the amount of vapour injected in the explosion chamber increases.

15. Method according to any one of the previous claims, wherein the regulation of the amount of vapour injected at each engine cycle is regulated based on the number of revolutions detected, on the power demand by the user and on the vapour properties detected by measuring the vapour temperature and pressure.

16. Method according to any one of the previous claims, wherein the amount of fuel injected in the explosion chamber is regulated based on the air fuel ratio measured and/or calculated in advance.

17. Method according to the previous claim, wherein the regulation of the amount of vapour injected at each engine cycle is regulated based on the number of revolutions detected, on the power demand by the user and on the amount of air loaded in the explosion chamber at each engine cycle.

18. Method according to any one of the previous claims, wherein the ignition time is regulated based on the air fuel ratio measured and/or calculated in advance.

19. Method according to the previous claim, wherein the regulation of the ignition time at each engine cycle is further regulated based on the number of revolutions of the engine and on the amount of vapour injected in the explosion chamber at each engine cycle.

20. Method according to any one of the previous claims, wherein other conditions being equal, as the amount of vapour injected at each engine cycle increases, the ignition timing is advanced relative to the top dead centre.

21. Internal combustion engine (1) comprising at least one cylinder-piston unit (2) defining an explosion chamber and wherein the piston is cyclically movable within the cylinder between a top dead centre (TDC) and a bottom dead centre (BTM), determining a suction step (3), a compression step (4), a combustion and

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expansion step (5) and an exhaust step (6) of the explosion chamber in a sequence, as well as a system (7) for feeding fuel to the explosion chamber, a system (8) for generating water vapour (V) and feeding the water vapour (V) to the explosion chamber, a system (9) for feeding comburent air to the explosion chamber and a fuel ignition device (10),

characterised in that it comprises a control and command system (17, 34) designed for piloting said system (7) for feeding fuel, said system (8) for generating water vapour (V) and for feeding the water vapour (V) and said system (9) for feeding comburent air so as to:

- generate dry and overheated water vapour (V);
- feed comburent air (52) into the explosion chamber during the suction step (3);
- feed (53) at least part of the dry and overheated water vapour generated in the explosion chamber during the suction step (3);
- feed fuel (54) into the explosion chamber during the suction step (3).

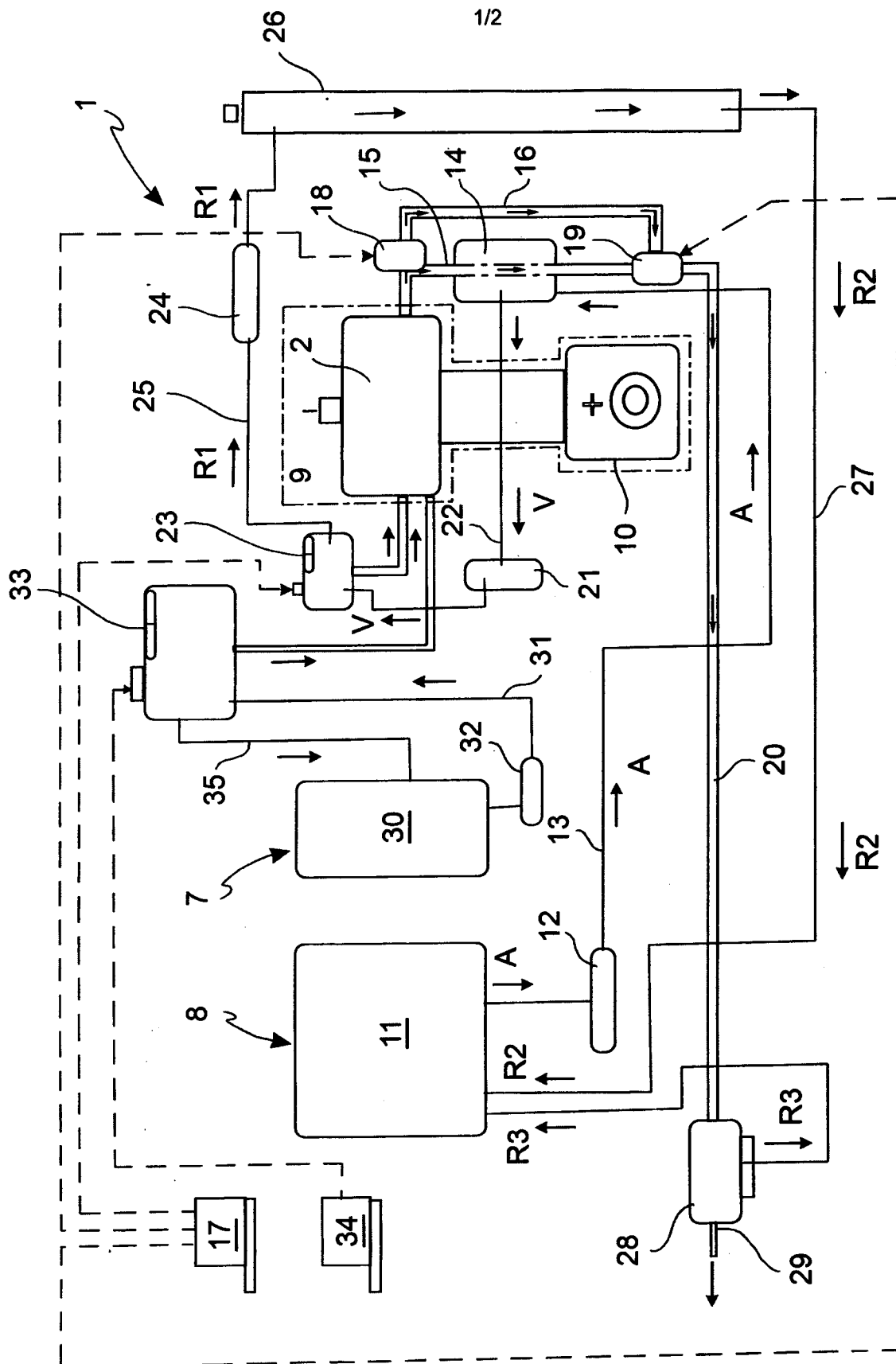


FIG. 1

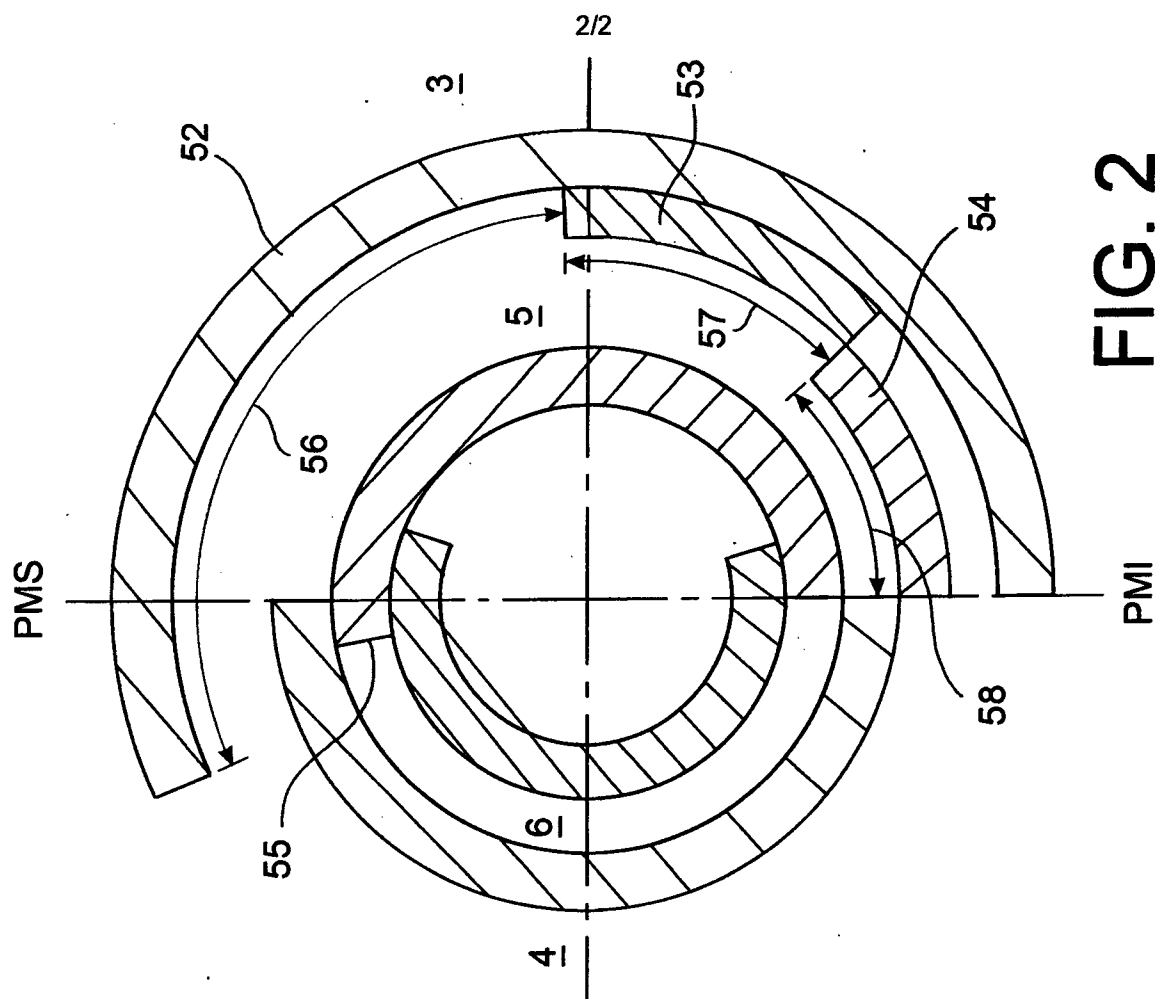


FIG. 2

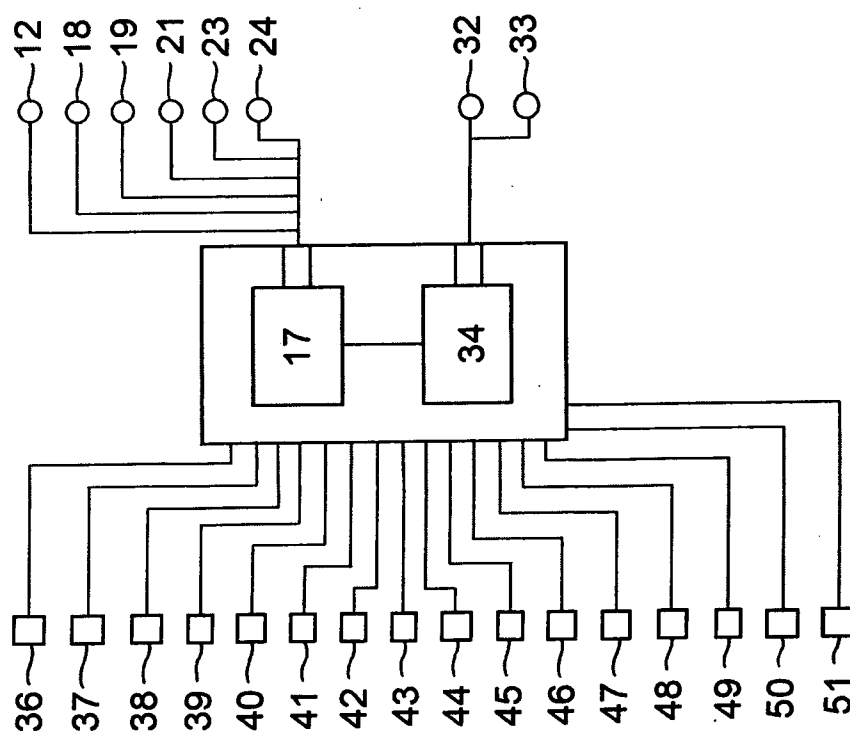


FIG. 3