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(54) ACCUMULATING FUEL PARTICLES IN A PORTION OF A COMBUSTION CHAMBER

(71) We, TOKAI TRW & Co., LTD., a corporation organized under the laws of Japan, of 1203 Ushiyama-cho, Kasugai Aichi, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method and apparatus for accumulating fuel particles in a portion of a combustion chamber.

The invention, the scope of which is defined in the appended claims includes a method of accumulating fuel particles in a portion of a combustion chamber, said method comprising the steps of establishing a first electrostatic field at a first electrode gap located in said portion of the combustion chamber between a surface of a main electrode and a first electrode surface of a secondary electrode, maintaining the atmosphere in the first electrode gap separate from the atmosphere in the combustion chamber, electrostatically attracting fuel particles in the combustion chamber toward the first electrode gap under the influence of electrostatic forces resulting from the first electrostatic field, establishing a second electrostatic field at a second electrode gap located in said portion of the combustion chamber between a second electrode surface of the secondary electrode and a tertiary electrode surface which is exposed to the atmosphere in the combustion chamber, and electrostatically attracting fuel particles in the combustion chamber toward the second gap under the influence of electrostatic forces resulting from the first electrostatic field.

The invention also provides apparatus for use in accumulating fuel particles in a portion of a combustion chamber, said apparatus comprising a main electrode surface disposed in said portion of the combustion chamber, a secondary electrode spaced from and electrically insulated from said main electrode surface and disposed in said portion of the combustion chamber, said secondary electrode having a first electrode surface which co-operates with said main electrode

surface to define a first electrode gap, wall means disposed in said portion of the combustion chamber and enclosing said main electrode surface and said first surface of said secondary electrode for maintaining the atmosphere in said first electrode gap separate from the atmosphere in the combustion chamber, said secondary electrode having a second electrode surface exposed to the atmosphere in the combustion chamber, a tertiary electrode surface exposed to the atmosphere in the combustion chamber, said tertiary electrode surface co-operating with said second surface of said secondary electrode to define a second electrode gap, and means for establishing a first electrostatic field in said portion of the combustion chamber by establishing an electrical potential across said first electrode gap and for establishing a second electrostatic field in said portion of the combustion chamber by establishing an electrical potential across said second electrode gap to electrostatically attract fuel particles to said portion of the combustion chamber under the influence of said first and second electrostatic fields.

In order that the invention may be well understood some embodiments thereof will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is a fragmentary sectional view of an ignition plug which is utilized to accumulate fuel particles in a portion of a combustion chamber and to subsequently ignite the fuel particles;

Fig. 2 is an enlarged view of a portion of Fig. 1 illustrating a pair of electrode gaps which are utilized in the establishing of electrostatic fields;

Fig. 3 is a fragmentary sectional view, generally similar to Fig. 2, of a second embodiment in which a secondary electrode is mounted on insulating material used in association with a main electrode;

Fig. 4 is a fragmentary sectional view, generally similar to Fig. 3, of a further embodiment in which portions of the secondary

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electrode are embedded in the body of insulating material;

5 An ignition plug 20 is shown in Fig. 1 mounted on a cylinder head 22 of a four-cycle internal combustion engine. The ignition plug 20 has side wall means providing a metal housing 24 with external threads 26 which engage internal threads 28 formed in the cylinder head 22 to hold the plug. A source of electrical potential or high voltage generating device 32 is connected with a generally cylindrical main or central electrode 34 of the ignition plug 20.

10 The high voltage generating device 32 is connected with a suitable battery (not shown) and includes a voltage-raising transformer which is effective to increase the magnitude of the negative voltage of a battery. This negative polarity voltage is impressed on the central electrode 34 through a voltage rectifier. During at least the intake and compression strokes of the engine, a constant negative electrical potential or voltage of approximately eight thousand volts is applied to the main electrode 34 by the voltage source 32. At the end of the compression stroke, the negative voltage applied to the main electrode 34 is increased to approximately twenty-five thousand volts. Although the voltage source 32 could have many different known constructions, it is contemplated that the voltage source could advantageously be constructed in the manner disclosed in U.S. Patent Specification No. 4,041,922. It is also contemplated that a source of positive polarity voltage could be utilized if desired.

20 The ignition device 20 includes a cylindrical secondary electrode 38 (see Fig. 2) which cooperates with the main electrode 34 and a third or tertiary electrode 40 to form a pair of electrode gaps 42 and 44 which are disposed in the engine combustion chamber 60. The first electrode gap 42 is formed between a main electrode surface or circular end face 48 of the cylindrical main electrode 34 and a first electrode surface or circular end face 50 of the cylindrical secondary electrode 38. The second electrode gap 44 is formed between a second electrode surface or circular outer end face 54 of the secondary electrode 38 and a generally rectangular tertiary electrode surface 56 on the tertiary electrode 40. The tertiary electrode 40 is integrally formed with a metallic housing 24 and is mechanically and electrically connected with the cylinder head 22.

25 The atmosphere in the electrode gap 42 is maintained separate from the atmosphere in the engine combustion chamber 60. This is accomplished by surrounding the first electrode gap 42 with a body or wall means 76 of ceramic insulating material which electrically insulates the main and secondary electrodes 34 and 38 from the housing 24.

Since the atmosphere in the electrode gap 42 is maintained separate from the atmosphere in the combustion chamber, the characteristics of the atmosphere in the electrode gap 42 remain constant during operation of the engine. Of course, the characteristics of the atmosphere in the combustion chamber 60 and the second electrode gap 44 vary during the operation of the engine.

70 Since the pressure and composition in the atmosphere at the electrode gap 44 varies during the operation of the engine, the electrical conductivity of the atmosphere in this electrode gap also varies. However, the pressure and composition of the atmosphere in the electrode gap 42 is maintained constant during operation of the engine. Therefore, the electrical conductivity characteristics of the atmosphere in the electrode gap 42 remain constant during operation of the engine.

75 To promote the electrostatic attraction of fuel particles to the portion of the combustion chamber 60 adjacent to the ignition plug 20 during operation of the engine, electrostatic fields are established in the combustion chamber at the electrode gaps 42 and 44. This is accomplished by the impression of the relatively large negative polarity voltages on the central or main electrode 34 by the voltage generating device 32. Thus, during operation of the engine, the voltage generating device 32 is effective to constantly apply a relatively large negative voltage of approximately eight thousand volts to the main electrode 34. It should be understood that a positive polarity voltage may be utilized if desired.

80 The electrode gap 42 is of a small size, preferably within the range of 0.2 to 0.8 mm. The secondary electrode 38 is charged across the gap 42 by the voltage applied to the main electrode 34 resulting in a strong electrostatic field being established between the outer end surface 48 of the main electrode 34 and the inner end surface 50 of the secondary electrode 38. This first electrostatic field extends into the combustion chamber 60 in the vicinity of the electrode gap 42.

85 A second electrostatic field is established in the combustion chamber 60 (Figure 1) between the outer end surface 54 (Figure 2) of the secondary electrode 38 and the surface 56 of tertiary or housing electrode 40. Depending upon the pressure and composition of the atmosphere in the combustion chamber 60, the electrostatic field between the secondary electrode 38 and the tertiary electrode 40 continuously fluctuates through a corona or glow discharge at the electrode gap 44. However at the end of the compression stroke, the voltage generating device 32 is effective to apply an increased negative voltage to the main electrode 34 to cause

sparkling to occur at the electrode gap 44.

When the pressure in the combustion chamber 60 is reduced during an initial portion of an intake stroke, the voltage potential between the secondary electrode 38 and the tertiary electrode 40 is effective to establish a corona discharge across the gap 44. This results in a reduction in the electrical potential across the gap 44 with a resulting decrease in the strength of the electrostatic field emanating from the gap 44. As the intake stroke continues, the pressure in the combustion chamber is further reduced and the corona discharge changes to a glow discharge. As this occurs, the strength of the electrostatic field is further reduced.

The pressure and composition of the atmosphere in the electrode gap 42 remains constant during operation of the engine so that a substantially constant electrical potential is established across the gap 42 during the intake stroke. This results in a relatively strong electrostatic field of substantially constant strength being formed in the combustion chamber 60 adjacent the electrode gap 42. It should be noted that the electrical potential across the electrode gap 42 is not sufficient to establish either a corona discharge or a glow discharge at this electrode gap during operation of the engine.

During the intake stroke, the strong electrostatic field extending from the electrode gap 42 is effective to negatively ionize fuel particles in a relatively lean air-fuel mixture which is being introduced into the combustion chamber 60. The resulting electrostatic forces on the air-fuel mixture results in a flow of the air fuel mixture through generally circular side openings 64 formed in the side wall means or housing 24 toward the main electrode 34, that is in the direction of the arrows in Fig. 2. At this time, the fuel particles are atomized under the influence of the strong negative D.C. voltage of approximately eight thousand volts which is being applied to the main electrode 34. The negatively charged fuel particles are attracted to a generally cylindrical inner surface 68 (Fig. 2) of the housing 24 which is at ground potential. In addition, the negatively charged fuel particles accumulate on the tertiary electrode 40 which is also at ground potential.

The housing 24 has a generally circular open end 72 through which the extremely lean air-fuel mixture flows after fuel particles have been electrostatically accumulated on the inside of the housing. During the intake stroke, the atmospheric pressure in the combustion chamber 60 is reduced so that a corona and then a glow discharge can be established at the electrode gap 44 between the tertiary electrode 40 and the secondary electrode 38. However, the establishment of the corona and glow discharges

at the electrode gap 44 is effective to reduce the electrostatic precipitation of fuel particles in the combustion chamber 60 adjacent to the ignition plug 20.

As the engine operating cycle continues and the compression stroke begins, the pressure in the combustion chamber 60 increases as the relatively lean air-fuel mixture in the combustion chamber is compressed. As this occurs, the conditions for establishing a glow and then a corona discharge across the electrode gap 44 become less favourable. Thus, sometime after the compression stroke has been undertaken and before ignition of the air-fuel mixture in the combustion chamber 60, the corona discharge is discontinued between the circular end face 54 of the secondary electrode 38 and the surface 56 of the tertiary electrode 40. This results in the simultaneous establishment and maintenance of strong electrostatic fields at the electrode gap 42 and at the electrode gap 44.

Whilst the pair of electrostatic fields are maintained at the electrode gaps 42 and 44 the accumulation of fuel particles in the combustion chamber 60 adjacent to the ignition plug 20 is promoted. This is because the first electrostatic field at the electrode gap 42 causes the air-fuel mixture to flow radially inwardly through the side openings 64 in the manner previously explained. This flow of the air-fuel mixture is directed toward the second electrode gap 44. The electrostatic field at the second electrode gap 44 further ionizes the fuel particles to promote the electrostatic accumulation of the negatively charged fuel particles on the housing 24 adjacent to the tertiary electrode 40. Thus, the effect of the two electrostatic fields at the electrode gaps 42 and 44 is additive to further enhance the electrostatic accumulation of fuel particles adjacent to the ignition plug 10.

At the end of the compression stroke, the magnitude of the negative voltage impressed on the central electrode 34 by the voltage generating device 32 is substantially increased to approximately twenty five thousand volts. This causes a spark to extend across the electrode gap 44 between the end face 54 of the secondary electrode 38 and the surface 56 of the tertiary electrode 40. This spark ignites the fuel particles which have been electrostatically accumulated around the ignition plug 20. By electrostatically accumulating fuel particles adjacent to the tertiary electrode 40, a relatively rich air-fuel mixture is provided around the ignition plug 20 even though the total charge introduced into a cylinder of the engine is very lean. This enables an air-fuel mixture which is leaner than could normally be ignited to be burned in an engine with a resulting reduction in the pollutants generated by the engine as described in U.S. Patent Speci-

fication No. 4,041,922 and in U.S. Patent Specification No. 4,124,003.

5 The effective duration of the simultaneous electrostatic fields associated with the ignition plug 20 is increased in order to increase the number of fuel particles which are electrostatically accumulated adjacent to the ignition plug 20. In the embodiment illustrated in Figs. 1 and 2 the increased duration of the electrostatic field is obtained by enclosing the electrode gap 42 with the generally cylindrical body or wall means 76 of insulating material. The insulating material 76 extends upwardly into the metallic body 24 of the ignition plug 20 and is effective to insulate the main electrode 34 from the metallic body 24 of the ignition plug. The body 76 of electrically insulating material has a cylindrical outer surface 80 of a smaller diameter than the cylindrical inner surface 68 of the metallic plug housing. This results in the formation of an annular space or chamber 82 between the cylindrical inner surface of the side wall means or plug housing 24 and the body 76 of the electrically insulating material to accommodate the flow of the air-fuel mixture from the side openings 64 to the outlet opening or open end 72 of the ignition plug housing 24.

10 In the embodiment illustrated in Figs. 1 and 2, the cylindrical secondary electrode 38 is held in the body 76 of insulating material by frictional forces between a cylindrical outer surface of the electrode and a cylindrical inner surface of the body 76 of insulating material. In the embodiments illustrated in Figs. 3 and 4, mounting prongs or legs are used in association with the secondary electrode to further hold it against axial movement relative to a body of insulating material. Since the embodiments illustrated in Figs. 3 and 4 are generally similar to the embodiment illustrated in Figs. 1 and 2, similar numerals will be utilized to designate similar components, the suffix letter "a" being associated with the numerals of Fig. 3 and the suffix letter "b" being associated with the numerals of Fig. 4 to avoid confusion.

15 In the embodiment illustrated in Fig. 3, the ignition plug 20a has a metallic housing 24a with circular opening 64a through which flow of a relatively lean air-fuel mixture is electrostatically induced in the manner previously explained. The ignition plug 20a has a main or central electrode 34a which is enclosed by a body 76a of electrically insulating material. A secondary or floating electrode 38a is connected with the body 76a of electrically insulating material by a pair of legs or prongs 90 and 92. The mounting legs 90 and 92 are embedded in the body 76a of electrically insulating material to accurately position an inner first surface 50a of the secondary electrode 38a relative to

an end surface 48a of the main electrode 34a to form a first electrode gap 42a. The atmosphere in the electrode gap 42a is maintained separate from the atmosphere in the associated combustion chamber to enable a strong electrostatic field to be established across the electrode gap 42a at any desired time in an operating cycle of an engine.

70 A second electrode gap 44a is formed between a second electrode surface of secondary electrode 38a and a surface of tertiary or housing electrode 40a. The electrode gap 44a is exposed to the atmosphere in the combustion chamber so that a corona discharge is established across the gap 44a in the manner previously explained in connection with Figs. 1 and 2. When the charge in the combustion chamber is to be ignited, a spark is established across the gap 44a.

75 In the embodiment illustrated in Fig. 4 the secondary electrode 38b is provided with a pair of legs 90b and 92b which are embedded in the body 76b of electrically insulating material. This results in the formation of a first electrode gap 42b between the secondary electrode 38b and a main electrode 34b. A second electrode gap 44b is formed between the secondary electrode 38b and a tertiary electrode 40b. The atmosphere in the electrode gap 42b is maintained separate from the atmosphere in the associated combustion chamber to enable a strong electrostatic field to be established across the electrode gap 42b while a corona discharge is established across the electrode gap 44b. This enables the duration of the electrostatic field to be increased to increase the electrostatic accumulation of fuel particles during each operating cycle of an engine.

80 In the embodiments illustrated in Figs. 1 through 4, the duration of the electrostatic field in the combustion chamber of an engine is increased. This is accomplished by establishing an electrostatic field across a first electrode gap having an atmosphere which is separate from the atmosphere of the combustion chamber while a corona discharge is being established in the combustion chamber.

85 In the above described embodiments illustrated in Figs. 1 through 4, the various ignition plugs have been described as being mounted directly on the cylinder head of an engine with the inner end portions of the ignition plugs exposed to a combustion chamber formed between the cylinder head, piston and cylinder wall of an engine. However, it is contemplated that it may be desirable to utilize these ignition devices in association with auxiliary combustion chambers similar to the ones disclosed in U.S. Patent Specification No. 4,041,922 and in U.S. Patent Specification No. 4,124,003. In this case the plug functions as hereinbefore

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described and when the spark has ignited the accumulated fuel particles the frame issuing from the auxiliary combustion chamber serves to ignite the remaining mixture.

5 A new and improved method and apparatus of using electrostatic fields and corona discharges to attract fuel particles to a portion of a combustion chamber has been described. In order to maximize the effect of the electrostatic fields during each operating cycle, a plurality of electrostatic fields are formed across a plurality of electrode gaps. The atmosphere in the first electrode gap 42 is maintained separate from the atmosphere in the combustion chamber 60 to enable an electrostatic field to be established at this electrode gap after a corona discharge has been established at the electrode gap 44 which is exposed to the atmosphere in the combustion chamber 60. The relatively long duration of the extremely strong electrostatic field at the electrode gap 42 enables a relatively large number of fuel particles to be electrostatically attracted to a portion of the combustion chamber 60 in which an ignition spark is provided to thereby promote the ignition of a very lean air-fuel mixture.

30 WHAT WE CLAIM IS:—

1. A method of accumulating fuel particles in a portion of a combustion chamber, said method comprising the steps of establishing a first electrostatic field at a first electrode gap located in said portion of the combustion chamber between a surface of a main electrode and a first electrode surface of a secondary electrode, maintaining the atmosphere in the first electrode gap separate from the atmosphere in the combustion chamber, electrostatically attracting fuel particles in the combustion chamber toward the first electrode gap under the influence of electrostatic forces resulting from the first electrostatic field, establishing a second electrostatic field at a second electrode gap located in said portion of the combustion chamber between a second electrode surface of the secondary electrode and a tertiary electrode surface which is exposed to the atmosphere in the combustion chamber, and electrostatically attracting fuel particles in the combustion chamber toward the second gap under the influence of electrostatic forces resulting from the first electrostatic field.

2. A method as claimed in claim 1, further including the step of providing a single source of electrical potential and wherein said steps of establishing first and second electrostatic fields are accomplished by applying electrical potential to the main electrode from the single source of electrical potential.

65 3. A method as claimed in claim 2

further including the step of maintaining the electrostatic fields without discharge for a period of time sufficient to electrostatically attract fuel particles.

4. A method as claimed in claim 3, wherein the electrical potential difference between the main and secondary electrodes is substantially constant during the step of maintaining.

5. A method as claimed in any one of the preceding claims, wherein the first and second electrostatic fields have the same polarity in series during the steps of establishing said first and second electrostatic fields.

6. A method as claimed in any one of the preceding claims, wherein said step of establishing a second electrostatic field includes the step of establishing a corona discharge at the second electrode gap.

7. A method as claimed in claim 6, wherein said step of establishing a corona discharge is performed after said step of establishing an electrostatic field at the first electrode gap and while the first electrostatic field is maintained at the first electrode gap.

8. A method as claimed in any one of claims 1 to 5, wherein said step of establishing a second electrostatic field includes the step of varying the second electrostatic field by changing between a corona and glow discharge at the second electrode gap.

9. A method as claimed in claim 8, wherein said first electrostatic field is maintained substantially constant while performing said step of varying the second electrostatic field.

10. A method as claimed in any one of the preceding claims, further including the step of establishing a spark at the second electrode gap to ignite fuel particles in said portion of the combustion chamber.

11. An apparatus for use in accumulating fuel particles in a portion of a combustion chamber, said apparatus comprising a main electrode surface disposed in said portion of the combustion chamber, a secondary electrode spaced from and electrically insulated from said main electrode surface and disposed in said portion of the combustion chamber, said secondary electrode having a first electrode surface which co-operates with said main electrode surface to define a first electrode gap, wall means disposed in said portion of the combustion chamber and enclosing said main electrode surface and said first surface of said secondary electrode for maintaining the atmosphere in said first electrode gap separate from the atmosphere in the combustion chamber, said secondary electrode having a second electrode surface exposed to the atmosphere in the combustion chamber, a tertiary electrode surface exposed to the atmosphere in the combustion chamber, said tertiary electrode

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5 surface co-operating with said second surface of said secondary electrode to define a second electrode gap, and means for establishing a first electrostatic field in said portion of the combustion chamber by establishing an electrical potential across said first electrostatic field in said portion of the combustion chamber by establishing an electrical potential across said second electrode gap to electrostatically attract fuel particles to said portion of the combustion chamber under the influence of said first and second electrostatic fields.

15 12. An apparatus as claimed in claim 11, wherein said means for establishing said first and second electrostatic fields comprises a single source of electrical potential.

20 13. An apparatus as claimed in claim 12, wherein said single source of electrical potential is connected only to said main electrode.

25 14. An apparatus as claimed in claim 11, 12 or 13, wherein said means for establishing said first and second electrostatic fields includes means for maintaining an electrical potential across said first and second gaps without discharge.

30 15. An apparatus as claimed in any one of claims 11, 12 or 13, wherein said means for establishing first and second electrostatic fields includes means for establishing a corona discharge across said second electrode gap after establishing an electrostatic field across said first electrode gap.

35 16. An apparatus as claimed in any one

of claims 11 to 15, further including side wall means disposed in said portion of the combustion chamber for at least partially defining a chamber, a plurality of side openings through which an air/fuel mixture can flow into said chamber and an outlet opening through which an air/fuel mixture can flow from said chamber, said first electrode gap being disposed in said chamber to enable the first electrostatic field to promote a flow of an air/fuel mixture into said chamber through said side openings.

17. An apparatus as claimed in claim 16, wherein said second electrode gap is disposed closer to said outlet opening than said first electrode gap to enable said second electrostatic field to promote a flow of an air/fuel mixture from said chamber through said outlet opening.

55 18. A method of accumulating fuel particles in a portion of a combustion chamber substantially as herein described with reference to the accompanying drawings.

60 19. An apparatus for use in accumulating fuel particles in a portion of a combustion chamber substantially as herein described with reference to Figures 1 and 2, or Figure 3 or Figure 4 of the accompanying drawings.

A. A. THORNTON & CO.,
Chartered Patent Agents,
Northumberland House,
303/306 High Holborn,
London WC1V 7LE.

