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(54) **A METHOD OF CONTROLLING A GAS FUELED RECIPROCATING INTERNAL COMBUSTION PISTON ENGINE PROVIDED WITH A PRECOMBUSTION CHAMBER AND THE ENGINE THEREOF**

(57) The present disclosure relates to a method of controlling a reciprocating internal combustion piston engine having a pre-chamber for igniting a main charge in a combustion chamber. The disclosure is based on the idea of introducing a first prescribed amount of gaseous fuel and a second prescribed amount gaseous fuel into the pre-chamber such that at least to a crankshaft rotation

of 30 deg is provided between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle. The present disclosure also concerns a reciprocating internal combustion piston engine implementing such a method.

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Description

FIELD OF THE DISCLOSURE

[0001] The present disclosure relates to a method of controlling a reciprocating internal combustion piston engine and more particularly to a method of controlling such an engine comprising a pre-chamber. The present disclosure further concerns a internal combustion piston engine comprising a pre-chamber.

BACKGROUND OF THE DISCLOSURE

[0002] In reciprocating internal combustion engines, a pre-chamber, often also known as a precombustion chamber, is used to pre-ignite a mixture of air and fuel so as to subsequently ignite and combust a mixture of air and fuel in the combustion cylinder.

[0003] It has been discovered, however, that exhaust fumes generated from the combustion of a preceding combustion cycle may remain in the pre-combustion chamber, thus resulting in undesirable pre-combustion performance. In addition, as the performance of engines have increased, it has been discovered that premature combustion in the combustion chamber may occur due to an excessively high temperature of pre-chamber tip, which extends at least partly into the combustion chamber, and through which fluid communication between the pre-chamber and the combustion chamber is provided.

BRIEF DESCRIPTION OF THE DISCLOSURE

[0004] An object of the present disclosure is to improve pre-chamber combustion and to prevent premature combustion in the combustion chamber of a reciprocating internal combustion piston engine comprising a pre-chamber.

[0005] The object of the disclosure is achieved by a method for controlling a reciprocating internal combustion piston engine and a reciprocating internal combustion piston engine, which are characterized by what is stated in the independent claims. The preferred embodiments of the disclosure are disclosed in the dependent claims.

[0006] The disclosure is based on the idea of introducing a first prescribed amount of gaseous fuel and a second prescribed amount gaseous fuel into the pre-chamber such that at least to a crankshaft rotation of 30 deg is provided between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle.

[0007] An advantage of this is that the first prescribed amount gaseous fuel at least partly scavenges residual gases, such as exhaust gases, generated in a preceding combustion cycle prior to a subsequent combustion cycle, while simultaneously cooling down the tip of the pre-chamber through which it flows. In addition, the interval

of at least a 30 deg crankshaft rotation between introducing the second prescribed amount of gaseous fuel into the pre-chamber promotes scavenging residuals gases from the pre-chamber to the combustion chamber have enough time mix within the combustion chamber before the second prescribed amount of gaseous fuel is introduced and ignited. As a result, a more controlled and uniform combustion is achieved in the combustion chamber.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0008] A first aspect of the disclosure relates to a method of controlling a reciprocating internal combustion piston engine comprising a pre-chamber. Particularly, the pre-chamber is in fluid communication with the combustion cylinder via a tip of the pre-chamber that extends at least partially into the combustion chamber.

[0009] The method comprises introducing charge gases into the combustion cylinder of the engine. Charge gasses, such as air, may be introduced via an inlet valve of the combustion chamber.

[0010] The method further comprises introducing a main amount of gaseous fuel into the combustion cylinder using a main gas admission device. Particularly, the main amount of gaseous fuel forms a main charge to be combusted within the combustion chamber with the charge gases. The main amount of gaseous fuel may be introduced via a gas admission valve in connection with an inlet of the combustion chamber, or a direct injection device for injecting gaseous fuel directly into the combustion chamber.

[0011] The method further comprises introducing a first prescribed amount of gaseous fuel into the pre-chamber using a pre-chamber gas admission device. Particularly, this first amount of gaseous fuel at least partially scavenges any residual gases generated in a preceding combustion cycle from the pre-chamber to the combustion chamber, prior to a subsequent combustion cycle.

[0012] The method further comprises introducing a second prescribed amount of gaseous fuel into the pre-chamber using the pre-chamber gas admission device to form a pre-chamber charge. Preferably, but not necessarily, the pre-chamber gas admission device is an electrically actuated valve, and more preferably a solenoid valve.

[0013] The method further comprises igniting the pre-chamber charge using an igniter at least partially disposed in the pre-chamber. Particularly, ignition of the pre-chamber charge subsequently ignites and combusts the main charge in the combustion chamber. Preferably, but not necessarily, the igniter device is chosen from a spark igniter device, plasma igniter device or a laser igniter device, although other alternatives may be envisaged.

[0014] Moreover, an interval corresponding at least to a crankshaft rotation of 30 deg is provided between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous

fuel within a single combustion cycle.

[0015] Preferably, but not necessarily, an interval corresponding at least to a crankshaft rotation of 40 deg is provided between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle.

[0016] Although not necessary for elaborating the basic concept of the first aspect of the present disclosure, it is readily apparent that the method may comprise expelling exhaust fumes from the combustion chamber, suitably via an exhaust valve, after combustion of the main charge.

[0017] In an embodiment of the first aspect according to the present disclosure, the first prescribed amount of gaseous fuel is introduced subsequent to closing the exhaust valve.

[0018] In another embodiment of the first aspect according to the present disclosure, the first prescribed amount of gaseous fuel is introduced when an inlet valve is open.

[0019] Preferably, the first prescribed amount of gaseous fuel is introduced prior to a closure of the inlet valve. More preferably, introducing the first prescribed amount of gaseous fuel is stopped at a time period corresponding to a crankshaft rotation of 20 deg prior to the closure of the inlet valve, at the latest.

[0020] In another embodiment of the first aspect according to the present disclosure, the second prescribed amount of gaseous fuel is introduced subsequent to the closure of the inlet valve.

[0021] In another embodiment of the first aspect according to the present disclosure, the first prescribed amount is more than 50% of a total prescribed amount of gaseous fuel introduced into the pre-chamber. In other words, the first prescribed amount of gaseous fuel exceeds the second prescribed amount of gaseous fuel.

[0022] It should be noted that the first aspect of the present disclosure encompasses the combination of one or more of the embodiments, and variants thereof, discussed above.

[0023] A second aspect of the disclosure relates to a reciprocating internal combustion piston engine. The engine comprises a combustion cylinder with an inlet valve and an exhaust valve. The engine further comprises a pre-chamber in fluid communication with the combustion cylinder via a tip of the pre-chamber extending at least partially into the combustion chamber. Moreover, the pre-chamber is equipped with a pre-chamber gas admission device for introducing gaseous fuel into the pre-chamber. The engine further comprises a control unit operationally coupled to, and configured for controlling:

- an igniter at least partially disposed in the pre-chamber;
- a main gas admission device for introducing gaseous fuel to the combustion cylinder, and

- a pre-chamber gas admission device for introducing gaseous fuel to the pre-chamber.

[0024] The inlet valve is configured to introduce charge gases into the combustion cylinder of the engine. If a mechanically actuated inlet valve is used, this may be achieved by configuring an associated mechanism accordingly. Alternatively, if a hydraulic, pneumatic or solenoid-actuated inlet valve operationally controlled to the control unit is used, this may be achieved by configuring the control unit to control the inlet valve accordingly.

[0025] Moreover, the control unit is further configured to:

- using the main gas admission device, introduce a main amount of gaseous fuel into the combustion cylinder, to form a main charge with the charge gases;
- using the pre-chamber gas admission device, introduce a first prescribed amount of gaseous fuel into the pre-chamber, wherein the gaseous fuel of the first prescribed amount at least partially scavenges residual gases generated in a preceding combustion cycle from the pre-chamber to the combustion chamber, prior to a subsequent combustion cycle;
- using the pre-chamber gas admission device, introduce a second prescribed amount of gaseous fuel into the pre-chamber to form a pre-chamber charge, and
- using the igniter, ignite the pre-chamber charge, wherein ignition of the pre-chamber charge subsequently ignites and combusts the main charge.

[0026] Particularly, the control unit is further configured to provide an interval corresponding at least to a crankshaft rotation of 30 deg between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle.

[0027] Preferably, but not necessarily, the control unit is further configured to provide an interval corresponding at least to a crankshaft rotation of 40 deg between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle.

[0028] Preferably, but not necessarily, the main gas admission device may be provided as a gas admission valve in connection with an inlet of the combustion chamber, or as a direct injection device for injecting gaseous fuel directly into the combustion chamber.

[0029] Preferably, but not necessarily, the pre-chamber gas admission device is an electrically actuated valve, and more preferably a solenoid valve.

[0030] Preferably, but not necessarily, the igniter device is chosen from a spark igniter device, plasma igniter

device or a laser igniter device, although other alternatives may be envisaged.

[0031] Although not necessary for elaborating the basic concept of the second aspect of the present disclosure, it is readily apparent that the engine may comprise an exhaust valve configured to expel exhaust gasses from the combustion chamber after combustion of the main charge. If a mechanically actuated exhaust valve is used, this may be achieved by configuring the associated mechanism accordingly. Alternatively, if a pneumatic, hydraulic or solenoid-actuated exhaust valve operationally coupled to, and controllable by the control unit is used, this may be achieved by configuring the control unit accordingly.

[0032] In an embodiment of the second aspect according to the present disclosure, the control device is configured to introduce the first prescribed amount of gaseous fuel subsequent to closing an exhaust valve.

[0033] In another embodiment of the second aspect according to the present disclosure, the control device is configured to introduce the first prescribed amount of gaseous fuel when an inlet valve is open.

[0034] Preferably, the control unit is configured to introduce the first prescribed amount of gaseous fuel prior to a closure of the inlet valve. More preferably, the control unit is configured to stop introducing the first prescribed amount of gaseous fuel at a time period corresponding to a crankshaft rotation of 20 deg prior to the closure of the inlet valve, at the latest.

[0035] In another embodiment of the second aspect according to the present disclosure, the control device is configured to introduce the second prescribed amount of gaseous fuel subsequent to the closure of the inlet valve

[0036] In another embodiment of the second aspect according to the present disclosure, the control device is configured to introduce at least 50% of a total prescribed amount of gaseous fuel introduced into the pre-chamber as the first prescribed amount of gaseous fuel. In other words, the first prescribed amount of gaseous fuel exceeds the second prescribed amount of gaseous fuel.

[0037] It should be noted that the second aspect of the present disclosure encompasses the combination of one or more of the embodiments, and variants thereof, discussed above.

Claims

1. A method of controlling a reciprocating internal combustion piston engine, the engine comprising a pre-chamber in fluid communication with a combustion cylinder via a tip of the pre-chamber extending at least partially into the combustion chamber, the method comprising the following method steps:

- introducing charge gases into the combustion

cylinder of the engine;

- introducing a main amount of gaseous fuel into the combustion cylinder using a main gas admission device, to form a main charge with the charge gases;

- introducing a first prescribed amount of gaseous fuel into the pre-chamber using a pre-chamber gas admission device, wherein the gaseous fuel of the first prescribed amount at least partially scavenges residual gases generated in a preceding combustion cycle from the pre-chamber to the combustion chamber, prior to a subsequent combustion cycle, and

- introducing a second prescribed amount of gaseous fuel into the pre-chamber using the pre-chamber gas admission device to form a pre-chamber charge, and

igniting the pre-chamber charge using an igniter at least partially disposed in the pre-chamber, wherein ignition of the pre-chamber charge subsequently ignites and combusts the main charge,

characterized in that an interval corresponding at least to a crankshaft rotation of 30 deg is provided between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle.

2. The method according to Claim 1, **characterized in that** the first prescribed amount of gaseous fuel is introduced subsequent to closing an exhaust valve

3. The method according to Claim 1 or 2, **characterized in that** the first prescribed amount of gaseous fuel is introduced when an inlet valve is open.

4. The method according to Claim 3, **characterized in that** the first prescribed amount of gaseous fuel is introduced prior to a closure of the inlet valve, preferably introducing the first prescribed amount of gaseous fuel is stopped at a time period corresponding to a crankshaft rotation of 20 deg prior to the closure of the inlet valve, at the latest.

5. The method according to any of the preceding Claims 1-4, **characterized in that** the second prescribed amount of gaseous fuel is introduced subsequent to the closure of the inlet valve

6. The method according to any of the preceding Claims 1-5, **characterized in that** the first prescribed amount is more than 50% of a total prescribed amount of gaseous fuel introduced into the pre-chamber.

7. The method according to any of the preceding Claims 1-6, **characterized in that** the pre-chamber

gas admission device is an electrically actuated valve.

8. The method according to Claim 7, **characterized in that** the electrically actuated valve is a solenoid valve.

9. A reciprocating internal combustion piston engine, comprising:

a combustion cylinder with an inlet valve and an exhaust valve,
a pre-chamber in fluid communication with the combustion cylinder via a tip of the pre-chamber extending at least partially into the combustion chamber, the pre-chamber being equipped with a pre-chamber gas admission device, and
a control unit for operationally coupled to, and configured for controlling:

- an igniter at least partially disposed in the pre-chamber, controllable by the control unit;
- a main gas admission device for introducing gaseous fuel to the combustion cylinder, controllable by the control unit, and
- a pre-chamber gas admission device for introducing gaseous fuel to the pre-chamber, controllable by the control unit,

wherein the inlet valve is configured to introduce charge gasses into combustion cylinder of the engine,

wherein the control unit being configured to:

- using the main gas admission device, introduce a main amount of gaseous fuel into the combustion cylinder, to form a main charge with the charge gases;
- using the pre-chamber gas admission device, introduce a first prescribed amount of gaseous fuel into the pre-chamber, wherein the gaseous fuel of the first prescribed amount at least partially scavenges residual gases generated in a preceding combustion cycle from the pre-chamber to the combustion chamber, prior to a subsequent combustion cycle;
- using the pre-chamber gas admission device, introduce a second prescribed amount of gaseous fuel into the pre-chamber to form a pre-chamber charge, and
- using the igniter, ignite the pre-chamber charge, wherein ignition of the pre-chamber charge subsequently ignites and combusts the main charge,

characterized in that the control unit is further

configured to provide an interval corresponding at least to a crankshaft rotation of 30 deg between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle.

10. The engine according to Claim 9, **characterized in that** the engine comprises an exhaust valve configured to expel exhaust gasses from the combustion chamber after combustion of the main charge, and wherein the control device is configured to introduce the first prescribed amount of gaseous fuel subsequent to closing an exhaust valve

11. The engine according to Claim 9 or 10, **characterized in that** the control device is configured to introduce the first prescribed amount of gaseous fuel when an inlet valve is open.

12. The engine according to Claim 11, **characterized in that** the control unit is configured to introduce the first prescribed amount of gaseous fuel prior to a closure of the inlet valve, and preferably configured to stop introducing the first prescribed amount of gaseous fuel at a time period corresponding to a crankshaft rotation of 20 deg prior to the closure of the inlet valve, at the latest.

13. The engine according to any of the preceding Claims 9-12, **characterized in that** the control device is configured to introduce the second prescribed amount of gaseous fuel subsequent to the closure of the inlet valve

14. The engine according to any of the preceding Claims 9-13, **characterized in that** the control device is configured to introduce at least 50% of a total prescribed amount of gaseous fuel introduced into the pre-chamber as the first prescribed amount of gaseous fuel.

15. The engine according to any of the preceding Claims 9-13, **characterized in that** the pre-chamber gas admission device is an electrically actuated valve.

16. The engine according to Claims 15, **characterized in that** the electrically actuated valve is a solenoid valve.

Amended claims in accordance with Rule 137(2) EPC.

1. A method of controlling a reciprocating internal combustion piston engine,
the engine comprising a pre-chamber in fluid communication with a combustion cylinder via a tip of the pre-chamber extending at least partially into the combustion chamber,

the method comprising the following method steps:

- introducing charge gases into the combustion cylinder of the engine;
- introducing a main amount of gaseous fuel into the combustion cylinder using a main gas admission device, to form a main charge with the charge gases;
- introducing a first prescribed amount of gaseous fuel into the pre-chamber using a pre-chamber gas admission device, wherein the gaseous fuel of the first prescribed amount at least partially scavenges residual gases generated in a preceding combustion cycle from the pre-chamber to the combustion chamber, prior to a subsequent combustion cycle, and
- introducing a second prescribed amount of gaseous fuel into the pre-chamber using the pre-chamber gas admission device to form a pre-chamber charge, and

igniting the pre-chamber charge using an igniter at least partially disposed in the pre-chamber, wherein ignition of the pre-chamber charge subsequently ignites and combusts the main charge,

characterized in that an interval corresponding at least to a crankshaft rotation of 30 deg is provided between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle,

wherein the first prescribed amount of gaseous fuel is introduced subsequent to closing an exhaust valve,

wherein the first prescribed amount of gaseous fuel is introduced when an inlet valve is open, such that the first prescribed amount of gaseous fuel is introduced prior to a closure of the inlet valve, preferably introducing the first prescribed amount of gaseous fuel is stopped at a time period corresponding to a crankshaft rotation of 20 deg prior to the closure of the inlet valve, at the latest, and

wherein the second prescribed amount of gaseous fuel is introduced subsequent to the closure of the inlet valve

2. The method according to Claim 1, **characterized in that** the first prescribed amount is more than 50% of a total prescribed amount of gaseous fuel introduced into the pre-chamber.
3. The method according to 1 or 2, **characterized in that** the pre-chamber gas admission device is an electrically actuated valve.
4. The method according to Claim 3, **characterized in that** the electrically actuated valve is a solenoid valve.

5. A reciprocating internal combustion piston engine, comprising:

a combustion cylinder with an inlet valve and an exhaust valve,
 a pre-chamber in fluid communication with the combustion cylinder via a tip of the pre-chamber extending at least partially into the combustion chamber, the pre-chamber being equipped with a pre-chamber gas admission device, and
 a control unit for operationally coupled to, and configured for controlling:

- an igniter at least partially disposed in the pre-chamber, controllable by the control unit;
- a main gas admission device for introducing gaseous fuel to the combustion cylinder, controllable by the control unit, and
- a pre-chamber gas admission device for introducing gaseous fuel to the pre-chamber, controllable by the control unit,

wherein the inlet valve is configured to introduce charge gasses into combustion cylinder of the engine,

wherein the control unit being configured to:

- using the main gas admission device, introduce a main amount of gaseous fuel into the combustion cylinder, to form a main charge with the charge gases;
- using the pre-chamber gas admission device, introduce a first prescribed amount of gaseous fuel into the pre-chamber, wherein the gaseous fuel of the first prescribed amount at least partially scavenges residual gases generated in a preceding combustion cycle from the pre-chamber to the combustion chamber, prior to a subsequent combustion cycle;
- using the pre-chamber gas admission device, introduce a second prescribed amount of gaseous fuel into the pre-chamber to form a pre-chamber charge, and
- using the igniter, ignite the pre-chamber charge, wherein ignition of the pre-chamber charge subsequently ignites and combusts the main charge,

characterized in that the control unit is further configured to provide an interval corresponding at least to a crankshaft rotation of 30 deg between introducing the first prescribed amount of gaseous fuel and introducing the second prescribed amount of gaseous fuel within a single combustion cycle,

wherein the engine comprises an exhaust valve

configured to expel exhaust gasses from the combustion chamber after combustion of the main charge, and wherein the control device is configured to introduce the first prescribed amount of gaseous fuel subsequent to closing an exhaust valve, 5
wherein the control device is configured to introduce the first prescribed amount of gaseous fuel when an inlet valve is open, such that the control unit is configured to introduce the first prescribed amount of gaseous fuel prior to a closure of the inlet valve, and preferably configured to stop introducing the first prescribed amount of gaseous fuel at a time period corresponding to a crankshaft rotation of 20 deg prior to the closure of the inlet valve, at the latest, and 10
wherein the control device is configured to introduce the second prescribed amount of gaseous fuel subsequent to the closure of the inlet valve 15
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6. The engine according to Claim 5, **characterized in that** the control device is configured to introduce at least 50% of a total prescribed amount of gaseous fuel introduced into the pre-chamber as the first prescribed amount of gaseous fuel. 25
7. The engine according to Claim 5 or 6, **characterized in that** the pre-chamber gas admission device is an electrically actuated valve. 30
8. The engine according to Claim 7, **characterized in that** the electrically actuated valve is a solenoid valve. 35

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EUROPEAN SEARCH REPORT

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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