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B. REYNOLDS

2,741,230

METHOD OF OPERATING AN INTERNAL COMBUSTION ENGINE

Filed July 14, 1952

2 Sheets-Sheet 1

FIG. 1.

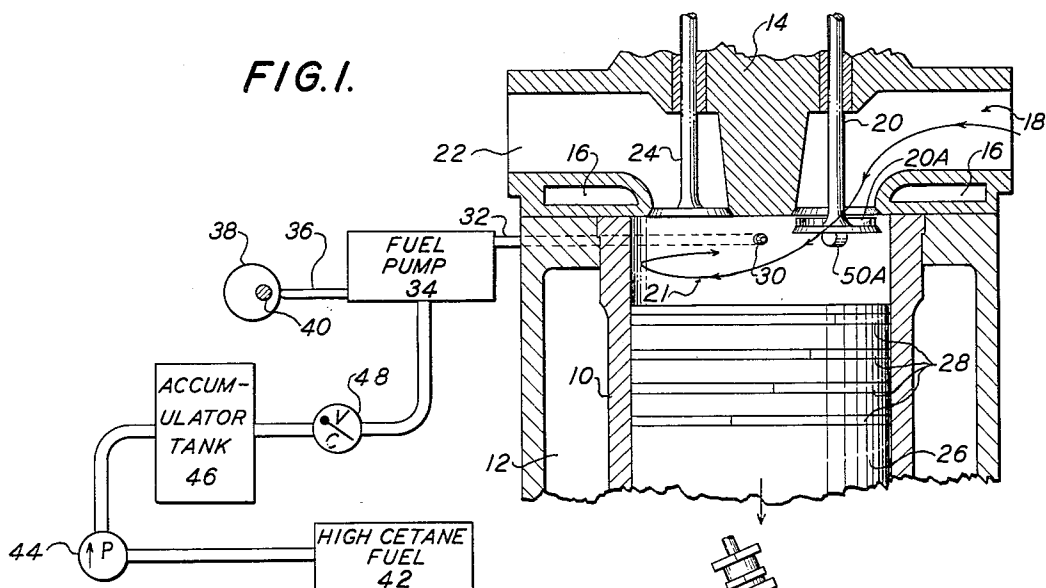


FIG. 2.

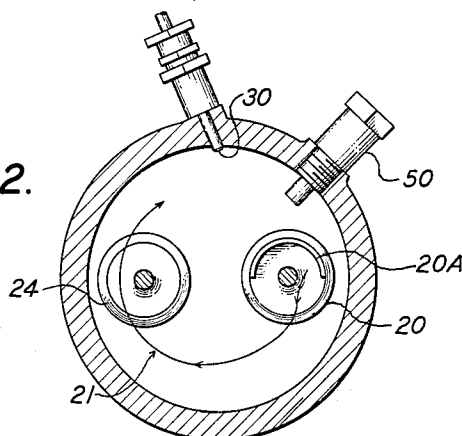
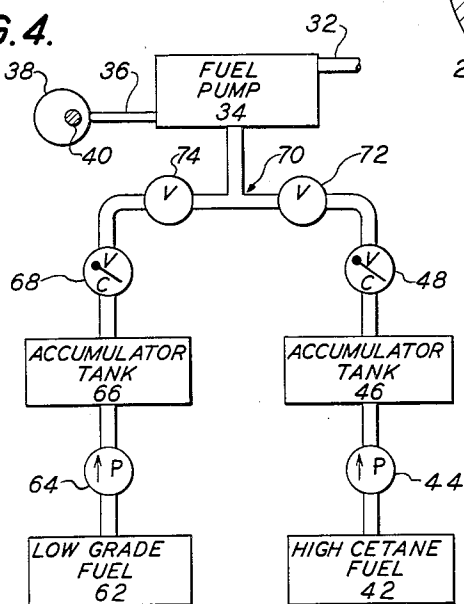


FIG. 4.



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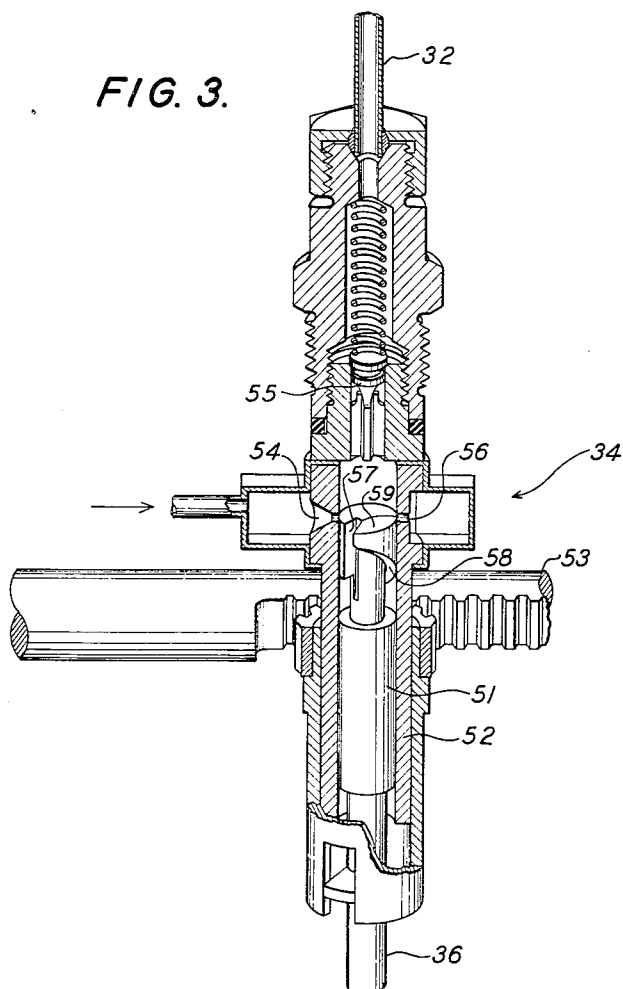
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2 Sheets-Sheet 2



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METHOD OF OPERATING AN INTERNAL COMBUSTION ENGINE

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6 Claims. (Cl. 123—32)

This invention relates to reciprocating internal combustion engines and methods of operating them. More particularly, the invention is concerned with methods and apparatus for igniting the fuel in engines of the general type disclosed in U. S. Patent No. 2,484,009, which was granted to E. M. Barber on October 11, 1949.

In the improved combustion process with which this invention is concerned, fluid fuel to be burned in the engine is injected during each cycle of operation of the engine. The injected fuel is formed into a patch of combustible mixture which is confined in one direction by a stream of oxidizing gas traveling toward the patch and containing little or no vaporized fuel so that it is incombustible. The patch is confined on the other side by gaseous products of combustion traveling away from a flame front at the edge of the patch where the mixture is burned substantially as fast as it is formed. Combustion is thus confined to and completed at the leading edge of the patch. Thus, during each cycle of operation of the engine a patch of combustible mixture is progressively formed and consumed in a localized area of the cylinder. As a result, little or no "end gases" are permitted to exist, and even when existent are not exposed to the pressure and the temperature at which spontaneous ignition occurs for the time required to bring about spontaneous ignition. Consequently, "ping" or "knock" is inhibited even with fuels of low anti-knock value at high compression ratios. Engines employing such a combustion process are more efficient than conventional engines, and they will function satisfactorily with low grade fuel and with fuels having widely different characteristics.

I have discovered that the improved combustion process described above can be achieved in an engine employing glow plug ignition, and that the glow plug can be heated by the combustion of fuel within the cylinder, so that an external source of power for heating the glow plug is unnecessary.

In accordance with my invention, the combustible mixture is first ignited in successive cycles by compression, and the heat generated in the successive compression-ignition cycles is utilized to heat the glow plug to a temperature at which the glow plug will itself ignite the combustible mixture. Thereafter, the combustible mixture is ignited by the glow plug during successive cycles of operation of the engine, and such ignition continues as long as substantial amounts of fuel are injected into the cylinder.

The glow plug is located so that, after it is sufficiently heated, it ignites the combustible mixture so as to provide the flame front required to burn the combustible mixture substantially as fast as it is made during each cycle of operation, thereby achieving the improved combustion process with which this invention is concerned.

When the engine operates at low power for a long time, as when the engine idles, the combustion within the cylinder may be insufficient to maintain the glow plug at the temperature required to ignite the combustible

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mixture, and the fuel is then ignited by compression until more power is required.

Thus, the ignition automatically changes from compression to glow plug and vice versa, depending upon the amount of power which the engine is required to produce.

When the engine operates at low power, it functions essentially as a diesel engine; however, at higher power the combustion process is of the improved type described above so that the combustion is more efficient and smoke and diesel knock are eliminated.

The fuel for the engine should have a cetane rating of 40 or more so that it will ignite by compression when the engine is started and while the engine operates at low speed. If desired, a fuel having a high cetane rating may be employed to start the engine, and then the engine can be switched over to practically any fluid fuel.

The invention is explained with reference to the drawings, in which:

Fig. 1 is a diagram, partly in vertical section, of an engine for practicing the invention;

Fig. 2 is a partial plan section of the engine of Fig. 1 showing the locations of the fuel injection nozzle, the glow plug, and the valves;

Fig. 3 shows a fuel pump which is suitable for use in the engine of Fig. 1; and

Fig. 4 is a diagram showing an alternative fuel supply arrangement for the engine shown in Fig. 1.

The engine illustrated in Fig. 1 is a four cycle engine of the general type described in U. S. Patent No. 2,484,009, except that it is provided with a glow plug for ignition, rather than a spark plug.

The engine comprises a cylinder 10 provided with a cooling jacket 12, and a head 14 provided with cooling channels 16. An air inlet port 18 in the head opens into the cylinder through a poppet valve 20 which is provided with a semicircular shroud 20A on one side.

The shroud is so placed that it causes the air to swirl rapidly around the axis of the cylinder as it is drawn in on the intake stroke, as indicated by the line 21. The swirl thus induced is "geared" to the engine crankshaft, in that the rate of swirl bears a substantially constant ratio to the R. P. M. of the engine regardless of changes in engine speed. Various ratios may be employed, but for four cycle engines of the type here considered, a swirl rate which is about six times the engine speed in R. P. M. is particularly suitable.

An exhaust port 22 in the head opens from the cylinder through a conventional poppet exhaust valve 24. A conventional piston 26 provided with rings 28 reciprocates in the cylinder. The piston is also provided with conventional connecting rod and crankshaft (not shown).

A fuel injector nozzle 30 projects into the upper portion of the cylinder above the top dead center position of the piston and sprays fuel into the swirling air stream therein so as to impregnate a localized segment of the air stream and form a combustible patch. Preferably the fuel is sprayed from the nozzle 30 in a fan or cone-shaped pattern, and the spray is directed downstream and across the swirling air stream. The rate of injection of the fuel is correlated with the velocity of the swirling air and the density of the air so as to impregnate a localized segment of the air stream located at one side of a diameter of the combustion space.

The nozzle is connected by a pipe 32 to a fuel pump 34. The fuel pump is actuated by a stem or plunger 36, and the plunger is moved by a cam 38 which is journaled on a pin 40. The cam is geared to the crankshaft by conventional means (not shown) and makes one complete revolution for each two revolutions of the crankshaft.

The fuel pump 34 is supplied with fuel from a supply

tank 42 which feeds a high-pressure pump 44. The outlet of the high-pressure pump is connected to an accumulator tank 46, which in turn is connected to the fuel pump 34 through a check valve 48.

A glow plug 50, having a portion 50A which extends within the cylinder, is provided for igniting the combustible mixture within the cylinder. Preferably the glow plug is located about 30 to 60° downstream from the injector nozzle 30. The glow plug is positioned so that when it is heated to a proper temperature, it serves to ignite the first increment of the combustible mixture as soon as it is formed. Thus, a flame is formed at the front of each patch of combustible mixture so that the mixture is burned substantially as fast as it is formed. This flame front tends to travel in a direction counter to the swirl of the air mass and toward the locus of fuel injection. The combustion products formed in the burning patch travel in the direction of swirl away from the flame front, and the flame front is fed by successive increments of combustible mixture swirling toward it and formed of fuel injected into the swirling air. The successive increments of combustible mixture are burned at or near the flame front of the patch substantially as fast as they are formed during each combustion period of the engine, the injection of fuel ceasing as soon as sufficient fuel for each power stroke has been injected. The combustible patch of mixture is thus confined on one side by an incombustible layer of the combustion products swirling away from the patch and on the opposite side by an incombustible layer of air into which no fuel has yet been injected or which does not yet contain enough vaporized fuel to form a combustible mixture. Under these conditions substantially no "end gases" are formed, and even if formed, do not attain the temperature and pressure for a sufficient length of time to result in spontaneous ignition. Consequently "ping" or "knock" is inhibited even with fuels of low anti-knock value at high compression ratios.

The end 50A of the glow plug 50 is a piece or coil of metal which is heat insulated with respect to the wall of the cylinder, and it is heated by the internal combustion within the cylinder so that an external source of power for heating the plug is not required. In order to heat the glow plug when the engine is started, the combustible material mixture is ignited by compression during the initial cycles of operation of the engine. Thus, the engine functions essentially as a diesel engine until the glow plug is heated to a sufficient temperature to ignite the first increments of the combustible patches as they are formed during successive cycles, whereupon the glow plug ignites the mixture before compression-ignition can occur.

When the engine operates at low power, such as when the engine idles, the combustion within the cylinder is insufficient to maintain the glow plug at the temperature required to ignite the combustible mixture, and the fuel is then ignited by compression until more power is required. Thus, the ignition automatically changes from compression to glow plug and vice versa, depending upon the amount of power which the engine is required to produce.

Glow plug ignition serves to provide the flame front required to burn the combustible mixture substantially as fast as it is formed and thereby provides a combustion process which is superior to diesel operation. Thus, when the engine is operated at higher power, the combustion is better than that of a conventional diesel engine, and smoke and knock are eliminated. However, conventional diesel fuel may be employed and the octane rating of the fuel is relatively unimportant.

Preferably the compression ratio of the engine is relatively low, say 12 to 1, so as to avoid heavy diesel construction. However, the compression ratio must be high enough to cause the fuel to be ignited by compression when the engine operates at low power.

In a preferred method of operating the engine at high

power, the fuel is injected into the air stream during about 80 to 90% of the time required for the air to complete one swirl around the cylinder. Thus, if the swirl rate is six times the engine speed in R. P. M., fuel is injected during the period required for the crankshaft to rotate approximately 50°.

For reduced load conditions, the amount of fuel may be reduced by maintaining the rate of injection approximately the same and reducing the relative duration of the injection period.

The fuel injection is initiated well in advance of top dead center when the engine operates at high power. Preferably, the fuel injection advance is adjustable so that the fuel injection is initiated later in the cycle for reduced load conditions. By way of example, the fuel injection may be initiated at about 15° before top dead center at low power, and it may be advanced uniformly as the power is increased so that the injection is initiated at about 30° before top dead center at high power.

Fig. 3 shows a fuel pump 34 which is suitable for adjusting the injection advance in accordance with the power at which the engine is operated. The fuel pump is a conventional type employed in diesel engines except that it is provided with a lead helix for controlling the relative time when fuel injection is initiated for different power requirements.

The fuel pump has a plunger 51 which reciprocates in a cylinder 52. A rack 53 is provided for controlling the orientation of the plunger in the cylinder so as to control the amount of fuel which is injected during each cycle of operation. Fuel is admitted through an inlet port 54, and it is transmitted through a valve 55 to the fuel injector nozzle. A spill port 56 serves to provide an exit for the fuel and preclude its flow through the valve 55 except during the portion of each cycle of operation when the port 56 is closed by the plunger.

The plunger 51 is provided with a conventional slot 57 and helical surface 58 for controlling the duration of fuel injection in accordance with the orientation of the plunger. The plunger is also provided with an auxiliary helical surface 59 for controlling the injection advance in accordance with the orientation of the plunger.

As shown in Fig. 3, the plunger is oriented to provide fuel injections of substantially maximum duration as required for high power operation. For low power operation, the amount of fuel which is injected is reached by moving the rack 53 so as to rotate the plunger counterclockwise as viewed from above. The auxiliary helical surface 59 causes the plunger to close the spill port 56 at a later time during each cycle for low power operation; hence the injection advance is controlled in accordance with the power which the engine is required to produce.

The fuel for the arrangement shown in Fig. 1 should have a high cetane rating, say 40 or more, so that it will ignite by compression when the engine operates at low power.

If desired a fuel having a high cetane rating may be employed to start the engine, and then the engine may be switched over to run on practically any low grade fuel. Such an arrangement is primarily suitable for use with engines which must operate at high power over long periods of time.

Fig. 4 shows a suitable fuel supply system for achieving this type of operation. This system comprises the same arrangement shown in Fig. 1 for supplying the high cetane fuel, and in addition a similar supply system is provided for the low grade fuel, which system comprises a tank 62, a pump 64, an accumulator tank 66, and a check valve 68. The two systems are connected to the fuel pump 34 through a T 70, and valves 72 and 74 are provided for turning the fuel on and off in the respective systems.

I claim:

1. In that method of operation of a reciprocating piston,

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internal combustion engine which comprises forming a mass of compressed swirling air rotating at high velocity within a combustion space of a cylinder of said engine, injecting fuel into said compressed swirling air so as to impregnate substantially uniformly with fuel a localized segment of said swirling air as it rotates past the locus of fuel injection, promptly igniting the first increment of injected fuel at a point near said locus of fuel injection substantially as soon as a combustible fuel vapor-air mixture has formed therefrom to establish a flame front traveling in the direction opposite that of said swirling air, the resulting incombustible combustion products rotating away from said flame front as fresh compressed air rotates toward said flame front, whereby the traveling flame front is confined on its rear side by a layer of said incombustible combustion products and on its front side by a layer of incombustible air, and continuing the injection of fuel into a localized portion of said fresh compressed air immediately in advance of said traveling flame front to form progressively additional combustible fuel vapor-air mixtures which are immediately ignited by said traveling flame front and burned substantially as rapidly as formed while maintaining said flame front confined between incombustible layers, the improvement which comprises the ignition of said first increment of injected fuel, as soon as a combustible mixture has formed therefrom, by compression when said engine operates at low power, and when said engine operates at high power, the ignition being effected by a solid member disposed at the mixture locus and heated by the combustion of fuel within said combustion space, said injected fuel having compression ignition characteristics favorable for easy starting and operation at low power, and comprising a low grade fuel for operation at high power.

2. In that method of operating a reciprocating piston, internal combustion engine which comprises forming a mass of compressed swirling air rotating at a substantially constant rate with respect to the speed of said engine within a combustion space of a cylinder of said engine, injecting fuel into said mass of compressed swirling air during each cycle of operation so as to impregnate substantially uniformly with fuel a localized segment of said swirling air as it rotates past the locus of fuel injection, promptly igniting the first increment of injected fuel at a point near said locus of fuel injection substantially as soon as a patch of combustible fuel vapor-air mixture has formed therefrom to establish a flame front traveling in the direction opposite that of said swirling air, the resulting incombustible combustion products rotating away from said flame front as fresh compressed air rotates toward said flame front, whereby the traveling flame front is confined on its rear side by a layer of said incombustible combustion products and on its front side by a layer of incombustible air, and continuing the injection of fuel into a localized portion of said fresh compressed air immediately in advance of said traveling flame front to form progressively additional combustible fuel vapor-air mixtures which are ignited immediately by said traveling flame front and burned substantially as rapidly as formed, while maintaining said flame front confined between incombustible layers, the improvement which comprises igniting the combustible mixture patch by compression when the engine operates at low power, and when the engine operates at high power, positively igniting on each cycle of operation the first increment of injected fuel substantially as soon as a combustible mixture patch is formed therefrom by a solid member disposed at the patch locus in said combustion space of a cylinder and heated to an ignition temperature solely by the combustion occurring in the cylinder on preceding cycles, said injected fuel having a high cetane rating for ease in engine starting and for engine operation at low power, and comprising a low grade fluid fuel for economic engine operation at high power.

3. In the method as set forth in claim 2, said solid

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member comprising a glow plug which is heated solely by the combustion of fuel within the cylinder, the shift from one type of ignition to the other being automatic and dependent upon the degree of heating of the glow plug by the combustion.

4. In the method of operation of a reciprocating piston, internal combustion engine as set forth in claim 2, the injection of fuel being initiated at a predetermined time during each cycle for low power operation and advanced to occur at an earlier time during each cycle for high power operation, the ignition at high power being effected by a glow plug which is heated by the combustion of fuel within the cylinder, the shift from one type of ignition to the other being automatic and dependent upon the degree that the glow plug is heated by the combustion.

5. In the method of operating a reciprocating piston, internal combustion engine which comprises forming a mass of compressed swirling air rotating at a controlled rate with respect to the speed of the engine within a combustion space of a cylinder of said engine, injecting fuel into said compressed swirling air so as to impregnate substantially uniformly with fuel a localized segment of said swirling air as it rotates past the locus of fuel injection, promptly igniting the first increment of injected fuel at a point near said locus of fuel injection substantially as soon as a patch of combustible fuel vapor-air mixture has formed therefrom to establish a flame front traveling in the direction opposite that of said swirling air, the resulting incombustible combustion products rotating away from said flame front as fresh compressed air rotates toward said flame front, whereby the traveling flame front is confined on its rear side by a layer of said incombustible combustion products and on its front side by a layer of incombustible air, and continuing the injection of fuel into a localized portion of said fresh compressed air immediately in advance of said traveling flame front to form progressively additional patches of combustible fuel vapor-air mixtures which are ignited immediately by said traveling flame front and burned substantially as rapidly as formed, while maintaining said flame front confined between incombustible layers, the improvement which comprises igniting by compression said first increment of injected fuel as soon as said patch of combustible mixture has formed therefrom, when said engine operates at low power and the amount of fuel injected in successive engine cycles is relatively small, and igniting said first increment of injected fuel in the patch of combustible mixture in successive cycles by a heated solid member disposed at the locus of said last mentioned patch when the amount of fuel injected in the later successive cycle is relatively large, and heating the solid member to ignition temperature solely with the heat generated by the combustion of fuel within said combustion space, the fuel injected for engine operation at low power having a high cetane rating for ease in compression ignition, and the fuel injected in relatively large amounts being a low grade fluid fuel for economical operation.

6. The method of operation of a reciprocating piston internal combustion engine comprising the formation of a mass of compressed swirling air rotating at high velocity within a combustion space of said engine, the injection of fuel into said mass of compressed swirling air to impregnate with fuel substantially uniformly a localized segment of said compressed swirling air as it rotates past the locus of fuel injection, the ignition of the first increment of injected fuel adjacent said locus of fuel injection and substantially as soon as a combustible fuel vapor-air mixture has formed therefrom to establish a flame front traveling in the direction opposite that of said compressed swirling air with the resulting combustion products rotating away from said flame front as fresh compressed swirling air rotates toward said flame front, and the continuation of the injection of fuel into localized portions of said fresh compressed swirling air immediately in advance of said traveling flame front to progressively form additional

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combustible fuel vapor-air mixtures which are immediately ignited by said traveling flame front and burned substantially as rapidly as formed, the ignition of said first increment of injected fuel being accomplished by compression when said engine operates at low power, said injected fuel having a relatively high cetane rating for ease of compression ignition, and when the engine operates at high power, the ignition being effected positively by a solid member disposed at the mixture locus and heated by the combustion of fuel within said combustion space, the fuel injected at high power engine operation not neces-

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sarily having easy compression ignition starting characteristics.

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