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(54) **Compression self-ignition internal combustion engine and fuel supply device therefor**

Brennkraftmaschine mit Selbstzündung und Brennstoffzuführeinrichtung

Moteur avec auto-allumage et dispositif de prélevement de combustible

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## Description

[0001] The present invention relates to improvements in a compression self-ignition internal combustion engine configured to accomplish combustion of air-fuel mixture in a combustion chamber upon self-ignition under compression by a piston, and to a method of operating a compression self-ignition internal combustion engine.

[0002] In general, recent gasoline-fueled internal combustion engines tend to be operated on lean air-fuel mixtures for the purpose of promoting fuel economy. However, there exists a lean limit for air-fuel mixture because the lean-fuel mixture makes unstable combustion made upon spark ignition by a spark plug and flame propagation. Additionally, during lean burn or combustion of lean air-fuel mixture, a catalyst for exhaust gas purification cannot exhibit a high exhaust gas purification effect, particularly reduction of NOx, as compared with that in combustion of stoichiometric air-fuel mixture.

[0003] To solve the above problems, a compression self-ignition internal combustion engine has been proposed as disclosed in Japanese Patent Provisional Publication No. 7-332141, in which combustion upon self-ignition is made under compression of a piston thereby achieving lean burn and low exhaust emission. In such a compression self-ignition engine, ignition timing is affected by difference in fuel amount to be supplied to the combustion chamber, i.e., difference in air-fuel ratio. Therefore, a range in which optimum ignition timing can be obtained is narrow, so that preignition and/or misfire will occur outside the range.

[0004] In view of this, a compression self-ignition internal combustion engine is proposed to control the ignition timing in order to prevent preignition and/or misfire, as disclosed in Japanese Patent Provisional Publication No. 10-196424. In this engine, a control piston is movably disposed at an upper part of a combustion chamber. This control piston additionally compresses compressed air-fuel mixture in the combustion chamber in the vicinity of top dead center of a piston in a cylinder. Accordingly, the temperature of the air-fuel mixture can be transiently raised thereby making self-ignition of the air-fuel mixture. Such transient rising of the temperature of the air-fuel mixture may be accomplished by injecting liquid fuel for ignition purpose into air-fuel mixture so as to accomplish effective combustion in the combustion chamber, other than the above method using the control piston.

[0005] However, drawbacks have been encountered in the above conventional techniques. In case of the conventional technique of raising the temperature of the air-fuel mixture under compression by the control piston, it is necessary to drive the control piston at high speeds, which will require a large-sized device for driving the control piston thereby increasing production cost. In case of the conventional technique of supplying the liquid fuel, although the above problem can be solved, the temperature of the air-fuel mixture is lowered owing to vaporization latent heat under vaporization of the liquid fuel, which may lead to no self-ignition. This narrows a range in which the ignition timing is controllable.

[0006] JP 09042116 discloses an arrangement in which a combustion chamber of a diesel engine is supplied with fuel from a usual fuel injector and additionally with bubble fuel from another fuel injector in a compression stroke. The bubble fuel is formed by stirring air fuel in a stirring device.

[0007] DE 3802669 A1 teaches that a mixture of fuel and air is either directly introduced into a combustion chamber for combustion or is indirectly introduced into a closed vaporization chamber in which the fuel is vaporized in the course of three piston strokes. Afterwards, by opening the blowout valve about the end of the compression stroke of the next combustion cycle, the highly compressed fuel-vapor/air mixture streams into the combustion chamber and is burned therein.

[0008] It is an objective of the present invention to provide an improved compression self-ignition internal combustion engine in which a timing of self-ignition can be easily controlled while requiring no large-sized driving device for an auxiliary device such as a control piston as well as a method of operating a compression self-ignition internal combustion engine.

[0009] According to an apparatus aspect of the present invention, said objective is solved by a compression self-ignition internal combustion engine having the combination of features of independent claim 1.

[0010] According to a method aspect of the present invention, the aforementioned objective is solved by a method of operating a compression self-ignition internal combustion engine having the combination of features of independent claim 9.

[0011] Preferred embodiments of the present invention are laid down in the subclaims.

[0012] In the following, the present invention is explained in greater detail by means of embodiments thereof in conjunction with the accompanying drawings, wherein:

Fig. 1 is a schematic illustration of an embodiment of a compression self-ignition internal combustion engine;
Fig. 2A is an explanatory view showing a manner for introducing fuel from a fuel injector to a mixture charge injector, usable in the engine of Fig. 1;
Fig. 2B is an explanatory view similar to Fig. 2A but showing another manner for introducing fuel from the fuel injector to the mixture charge injector, usable in the engine of Fig. 1;
Fig. 3 is a longitudinal sectional view of the mixture charge injector used in the engine of Fig. 1;
Fig. 4A is a longitudinal sectional view of the mixture charge injector the same as that in Fig. 3, showing an operational state of the mixture chamber injector;
Fig. 4B is a longitudinal sectional view similar to Fig. 4A but showing another operational state of the mixture charge injector;

Fig. 4C is a longitudinal sectional view similar to Fig. 4A but showing a further operational state of the mixture charge injector;

Fig. 5 is a timing chart illustrating operational timings of the mixture charge injector in terms of engine cycle, usable in the engine of Fig. 1;

Fig. 6 is a graphic representation illustrating an idea of the present teaching in which self-ignition is made in a combustion chamber upon supply of the mixture charge to an air-fuel mixture field in the combustion chamber; and

Fig. 7 is a flow chart showing a control operation of an electronic control unit used in the engine of Fig. 1.

**[0013]** Referring now to Fig. 1 of drawings, an embodiment of a compression self-ignition internal combustion engine will be illustrated by the reference character E. The engine E comprises an engine main body B which includes a plurality of engine cylinders 1. Piston 3 is disposed movable in a reciprocating manner in each cylinder 1 so as to define combustion chamber 5. The engine main body is provided with intake air passageway 7 and exhaust gas passageway 9 which are respectively communicable with the combustion chamber through intake and exhaust valves 11, 13. Intake air is supplied through the intake air passageway into the combustion chamber, while exhaust gas is discharged from the combustion chamber through the exhaust gas passageway.

**[0014]** Mixture charge injector 17 serving as a fuel supply device is disposed for each combustion chamber 5 in such a manner that its tip end section projects at the central and upper portion of the combustion chamber. The mixture charge injector injects a mixture charge which is prepared by mixing air or air-fuel mixture introduced from the combustion chamber and fuel injected from fuel injector 15. Fuel injector 15 is supplied with fuel from fuel tank 19 through pressure regulator 23 under the action of fuel pump 21. The mixture charge to be injected from the mixture charge injector has a fuel concentration which is higher than that in an air-fuel mixture field formed in the combustion chamber. Additionally, at least a part of fuel in the mixture charge is vaporized. At the fuel concentration of the air-fuel mixture field, no self-ignition occurs though the air-fuel mixture is high in temperature.

**[0015]** Electronic control unit (ECU) 27 is provided to control an injection amount and an injection timing of fuel to be injected from fuel injector 15 and of the mixture charge to be injected from mixture charge injector 17. The injection amount is an amount of the fuel or the charge mixture to be injected. The injection timing is a timing at which the fuel or the mixture charge is injected. Sensors (not shown) are provided to detect an intake vacuum Bint of engine, an intake air temperature Tint, an engine speed Ne, an engine coolant temperature Tw and a throttle (valve) opening degree (or a required engine load) Tvo. The intake vacuum is a vacuum generated at an intake system of the engine. The intake air temperature is a temperature of intake air to be introduced into the combustion chamber. The engine speed is of the engine. The engine coolant temperature is a temperature of coolant in the engine. The engine coolant temperature may be replaced with an engine lubricating oil temperature or a transmission oil (fluid) temperature. The throttle opening degree is an opening degree of a throttle valve (not shown) in the intake system and corresponds to an engine load to be required.

**[0016]** Fuel injected from fuel injector 15 is introduced to mixture charge injector 17 in such manners as shown in Figs. 2A and 2B. In Fig. 2A, the tip end section of fuel injector 15 is directly installed to the mixture charge injector so that fuel is directly injected from the fuel injector into mixture charge chamber 29 of the mixture charge injector. In Fig. 2B, fuel injector 15 is connected through fuel passage 31 with mixture charge chamber 29. Check valve 33 for preventing a reverse flow of fuel is disposed at the tip end section of the fuel passage 31 which tip end section is connected to the mixture charge chamber. In the example of Fig. 2B, fuel injector 15 is disposed separate from mixture charge injector 17, which is effective in case that a space for installing the mixture charge injector 17 is narrow.

**[0017]** Mixture charge injector 17 is arranged as shown in Fig. 3. The fuel injector includes a generally cylindrical body 35 which is formed thereinside with mixture charge chamber 29. Pressure increasing piston 37 is disposed movable in a reciprocating manner inside mixture charge chamber 29 in order to increase the pressure within mixture charge chamber 29. Air chamber 39 is located above the mixture chamber 29 so as to be contiguous with mixture charge chamber 29. The air chamber is larger in diameter than the mixture chamber. Air chamber 39 is connected through air introduction passage 41 to combustion chamber 5 of the engine so that air or I air-fuel mixture from the combustion chamber is introduced into the air chamber. Check valve 43 is disposed in air introduction passage 41. Check valve 43 includes a ball 47 which is biased leftward in the drawing by spring 45 so as to normally maintain the check valve at a closed state. When the ball is moved rightward against the biasing force of the spring under the pressure of air or air-fuel mixture flowing through the air introduction passage 41 which pressure is higher than a preset value of the spring, the check valve is changed from the closed state to an open state. Additionally, when the pressure of air or air-fuel mixture passing through the air introduction passage further rises over the preset value of the spring, the ball is further moved rightward, so that the check valve takes its closed state. As a result, a timing at which air or air-fuel mixture is introduced from combustion chamber 5 to air chamber 39 can be set in the latter half period of compression stroke in each engine cylinder.

**[0018]** Air chamber 39 is connected through a communication passage 49 with mixture charge chamber 29. Check valve 51 is disposed in communication passage 49 so as to prevent a reverse flow of air or air-fuel mixture in a direction of from mixture charge chamber 29 to air chamber 39. Mixture charge chamber 29 is communicable with or openable to combustion chamber 5 of the engine through injection hole 53. The injection hole is closable or openable by an injection valve member M. The injection valve member M includes a valve head section 55 which is contactable with a generally frustoconical wall (no numeral) defining injection hole 53 so as to close or open the injection hole. The valve head section is connected though a valve shaft 57 with armature 59 located in mixture charge chamber 29. Spring 61 is interposed between the armature 59 and an annular flat portion (no numeral) formed inside body 35 which flat portion is located above injection hole 53. Accordingly, injection valve member M is normally biased upward under the biasing force of spring 61 so as to close injection hole 53. Solenoid 63 is embedded in a wall of the body 35 and located around armature 59. The armature is arranged to be moved downward or upward under current supply control accomplished by electronic control unit 27, so that injection hole 53 is controlled to be opened or closed.

**[0019]** Flange or disc section 65 is integrally formed at the top portion of pressure increasing piston 37 and contactable with an annular flat portion (no numeral) formed between mixture charge chamber 29 and air chamber 39. Rod 67 is integrally connected to disc section 65 and extends upward and out of air chamber 39. The rod is provided at its upper end with spring retainer 69. Spring 73 is interposed between spring retainer 69 and annular rod guide 71 formed integrally inside the body 35 in order to bias piston 37 upward. Suitable sealing member is disposed at the inner periphery of rod guide 71 defining rod insertion hole 71a thereby securing sealing between the inner periphery of the rod guide and the outer periphery of the rod, though not shown. Additionally, similar sealing is made between the outer periphery of pressure increasing piston 37 and the inner periphery of body 35, though not shown. Spring retainer 69 is covered with cup-shaped tappet 75 on which cam 77 for driving pressure increasing piston 37 is rotatably disposed in contact with the tappet 75.

**[0020]** Manner of operation of mixture charge injector 17 will be discussed with reference to Figs. 4A, 4B and 4C.

**[0021]** In a state of Fig. 4A, air or air-fuel mixture is introduced from combustion chamber 5 into air chamber 39 while piston 37 descends to increase the pressure within mixture charge chamber 29. At this time, valve head section 55 of injection valve member M closes the injection hole; check valve 43 is opened; and check valve 51 is closed.

**[0022]** In a state of Fig. 4B, valve head section 55 of the injection valve member opens the injection hole so that the mixture charge increased in pressure within mixture charge chamber 29 is injected into combustion chamber 5. At this time, check valve 43 is closed; and check valve 51 is closed.

**[0023]** In a state of Fig. 4C, air or air-fuel mixture introduced into air chamber 39 in the state of Fig. 4A is moved through communication passage 49 into mixture charge chamber 29 under ascending of pressure increasing piston 37. At this time, valve head section 55 of the injection valve member closes the injection hole; check valve 43 is closed; and check valve 51 is opened. With movement of air or air-fuel mixture into mixture charge chamber 29, fuel is injected or introduced from fuel injector 15 into mixture charge chamber 29.

**[0024]** Next, manner of control for operational timings of mixture charge injector 17 will be discussed with reference to Fig. 5 which includes a control manner (a) and another control manner (b). In the control manner (a), injection of the mixture charge is carried out once in each engine cycle for each engine cylinder so as to inject the whole amount of the mixture charge contained in mixture charge chamber 29. In the control manner (b), injection of the mixture charge is carried out twice in each engine cycle for each engine cylinder so as to inject two portions of the mixture charge separately upon dividing the mixture charge within the mixture charge chamber into the two portions. Both in the control manners (a) and (b), timings of introduction of air or air-fuel mixture into air chamber 39 is indicated at an upper column, while timings of introduction of air or air-fuel mixture into mixture charge chamber 29, timings of the mixture charge from mixture charge injector 17, timings of injection (introduction) of fuel from fuel injector 15 into mixture charge chamber 29, and the like timings are indicated at a lower column.

**[0025]** Both in the control manners (a) and (b), introduction of air or air-fuel mixture into air chamber 39 is carried out in the latter half period of the compression stroke in the engine cycle. By this, air or air-fuel mixture at high temperature and pressure is introduced into air chamber 39. Additionally, air or air-fuel mixture within combustion chamber 5 is released out of the combustion chamber in the latter half period of the compression stroke, i.e., into air chamber 39, and therefore the pressure within the combustion chamber of the engine lowers in the latter half period of the compression stroke thereby preventing early ignition within combustion chamber 5.

**[0026]** Then, the pressure within mixture charge chamber 29 is increased under descending of pressure increasing piston 37, in parallel with proceeding of compression stroke of the engine cycle. Thereafter, the mixture charge within mixture charge chamber 29 is injected into combustion chamber 5 of the engine.

**[0027]** After injection of the mixture charge, high temperature and pressure air or air-fuel mixture is moved through the communication passage 49 into mixture charge chamber 29 under ascending of pressure increasing piston 37. Concurrently with this, fuel is ejected and supplied from fuel injector 15 into mixture charge chamber 29. The supplied fuel within the mixture chamber is promoted in vaporization by the high temperature and pressure air or air-fuel mixture moved from air chamber 39, in which the supplied fuel is mixed with air or air-fuel mixture to form a mixture charge. This mixture charge is increased in pressure and injected into combustion chamber 5 of the engine during the next engine cycle, in which the whole amount of the mixture charge is injected at one time as shown in the control manner (a), or the two portions of the mixture charge are separately injected respectively at separate two times as show in the control manner (b). Thus, the mixture charge increased in pressure is injected into combustion chamber 5 during the next engine cycle, and therefore vaporization of fuel is accomplished in a time duration before injection of the mixture charge into the combustion chamber. This prolongs the time required for vaporization of fuel, thereby effectively promoting vaporization of fuel.

**[0028]** In case that air or air-fuel mixture is injected or introduced into air chamber 39 at a timing other than the latter half period of compression stroke, air or air-fuel mixture is low in temperature and pressure as it is so as to be insufficient to vaporize fuel, and therefore air or air-fuel mixture may be pressurized and heated.

**[0029]** Fig. 6 depicts an idea exhibiting advantageous effects of the present teaching, in which the mixture charge is injected to the air-fuel mixture field A formed within combustion chamber 5 which air-fuel mixture field is high in temperature and has such a fuel concentration as not to occur self-ignition. The mixture charge to be injected from the mixture charge injector has a fuel concentration which is higher than that in the air-fuel mixture field A formed in the combustion chamber. Additionally, at least a part of fuel in the mixture charge is vaporized. It will be understood that the air-fuel mixture field A is formed in the combustion chamber by supplying fuel into combustion chamber 5 from a fuel injector (not shown).

**[0030]** By supplying to the air-fuel mixture field A the mixture charge B containing fuel whose at least a part is vaporized, the fuel concentration in the air-fuel mixture field A is raised while suppressing temperature-lowering owing to vaporization latent heat of fuel. This puts the air-fuel mixture field A into such a condition P as to initiate self-ignition. Therefore, a timing at which self-ignition occurs can be controlled by suitably controlling the injection timing of the mixture charge B.

**[0031]** In comparison with the above, if liquid fuel C for ignition is supplied into combustion chamber 5 as in a conventional technique, the fuel concentration in the air-fuel mixture becomes generally the same as that in the above condition P, as indicated as a condition Q; however, the temperature of the air-fuel mixture cannot be raised under the influence of the vaporization latent heat of the ignition fuel C so as not to occur self-ignition.

**[0032]** In the above compression self-ignition internal combustion engine of the embodiment in which the self-ignition timing can be controlled, the mixture charge including air or air-fuel mixture and fuel whose part is vaporized is injected into combustion chamber 5 of the engine by mixture charge injector 17. This makes unnecessary using a large-sized driving device for driving a control piston at high speeds as in a conventional technique.

**[0033]** Next, control manner of electronic control unit 27 will be discussed on the case where the mixture charge is divided into the two portions which are separately injected respectively at two times as shown in the control manner (b) in Fig. 5, with reference to a flowchart of Fig. 7.

**[0034]** First, electronic control unit 27 receives input of the intake vacuum Bint, the intake air temperature Tint, the engine coolant temperature Tw, the engine speed Ne, and the required engine load (throttle opening degree) Tov which are detected respectively by the corresponding sensors, at step S1.

**[0035]** A bottom dead center pressure P1 and a bottom dead center temperature T1 within combustion chamber 5 are read from a map stored in a memory in the electronic control unit, in accordance with the intake vacuum Bint, the intake air temperature Tint and the engine coolant temperature Tw which have been input to the electronic control unit, at step S3. The bottom dead center pressure P1 is a pressure within the combustion chamber at bottom dead center of a piston in the cylinder. The bottom dead center temperature T1 is a temperature within the combustion chamber at bottom dead center of the piston in the cylinder.

**[0036]** Then, a combustion chamber pressure (or a pressure within the combustion chamber) P and a combustion chamber temperature (or a temperature within the combustion chamber) T are respectively calculated every any crank angle from the read bottom dead center pressure P1 and the bottom dead center temperature T1, at step S5. The combustion chamber pressure P and the combustion chamber temperature T are calculated by the following equations:

$$P = P1 \times (\varepsilon)^{\kappa}$$

$$T = T1 \times (\varepsilon)^{(\kappa - 1)}$$

where $\varepsilon$ is the compression ratio, and $\kappa$ is the ratio of specific heat.

**[0037]** Consequently, a fuel concentration K in the air-fuel mixture field causing abnormal combustion in the combustion chamber is read from a map stored in the memory, in accordance with the engine speed Ne and the combustion chamber temperature T which have been determined above, at step S7. This fuel concentration K tends to become high as the combustion chamber temperature T is low and as the engine speed Ne is high.

**[0038]** Then, judgment is made as to whether or not the fuel concentration in the air-fuel mixture field A formed after injection the whole amount of the mixture charge at one time so as to correspond to the fuel amount determined in accordance with the required engine load is higher than the above-mentioned fuel concentration K causing abnormal combustion in the combustion chamber, at step S9. In case that the fuel concentration is higher than the fuel concentration K, abnormal combustion such as early ignition is caused if the whole amount of the mixture charge is injected as it is. Consequently, the whole amount of the mixture charge is divided into two (first and second) portions which will be respectively injected at first and second times which are separate from each other. The first portion is controlled in amount so as to obtain the fuel concentration of the air-fuel mixture field A not higher than the above-mentioned fuel concentration K, and injected from mixture charge injector 17, at step S11. This prevents abnormal combustion from occurring in the combustion chamber of the engine. Thereafter, in order to meet a target engine load, the remaining fuel (or the second portion) of the mixture charge is injected from mixture charge injector 17 at a previously set timing (or the second timing), at step S13. The second (injection) timing of the mixture charge corresponds to initiation of combustion in the combustion chamber, thereby controlling the ignition timing of the air-fuel mixture within the combustion chamber. The above-mentioned control for the amount of the first and second portions of the mixture charge can be easily accomplished by controlling a time in which current is passed through solenoid 63 in the mixture charge injector 17.

**[0039]** In case that the fuel concentration in the air-fuel mixture field A formed after injection of the whole amount of the mixture charge at one time so as to correspond to the fuel amount determined in accordance with the required engine load is judged to be not higher than the above-mentioned fuel concentration K at step S9, the whole amount of the mixture charge in mixture charge chamber 29 is injected at one time at a previously set timing, at step 15.

**[0040]** Thus, the amount of the mixture charge injected at the first time and the number of injections for the mixture charge are decided in accordance with the engine operating conditions such as the combustion chamber temperature, the engine speed and the required engine load. This can prevent abnormal combustion in the combustion chamber and can control the timing of initiation of combustion throughout a wide engine operating range extending from a low engine load condition to a high engine load condition, thereby enlarging a range in which compression self-ignition engine operation is made.

**[0041]** As appreciated from the above, according to the present teaching, at least a part of the fuel contained in the mixture chamber to be supplied to the air-fuel mixture field within the combustion chamber is vaporized. This suppresses a temperature lowering of the air-fuel mixture within the combustion chamber due to vaporization latent heat of the fuel, thereby facilitating self-ignition of the air-fuel mixture. Additionally, the mixture charge is supplied from the mixture charge injector into the combustion chamber, and therefore no large-sized device for driving an auxiliary device such as a control piston is required.

**Claims**

**1.** A compression self-ignition internal combustion engine (E) comprising:

a piston (3) defining a combustion chamber (5) in which a high temperature air-fuel mixture field (A) is formed, the air-fuel mixture field (A) having a fuel concentration which does not cause self-ignition within the combustion chamber (5); and a supply device (17, 77, 41, 43, 45, 47, 15) for supplying to said air-fuel mixture field (A) a mixture charge (B) which has a fuel concentration higher than that in said air-fuel mixture field (A) and contains fuel and a fluid containing air, at least a part of the fuel being vaporized,

wherein combustion of air-fuel mixture in the combustion chamber (5) is made upon self-ignition under compression of the piston (3),

wherein said supply device (17, 77, 41, 43, 45, 47, 15) includes a mixture charge injector (17) for injecting said mixture charge (B) into the combustion chamber (5), said mixture charge (B) being formed in said mixture charge injector (17) by mixing said fluid introduced from the combustion chamber (5) and fuel introduced from a fuel injector.

**2.** A compression-self ignition internal combustion engine as claimed in claim 1, further comprising a device (27) for allowing the fluid from the combustion chamber (5) to be introduced into the mixture charge injector (17) at a timing of a latter half period of compression stroke in a first engine cycle of a cylinder of the engine.

**3.** A compression-self ignition internal combustion engine as claimed in claim 1 or 2, further comprising a device (27, 63, M) for allowing the mixture charge (B) to be supplied into the combustion chamber (5) in a period including intake and compression strokes in a second engine cycle of the cylinder of the engine upon pressuring the mixture charge (B), the second engine cycle being subsequent to the first engine cycle.

**4.** A compression-self ignition internal combustion engine as claimed in any of claims 1 to 3, further comprising a device (27, 63, M) for allowing a first portion of the mixture charge to be supplied into the combustion chamber (5) at a first time so as to obtain a target fuel concentration of the air-fuel mixture field, and for allowing a second portion of the mixture charge to be supplied into the combustion chamber (5) at a second time after the first time so as to meet a target engine load, the target fuel concentration being set in accordance with an engine operating condition of the engine, the first and second portions constituting the mixture charge (B).

5. A compression self-ignition internal combustion engine as claimed in any of claims 1 to 4, wherein the fluid containing air is air introduced from the combustion chamber (5).

6. A compression self-ignition internal combustion engine as claimed in any of claims 1 to 4, wherein the fluid containing air is air-fuel mixture introduced from the combustion chamber (5).

7. A compression self-ignition internal combustion engine as claimed in any of claims 1 to 6, wherein a passage (41, 49) is provided through which the fluid containing air is supplied from the combustion chamber (5), and the mixture charge injector (17) has a mixture charge chamber (29) connected to the passage (41, 49) and the fuel injector so as to be supplied with the fluid and the fuel to form the mixture charge (B) which has a fuel concentration higher than that in the air-fuel mixture field (A), at least a part of the fuel being vaporized in the mixture charge (B), the mixture charge chamber (29) being communicable with the combustion chamber (5) of the engine so that the mixture charge (B) is injected to the air-fuel mixture field (A) in the combustion chamber (5) of the engine.

8. A compression self-ignition internal combustion engine as claimed in one of claims 1 to 7, having a fuel supply device (17), comprising:

a section (35, 37) defining a mixture charge chamber (29);
a section (41, 43, 47, 45) for introducing the fluid containing air from the combustion chamber (5) of the engine in compression stroke of a cylinder (1) of the engine into the mixture charge chamber (29);
a section (15; 15, 31, 33) for introducing fuel into the fluid within the mixture charge chamber (29) so as to prepare the mixture charge (B); and
a section (M, 53) for supplying the mixture charge (B) to the high temperature air-fuel mixture field (A) within the combustion chamber (5), the air-fuel mixture field (A) having a fuel concentration which does not cause self-ignition in the combustion chamber (5).

9. A method of operating a compression self-ignition internal combustion engine (E), said method comprising:

forming a high temperature air-fuel mixture field (A) in a combustion chamber (5) of the engine, said air-fuel mixture field (A) having a fuel concentration which does not cause self-ignition within the combustion chamber (5); and
supplying to the air-fuel mixture field (A) a mixture charge (B) which has a fuel concentration higher than that in the air-fuel mixture field (A) and contains fuel and a fluid containing air, at least a part of the fuel being vaporized,

wherein the mixture charge is formed in a mixture charge injector (17) by mixing the fluid introduced from the combustion chamber (5) and fuel introduced from a fuel injector, and the mixture charge (B) is injected into the combustion chamber (5), and
wherein combustion of air-fuel mixture in the combustion chamber is made upon self-ignition under compression of a piston (3) defining the combustion chamber (5).

## Patentansprüche

1. Brennkraftmaschine (E) mit Kompressionsselbstzündung, aufweisend:

einen Kolben (3), der eine Brennkammer (5) begrenzt, in der ein Hochtemperatur- Luft- Kraftstoff- Gemischfeld (A) gebildet wird, wobei das Luft- KraftstoffGemischfeld (A) eine Kraftstoffkraftkonzentration hat, die keine Selbstzündung innerhalb der Brennkammer (5) verursacht; und
eine Zuführungsvorrichtung (17, 77, 41, 43, 45, 47, 15) zum Zuführen eines Ladungsgemischs (B) zu dem Luft- Kraftstoff- Gemischfeld (A), das eine Kraftstoffkonzentration höher als die in dem Luft- Kraftstoff- Gemischfeld (A) hat und Kraftstoff und ein Fluid enthält, das Luft enthält, wobei zumindest ein Teil des Kraftstoffes verdampft wird,

wobei die Verbrennung des Luft- Kraftstoff- Gemischs in der Brennkammer (5) unter Selbstzündung unter der Verdichtung des Kolbens (3) veranlasst wird,
wobei die Zuführungsvorrichtung (17, 77, 41, 43, 45, 47, 15) eine Ladungsgemisch- Einspritzvorrichtung (17) zum Einspritzen des Ladungsgemischs (B) in die Brennkammer (5) enthält, das Ladungsgemisch (B) in der Ladungsgemisch- Einspritzvorrichtung (17) durch Mischen des Fluids, eingeführt aus der Brennkammer (5), mit Kraftstoff, eingeführt aus einer Kraftstoffeinspritzvorrichtung, gebildet wird.

2. Brennkraftmaschine mit Kompressionsselbstzündung nach Anspruch 1, außerdem aufweisend eine Vorrichtung (27), um dem Fluid aus der Brennkammer (5) zu gestatten, in die Ladungsgemisch- Einspritzvorrichtung (17) zu einem Zeitpunkt einer letzten halben Zeitdauer des Verdichtungshubes in einem ersten Motortakt eines Zylinders des Motors

eingeführt zu werden.

3. Brennkraftmaschine mit Kompressionsselbstzündung nach Anspruch 1 oder 2, außerdem aufweisend eine Vorrichtung (27, 63, M), um dem Ladungsgemisch (B) zu gestatten, in die Brennkammer (5) in einem Zeitraum, der den Einlass- und den Verdichtungshub in einem zweiten Motortakt des Zylinders des Motors enthält, während des Verdichtens des Ladungsgemischs (B) zugeführt zu werden, wobei der zweite Motortakt an den ersten Motortakt anschließend ist.

4. Brennkraftmaschine mit Kompressionsselbstzündung nach einem der Ansprüche 1 bis 3, außerdem aufweisend eine Vorrichtung (27, 63, M), um einem ersten Teil des Ladungsgemischs zu gestatten, in die Brennkammer (5) zu einer ersten Zeit zugeführt zu werden, um eine Ziel- Kraftstoffkonzentration des Luft-Kraftstoff- Gemischfeldes zu erhalten, und um einem zweiten Teil des Ladungsgemischs zu gestatten, zu der Brennkammer (5) zu einer zweiten Zeit nach der ersten Zeit zugeführt zu werden, um eine Ziel- Motorlast zu treffen,
wobei die Ziel- Kraftstoffkonzentration in Übereinstimmung mit der Motorbetriebsbedingung des Motors festgelegt wird, wobei die ersten und zweiten Teile das Ladungsgemisch (B) bilden.

5. Brennkraftmaschine mit Kompressionsselbstzündung nach einem der Ansprüche 1 bis 4, wobei das Fluid, das Luft enthält, Luft ist, die aus der Brennkammer (5) eingeleitet wird.

6. Brennkraftmaschine mit Kompressionsselbstzündung nach einem der Ansprüche 1 bis 4, wobei das Fluid, das Luft enthält, ein Luft- Kraftstoff- Gemisch ist, das aus der Brennkammer (5) eingeleitet wird.

7. Brennkraftmaschine mit Kompressionsselbstzündung nach einem der Ansprüche 1 bis 6, wobei ein Kanal (41, 49) vorgesehen ist, durch den die Luftenthaltende Fluid aus der Brennkammer (5) zugeführt wird, und die Ladungsgemisch- Einspritzvorrichtung (17) eine Ladungsgemischkammer (29), verbunden mit dem Kanal (41, 49) und der Kraftstoffeinspritzvorrichtung, hat, um mit dem Fluid und dem Kraftstoff versorgt zu werden, um das Ladungsgemisch (B) zu bilden, das eine Kraftstoffkonzentration höher als diejenige in dem Luft- Kraftstoff- Gemischfeld (A) hat, wobei zumindest ein Teil des Kraftstoffes in dem Ladungsgemisch (B) verdampft wird, die Ladungsgemischkammer (29) mit der Brennkammer (5) des Motors verbindbar ist, so dass das Ladungsgemisch (B) in das Luft- Kraftstoff- Gemischfeld (A) in der Brennkammer (5) des Motors eingespritzt wird.

8. Brennkraftmaschine mit Kompressionsselbstzündung nach einem der Ansprüche 1 bis 7, mit einer Kraftstoffzuführungsvorrichtung (17) hat, aufweisend:

einen Abschnitt (35, 37), der eine Ladungsgemischkammer (29) bildet; einen Abschnitt (41, 43, 47, 45) zum Einleiten des Fluids, das Luft enthält, aus der Brennkammer (5) des Motors in dem Verdichtungshub des Zylinders (1) des Motors in die Ladungsgemischkammer (29);
ein Abschnitt (15; 15, 31, 33) zum Einleiten von Kraftstoff in das Fluid innerhalb der Ladungsgemischkammer (29), um das Ladungsgemisch (B) vorzubereiten; und
einen Abschnitt (M, 53) zum Zuführen des Ladungsgemischs (B) in das Hochtemperatur-Kraftstoffgemischfeld (A) innerhalb der Brennkammer (5), wobei das Luft- Kraftstoff- Gemischfeld (A) eine Kraftstoffkonzentration hat, die keine Selbstzündung in der Brennkammer (5) verursacht.

9. Verfahren zum Betreiben einer Brennkraftmaschine (E) mit Kompressionsselbstzündung, wobei das Verfahren aufweist:

Bilden eines Hochtemperatur- Luft- Kraftstoff-Gemischfeldes (A) in der Brennkammer (5) des Motors, wobei das Luft- Kraftstoff- Gemischfeld (A) eine Kraftstoffkonzentration hat, die keine Selbstzündung innerhalb der Brennkammer (5) verursacht; und
Zuführen eines Ladungsgemischs (B) in das Luft- Kraftstoff- Gemischfeld (A), das eine Kraftstoffkonzentration höher als die in dem Luft-Kraftstoff- Gemischfeld (A) hat und Kraftstoff und ein Luft enthaltendes Fluid enthält, wobei zumindest ein Teil des Kraftstoffes verdampft wird,

wobei das Ladungsgemisch in einer Ladungsgemisch- Einspritzvorrichtung (17) durch Mischen des Fluids, eingeleitet aus der Brennkammer (5), und des Kraftstoffes, eingeleitet aus einer Kraftstoffeinspritzeinrichtung, gebildet wird und das Ladungsgemisch (B)in die Brennkammer (5) eingespritzt wird, und
wobei die Verbrennung des Luft- Kraftstoff- Gemisches in der Brennkammer während der Selbstzündung unter der Verdichtung eines Kolbens (3), der die Brennkammer (5) begrenzt, vorgenommen wird.

## Revendications

1. Moteur à combustion interne à auto-allumage par compression (E) comprenant:

un piston (3) définissant une chambre de combustion (5) dans laquelle un champ de mélange air-carburant à haute température (A) est formé, le champ de mélange air-carburant (A) ayant une concentration de carburant qui ne provoque d'auto-allumage dans la chambre de combustion (5); et

un dispositif d'amenée (17, 77, 41, 43, 45, 47, 15) pour amener audit champ de mélange air-carburant (A) une charge de mélange (B) qui possède une concentration de carburant plus élevée que celle dans ledit champ de mélange air-carburant (A) et contient du carburant et un fluide contenant de l'air, au moins une partie du carburant étant vaporisée,

où la combustion de mélange air-carburant dans la chambre de combustion (5) est exécutée lors de l'auto-allumage sous compression du piston (3),

où ledit dispositif d'amenée (17, 77, 41, 43, 45, 47, 15) comprend un injecteur de charge de mélange (17) pour injecter ladite charge de mélange (B) dans la chambre de combustion (5), ladite charge de mélange (B) étant formée dans ledit injecteur de charge de mélange (17) en mélangeant ledit fluide introduit depuis la chambre de combustion (5) et le carburant introduit par un injecteur de carburant.

**2.** Moteur à combustion interne à auto-allumage par compression selon la revendication 1, comprenant en outre un dispositif (27) pour permettre au fluide de la chambre de combustion (5) d'être introduit dans l'injecteur de charge de mélange (17) au moment d'une dernière demi-période de la course de compression lors d'un premier cycle du moteur d'un cylindre du moteur.

**3.** Moteur à combustion interne à auto-allumage par compression selon la revendication 1 ou 2, comprenant en outre un dispositif (27, 63, M) pour permettre que la charge de mélange (B) soit introduite dans la chambre de combustion (5) dans une période incluant les courses d'admission et de compression lors d'un deuxième cycle du moteur du cylindre du moteur lors de la mise en pression de la charge de mélange (B), le deuxième cycle du moteur faisant suite au premier cycle du moteur.

**4.** Moteur à combustion interne à auto-allumage par compression selon l'une des revendications 1 à 3, comprenant en outre un dispositif (27, 63, M) pour permettre qu'une première portion de la charge de mélange soit introduite dans la chambre de combustion (5) à un premier temps pour obtenir une concentration de carburant cible du champ de mélange air-carburant, et pour permettre qu'une seconde portion de la charge de mélange soit introduite dans la chambre de combustion (5) à un deuxième temps après le premier temps de manière à répondre à une charge cible du moteur, la concentration cible du carburant étant réglée en accord avec un état de fonctionnement du moteur, les première et seconde portions constituant la charge de mélange (B).

**5.** Moteur à combustion interne à auto-allumage par compression selon l'une des revendications 1 à 4, où le fluide contenant de l'air est de l'air introduit depuis la chambre de combustion (5).

**6.** Moteur à combustion interne à auto-allumage par compression selon l'une, des revendications 1 à 4, où le fluide contenant de l'air est le mélange air-carburant introduit depuis la chambre de combustion (5).

**7.** Moteur à combustion interne à auto-allumage par compression selon l'une des revendications 1 à 6, où un passage (41, 49) est réalisé à travers lequel le fluide contenant de l'air est fourni depuis la chambre de combustion (5), et l'injecteur de charge de mélange (17) possède une chambre de charge de mélange (29) reliée au passage (41, 49) et l'injecteur de carburant de manière à être alimenté en fluide et en carburant pour former la charge de mélange (B) dont la concentration de carburant est plus élevée que celle dans le champ de mélange air-carburant (A), au moins une partie du carburant étant vaporisée dans la charge de mélange (B), la chambre de mélange (29) pouvant communiquer avec la chambre de combustion (5) du moteur de sorte que la charge de mélange (B) est injectée dans le champ de mélange air-carburant (A) dans la chambre de combustion (5) du moteur.

**8.** Moteur à combustion interne à auto-allumage par compression selon l'une des revendications 1 à 7, comportant un dispositif d'amenée de carburant (17), comprenant:

une section (35, 37) définissant une chambre de charge de mélange (29);

une section (41, 43, 47, 45) pour introduire le fluide contenant de l'air de la chambre de combustion (5) du moteur lors de la course de compression d'un cylindre (1) du moteur dans la chambre de charge de mélange (29) ;

une section (15; 15, 31, 33) pour introduire le carburant dans le fluide dans la chambre de charge de mélange (29) de manière à préparer la charge de mélange (B); et

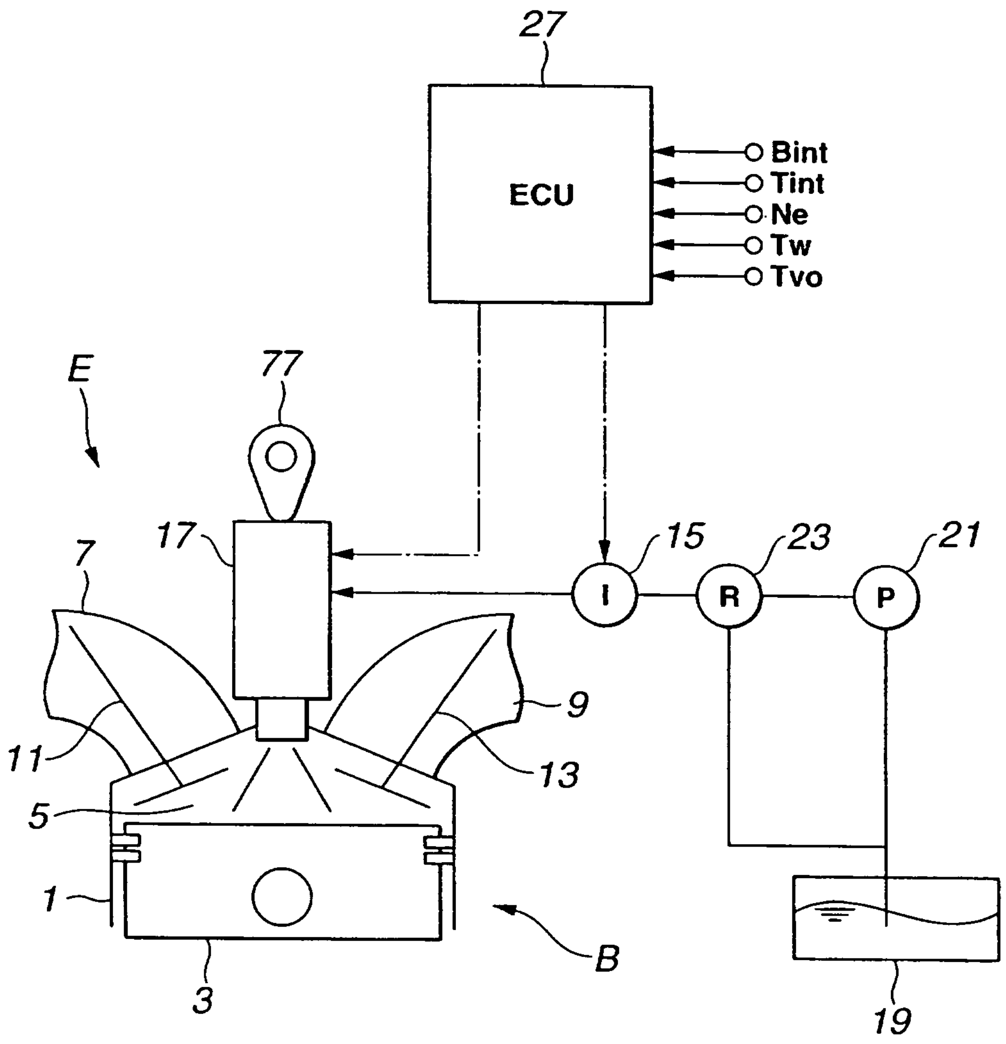
une section (M, 53) pour amener la charge de mélange (B) dans le champ de mélange air-carburant à haute température (A) dans la chambre de combustion (5), le champ de mélange air-carburant (A) ayant une concentration de carburant qui ne provoque pas d'auto-allumage dans la chambre de combustion (5).

**9.** Procédé de fonctionnement d'un moteur à combustion interne (E) à auto-allumage par compression, ledit procédé comprenant:

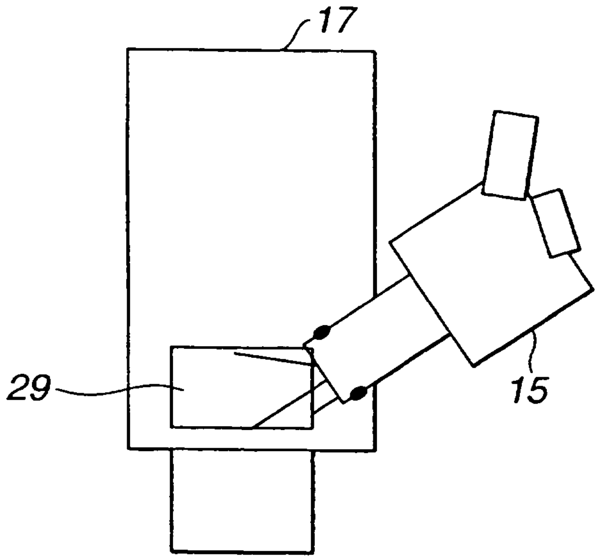
la formation d'un champ de mélange air-carburant à haute température (A) dans une chambre de combustion (5) du moteur, ledit champ de mélange air-carburant (A) ayant une concentration de carburant qui ne provoque pas d'auto-allumage dans la chambre de combustion (5); et l'amener au champ de mélange air-carburant (A) d'une charge de mélange (B) qui a une concentration de carburant plus élevée que celle dans le champ de mélange air-carburant (A) et qui contient du carburant et un fluide contenant de l'air, au moins une partie du carburant étant vaporisée,

où la charge de mélange est formée dans un injecteur de charge de mélange (17) en mélangeant le fluide introduit depuis la chambre de combustion (5) et le carburant introduit par un injecteur de carburant, et la charge de mélange (B) est injectée dans la chambre de combustion (5), et
où la combustion du mélange air-carburant dans la chambre de combustion est exécutée suite à l'auto-allumage sous compression d'un piston (3) définissant la chambre de combustion (5) .

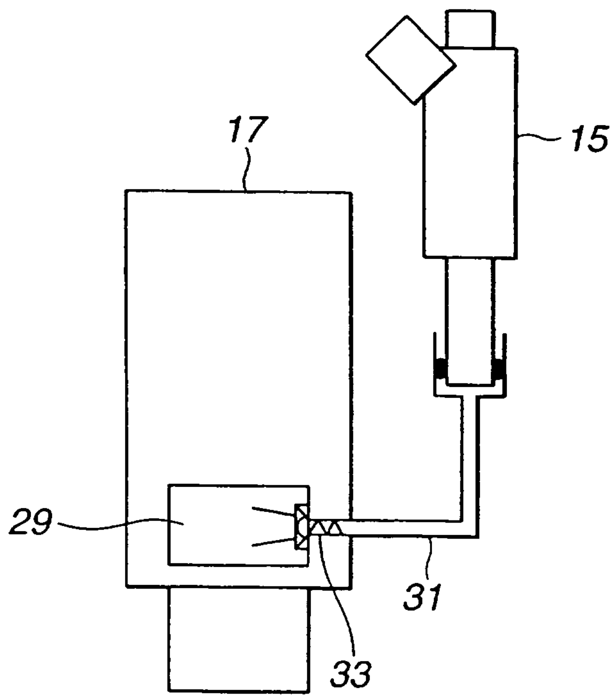
FIG.1



# FIG.2A




# FIG.2B



# FIG.3

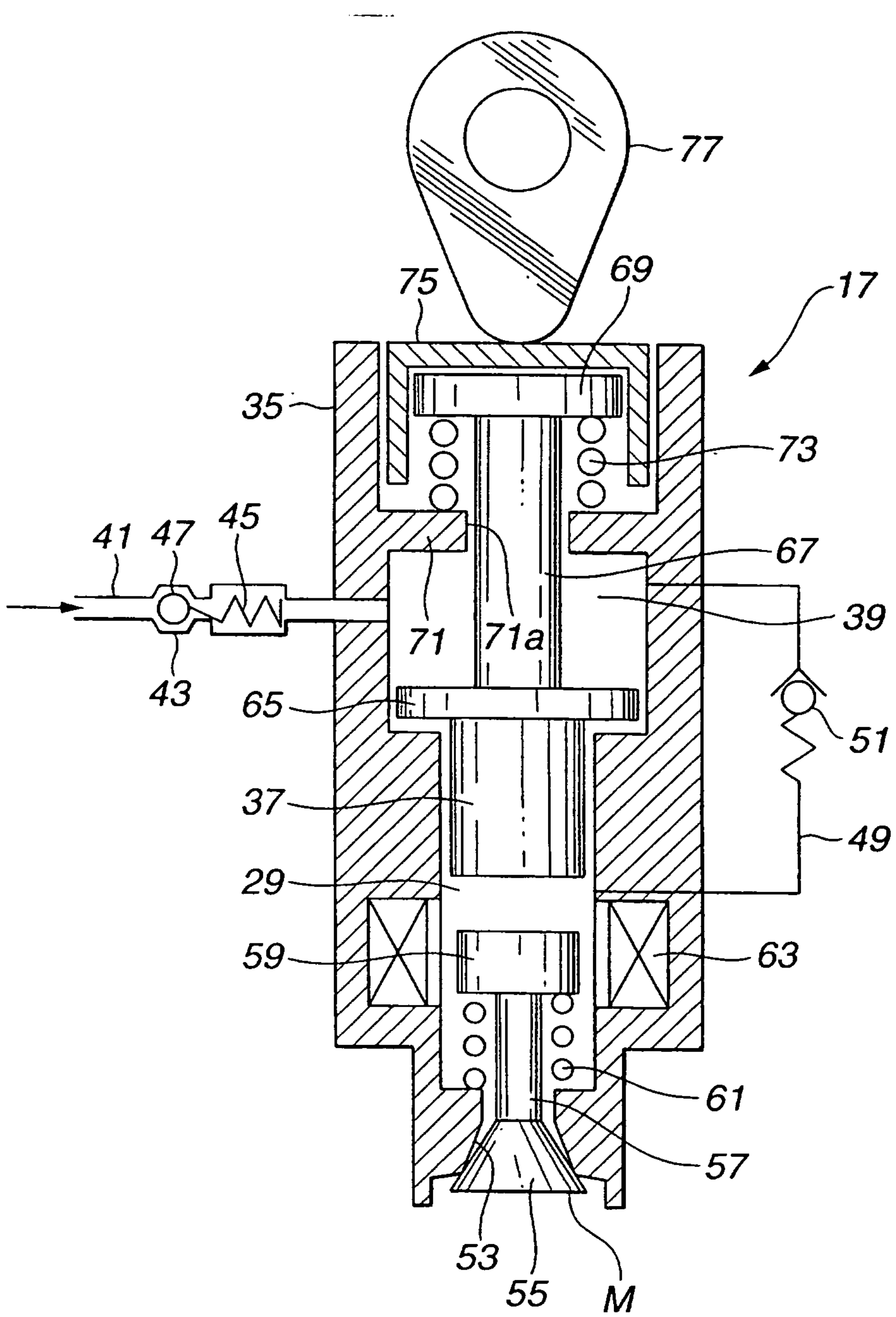

77
75
69
17
35
73
41
47
45
67
39
71
71a
43
65
51
37
49
29
59
63
61
57
53
55
M

FIG.4A

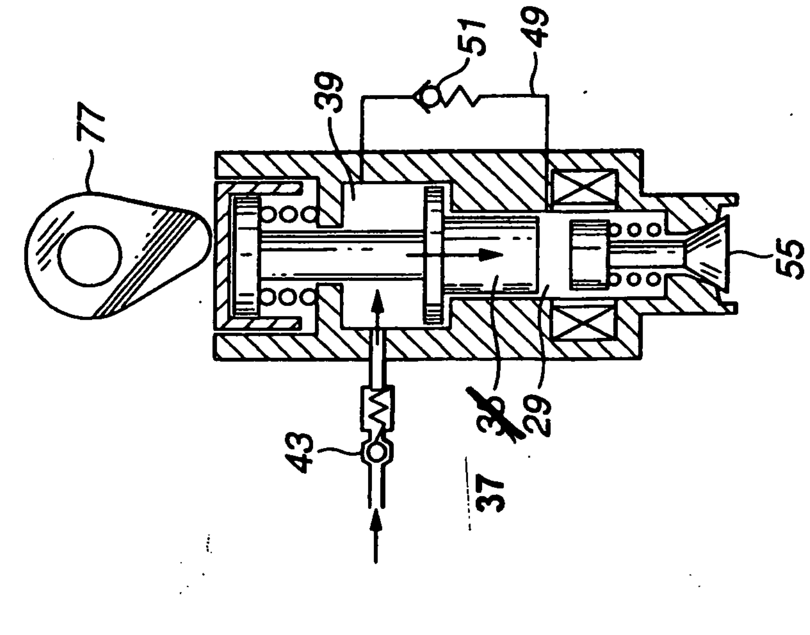



FIG.4B

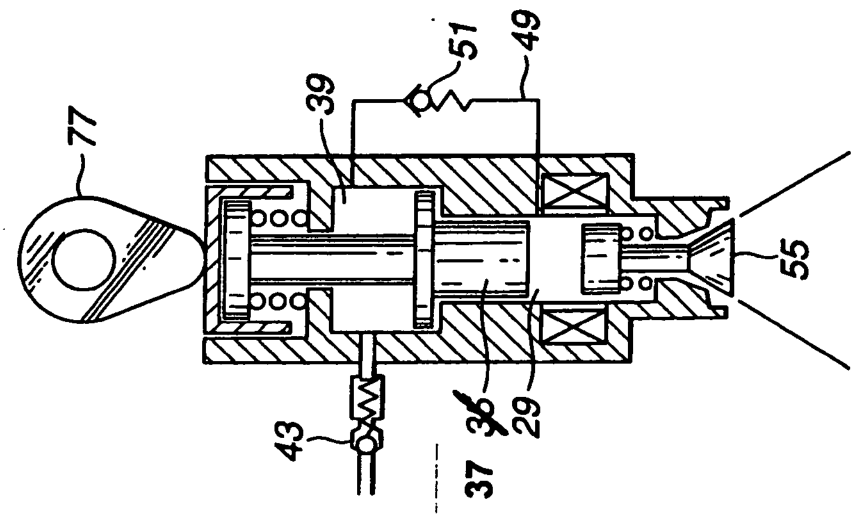



FIG.4C

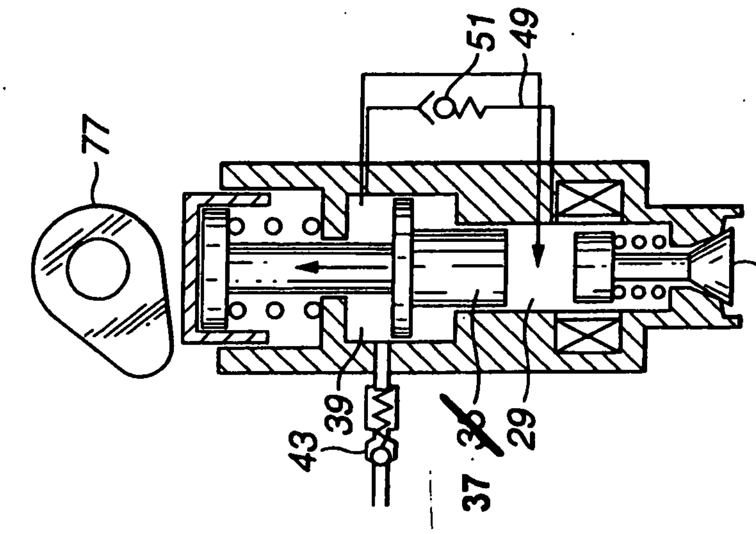
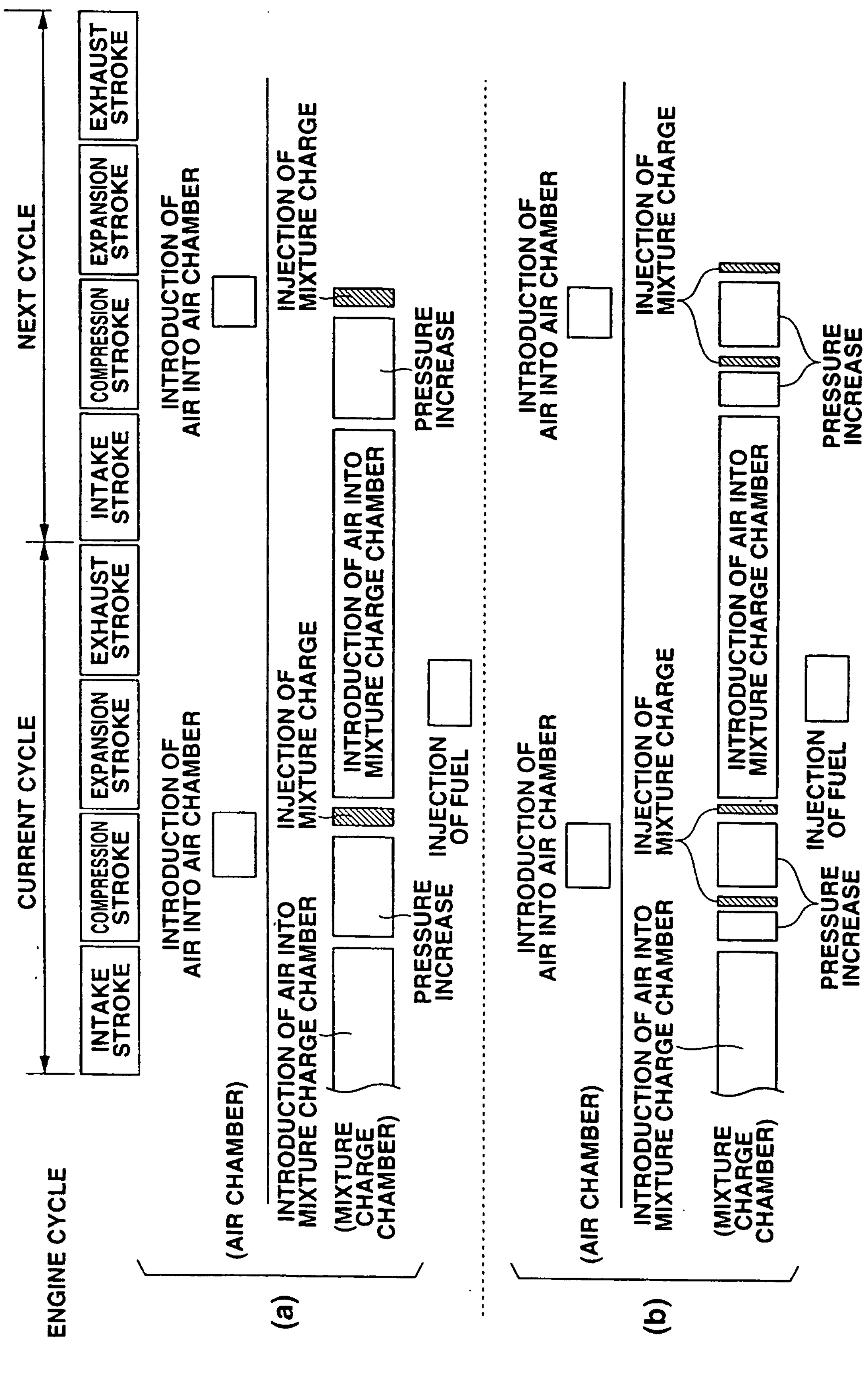


FIG.5


ENGINE CYCLE
CURRENT CYCLE
NEXT CYCLE
INTAKE STROKE
COMPRESSION STROKE
EXPANSION STROKE
EXHAUST STROKE
INTAKE STROKE
COMPRESSION STROKE
EXPANSION STROKE
EXHAUST STROKE
(a)
(AIR CHAMBER)
INTRODUCTION OF AIR INTO AIR CHAMBER
INTRODUCTION OF AIR INTO AIR CHAMBER
INTRODUCTION OF AIR INTO MIXTURE CHARGE CHAMBER
(MIXTURE CHARGE CHAMBER)
INTRODUCTION OF AIR INTO MIXTURE CHARGE CHAMBER
INJECTION OF MIXTURE CHARGE
INTRODUCTION OF AIR INTO MIXTURE CHARGE CHAMBER
INJECTION OF MIXTURE CHARGE
PRESSURE INCREASE
INJECTION OF FUEL
PRESSURE INCREASE
(b)
(AIR CHAMBER)
INTRODUCTION OF AIR INTO AIR CHAMBER
INTRODUCTION OF AIR INTO AIR CHAMBER
INTRODUCTION OF AIR INTO MIXTURE CHARGE CHAMBER
(MIXTURE CHARGE CHAMBER)
INTRODUCTION OF AIR INTO MIXTURE CHARGE CHAMBER
INJECTION OF MIXTURE CHARGE
INTRODUCTION OF AIR INTO MIXTURE CHARGE CHAMBER
INJECTION OF MIXTURE CHARGE
PRESSURE INCREASE
INJECTION OF FUEL
PRESSURE INCREASE

# FIG.6

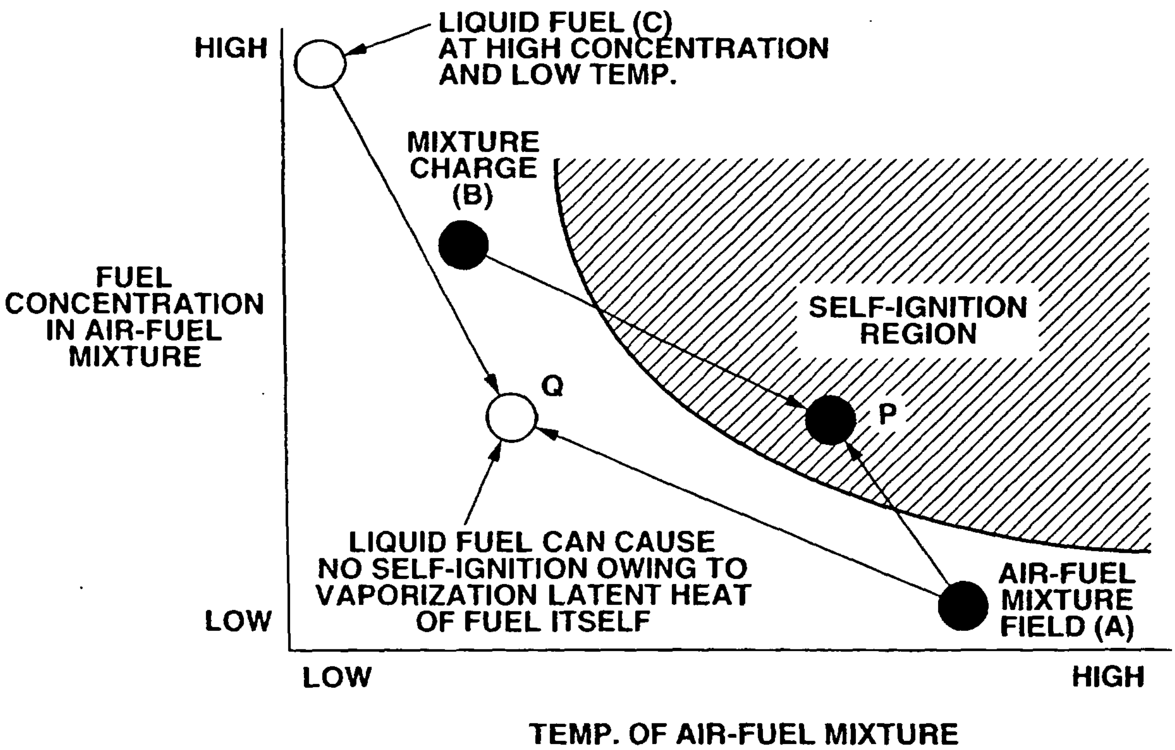
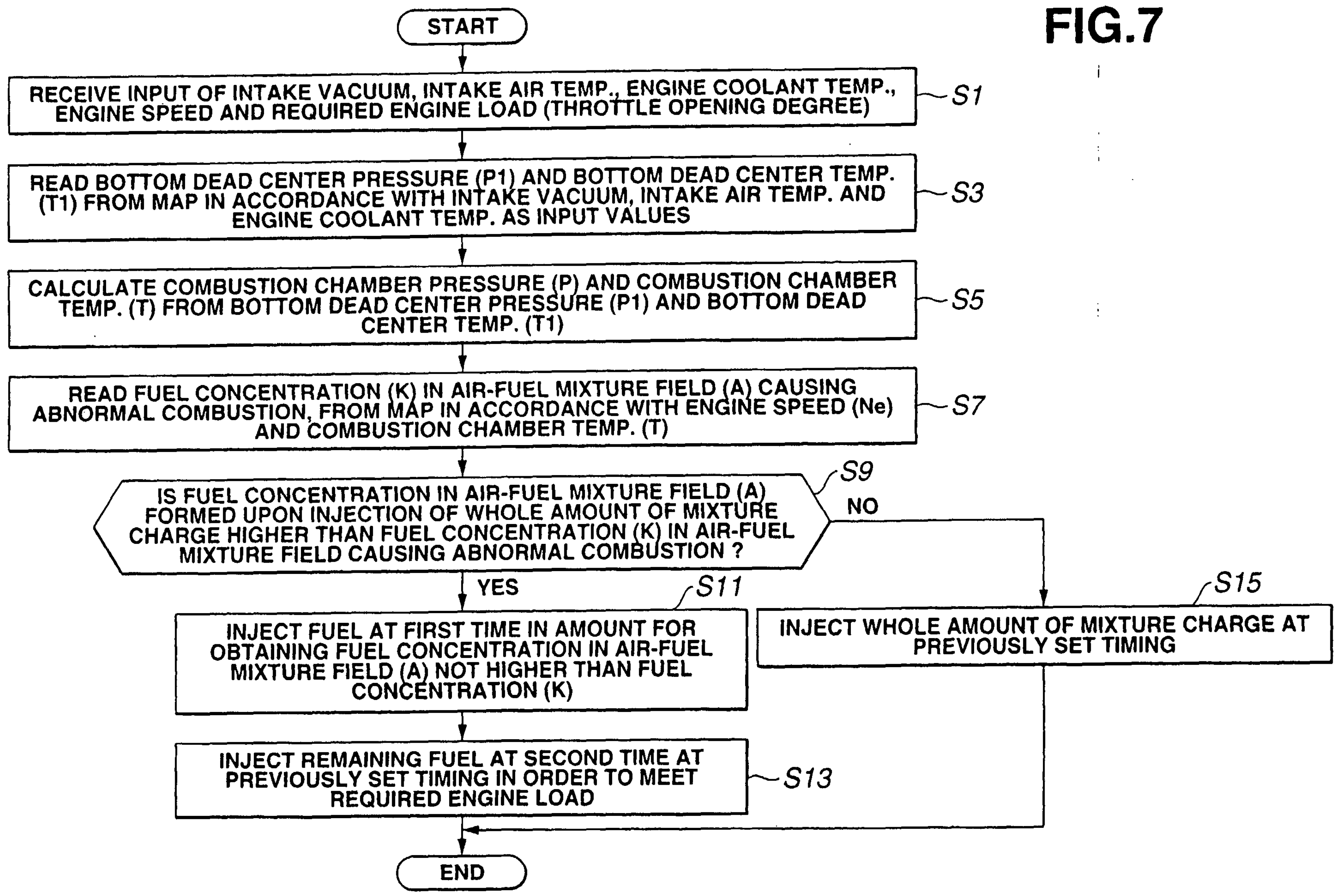

LIQUID FUEL (C)
AT HIGH CONCENTRATION
AND LOW TEMP.
HIGH
MIXTURE
CHARGE
(B)
FUEL
CONCENTRATION
IN AIR-FUEL
MIXTURE
SELF-IGNITION
REGION
Q
P
LIQUID FUEL CAN CAUSE
NO SELF-IGNITION OWING TO
VAPORIZATION LATENT HEAT
OF FUEL ITSELF
LOW
AIR-FUEL
MIXTURE
FIELD (A)
LOW
HIGH
TEMP. OF AIR-FUEL MIXTURE

FIG.7


START
RECEIVE INPUT OF INTAKE VACUUM, INTAKE AIR TEMP., ENGINE COOLANT TEMP., ENGINE SPEED AND REQUIRED ENGINE LOAD (THROTTLE OPENING DEGREE)
S1
READ BOTTOM DEAD CENTER PRESSURE (P1) AND BOTTOM DEAD CENTER TEMP. (T1) FROM MAP IN ACCORDANCE WITH INTAKE VACUUM, INTAKE AIR TEMP. AND ENGINE COOLANT TEMP. AS INPUT VALUES
S3
CALCULATE COMBUSTION CHAMBER PRESSURE (P) AND COMBUSTION CHAMBER TEMP. (T) FROM BOTTOM DEAD CENTER PRESSURE (P1) AND BOTTOM DEAD CENTER TEMP. (T1)
S5
READ FUEL CONCENTRATION (K) IN AIR-FUEL MIXTURE FIELD (A) CAUSING ABNORMAL COMBUSTION, FROM MAP IN ACCORDANCE WITH ENGINE SPEED (Ne) AND COMBUSTION CHAMBER TEMP. (T)
S7
IS FUEL CONCENTRATION IN AIR-FUEL MIXTURE FIELD (A) FORMED UPON INJECTION OF WHOLE AMOUNT OF MIXTURE CHARGE HIGHER THAN FUEL CONCENTRATION (K) IN AIR-FUEL MIXTURE FIELD CAUSING ABNORMAL COMBUSTION ?
S9
NO
YES
S11
INJECT FUEL AT FIRST TIME IN AMOUNT FOR OBTAINING FUEL CONCENTRATION IN AIR-FUEL MIXTURE FIELD (A) NOT HIGHER THAN FUEL CONCENTRATION (K)
S15
INJECT WHOLE AMOUNT OF MIXTURE CHARGE AT PREVIOUSLY SET TIMING
INJECT REMAINING FUEL AT SECOND TIME AT PREVIOUSLY SET TIMING IN ORDER TO MEET REQUIRED ENGINE LOAD
S13
END

## REFERENCES CITED IN THE DESCRIPTION

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- JP 10196424 A **[0004]**
- JP 09042116 B **[0006]**
- DE 3802669 A1 **[0007]**