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LIQUID FUEL INJECTION DEVICES FOR FREE
PISTON INTERNAL COMBUSTION ENGINES

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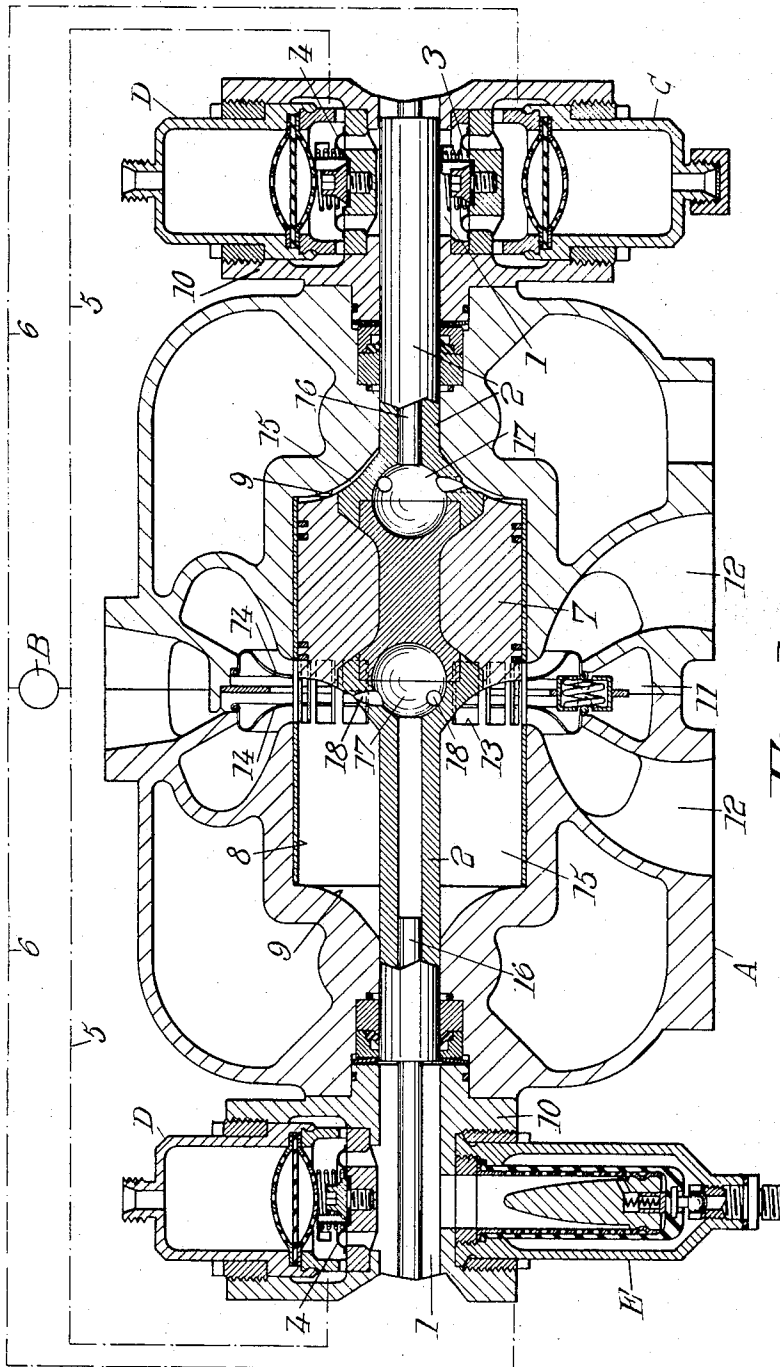


Fig. 1.

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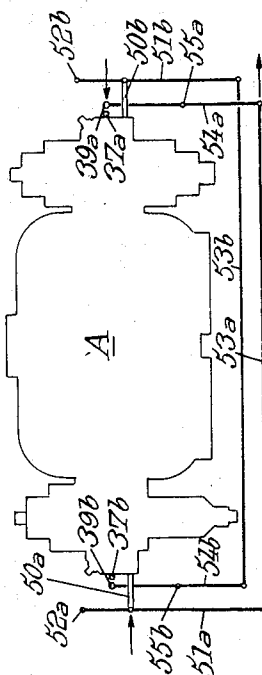
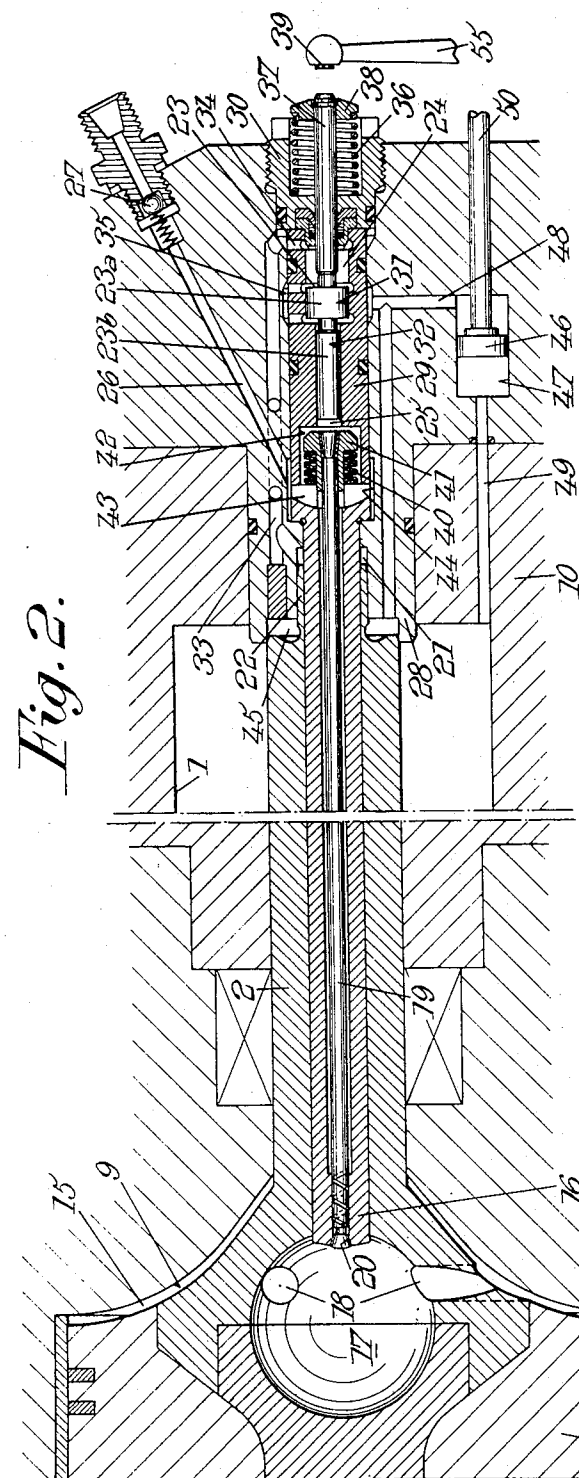
J. CADIOU

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LIQUID FUEL INJECTION DEVICES FOR FREE PISTON INTERNAL COMBUSTION ENGINES

Jean Cadiou, Paris, France, assignor to Societe Anonyme

Andre Citroen, Paris, France, a society of France

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ABSTRACT OF THE DISCLOSURE

On either side of an internal combustion engine having a reciprocating piston, a cylinder constantly full of liquid is connected with a fixed bore having an inner diameter equal to the outer diameter of the end of a plunger rigid with the engine piston. This bore is disposed in such manner that the end of said plunger penetrates thereinto near the end of the compression stroke of the piston. An auxiliary piston is disposed in an auxiliary cylinder so as to divide the latter into a space connected with the above mentioned bore and a space connected, on the one hand, with a fuel inlet conduit provided with a check valve and, on the other hand, with a fuel injection orifice opening into the internal combustion engine cylinder.

The present invention relates to liquid fuel injection devices for free piston internal combustion engines of the type working by injection of liquid fuel. The invention is more especially, but not exclusively, concerned with engines having a piston rigid, at one longitudinal end thereof, with a piston or plunger of a pump for the hydraulic transmission of power.

The object of the present invention is to provide a device of this kind which is better adapted to meet the requirements of practice than those known at the present time and in particular which is of simpler construction and capable of supplying a high injection pressure, the beginning of injection being adjusted with accuracy and the end of injection being possibly made variable in accordance with the load of the engine.

The invention is concerned with feed devices of this kind wherein the engine piston carries a plunger rod extending with a fluidtight fit through the cylinder head of the internal combustion engine so as to project into a chamber full of liquid. According to the present invention this chamber communicates with a blind bore of a diameter equal (with the approximation corresponding to a sliding fit) to the external diameter of the end of said rod and disposed in such manner that said rod end enters said bore near the end of the piston compression stroke (before the external dead center position) and in dividing an auxiliary cylinder by means of an auxiliary piston into two spaces, to with a first space connected with said blind bore and a second space connected, on the one hand, with a fuel feed conduit provided with a check valve and, on the other hand, with an injection orifice, whereby the liquid moved by the penetration of the end of the rod into the blind bore moves the auxiliary piston in the direction producing injection of fuel. Advantageously said auxiliary piston is of stepped construction with a portion of large cross section in the first space (control liquid) and a portion of small cross section in the second space (fuel), whereby the injection pressure is increased with respect to the pressure of the control liquid in a ratio equal to that of said cross sections.

A preferred embodiment of the present invention will be hereinafter described with reference to the appended drawings, given merely by way of example, and in which:

FIG. 1 is a diagrammatic axial section view of a free piston engine fed with fuel by means of a device according to this invention;

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FIG. 2 shows, similarly to FIG. 1 and on an enlarged scale, an injection device according to the present invention as applied to the engine of FIG. 1; and

FIG. 3 shows, on a smaller scale, the outline of the engine of FIG. 1 with the external elements of a regulation system combined with two fuel injection devices such as shown by FIG. 2.

This power plant is advantageously made as disclosed in the French patent application P.V. 59,669 of April 29, 1966.

It includes:

A free piston internal combustion engine A;

A hydraulic generator or pump, preferably, as shown, with two opposed groups comprising each a cylinder 1 and a hollow rod or plunger 2, each group including a suction valve 3 and a delivery valve 4;

A receiver B (or hydraulic motor) fed from the generator, to the delivery of which it is connected through pipes 5, the delivery of said receiver B being connected through pipes 6 with the suction of said generator, receiver B being coupled with the wheels (not shown) of the vehicle;

Two damping chambers C and D fixed to each cylinder 1 respectively, chamber C being connected upstream of suction valve 3 and chamber D downstream of delivery valve 4; and

A storing chamber E connected with each cylinder 1 between valves 3 and 4 to receive a variable amount of the liquid delivered on every cycle of the engine from said cylinder 1 so as to vary the ratio of transmission between engine A and receiver B.

The upper half of FIG. 1 is shown in section by a first axial plane so as to show the respective damping chambers C and D of the two groups whereas the lower half of FIG. 1 is shown, on the left of FIG. 1, in section by a second axial plane making an angle of 60° with said first axial plane on one side thereof so as to show a storing chamber E, and, on the right of FIG. 1, in section by a third axial plane making an angle of 60° with said first axial plane on the other side thereof, so as to show a damping chamber C.

Engine A is of the double action type and provided with a single free piston 7 slidable in a cylinder 8 having two cylinder heads 9. Said piston 7 carries, at each end thereof, a rod 2 extending in a fluidtight fashion through the corresponding cylinder head 9. The hydraulic pump cylinders 1 are formed in blocks 10 rigid with cylinder heads 9. The air inlet conduits of the internal combustion engine are designated by 11 and the exhaust conduits by 12, the corresponding ports being controlled by piston 7. The inlet and outlet ports may be constituted by the same openings 13 divided by movable annular partitions 14.

To feed fuel into each space 15 existing between piston 7 and the corresponding cylinder head 9, use is made of an injection conduit 16 fixed with respect to cylinder 8 and disposed, with a very small radial clearance, in the corresponding hollow plunger 2.

In piston 7, at each end thereof, there is formed an approximately spherical chamber 17 located close to the end of plunger 2. Each of said spherical chambers 17 communicates with the corresponding space 15 through orifices or passages 18 which permit successively the air imprisoned in space 15 to enter with a high velocity into said chamber 17 at the end of the compression stroke and the flame resulting from combustion to flow into said space 15 when the pressure has increased in chamber 17.

In order to permit injection of fuel through conduit 16 there is provided therein an injection needle 19 (FIG. 2) adapted to be moved away from its seat to open an injection orifice 20 under the effect of the fuel pressure

created through means which will be hereinafter described.

Such an internal combustion engine works as follows. When piston 7 is getting close to the end of its stroke toward the right (FIGS. 1 and 2), the air compressed in chamber 15 enters chamber 17 through passages 13 with a high velocity. When the pressure of the ignited fuel mixture reaches a sufficient value, the flame is projected into space 15 where fuel combustion is completed. This operation takes place repeatedly on every dead center position of the piston.

On every stroke of the internal combustion engine piston 7, liquid is sucked in into that of the pump cylinders 1 the plunger of which is moving inwardly whereas liquid is delivered from the other cylinder 1. Each cylinder 1 of the hydraulic pump remains at any time full of liquid between its suction valve 3 and its delivery valve 4.

Piston 7 carries, on either side thereof, a hollow plunger 2 passing with a fluidtight fit through the corresponding cylinder head 9 to extend into a cylinder 1 constantly full of liquid.

Now, as long as plunger 2 is not near the end of its outward stroke, its cylinder 1 is in communication with a bore 21 having a diameter practically equal to the external diameter of the end 22 of said plunger 2 and disposed in such manner that said end 22 penetrates into said bore 21 at the end of the outward stroke of plunger 2. On the other hand, an auxiliary piston 23 is mounted slidable in a stationary auxiliary cylinder, in line with cylinder 1, and divided by said auxiliary piston 23 into spaces 24 and 25. Space 24 is connected with bore 21 whereas space 25 is connected, on the one hand, with a fuel inlet conduit 26 provided with a check valve 27 and, on the other hand, with injection orifice 20.

Advantageously, as shown, auxiliary piston 23 comprises a portion 23a of larger cross section, located in space 24 (control liquid) and a portion 23b of smaller cross section located in the second space 25 (fuel).

Both the end 22 of plunger 2 and bore 21 are annular and surround injection conduit 16. Bore 21 is provided in a piece 28 fixed with respect to block 10. Said end 22 is of an outer diameter smaller than that of the remainder of plunger 2 for reasons hereinafter stated.

Auxiliary piston 23 is located in a block 29 secured in piece 28 by means of a hollow screw 30. This block 24 is provided with two bores 31 and 32 in line with each other and accommodating portions 23a and 23b of piston 23 respectively. Bore 21 is connected with space 24 through channels 33 and 34 formed in piece 28 and block 29, respectively. In order to limit the displacement of auxiliary piston 23 in the direction corresponding to injection, there is provided, in block 29 and piece 28, a passage 35 extending from space 24, limited by one of the sides of the portion 23a of piston 23, to the portion of bore 31 on the other side of said piston portion 23a. This passage 35 is cleared at the end of said displacement of auxiliary piston 23 by the edge of portion 23a located in space 24 (position shown by FIG. 2).

The return stroke of auxiliary piston 23 is produced both by the pressure of the fuel fed through conduit 26 into space 25 and by a spring 36 housed in screw 30 and acting upon an extension 37 of piston 23 through a ring 38 secured to said extension. This return stroke is limited by an abutment 39 adjustable in accordance with the load, as it will be hereinafter explained. At the beginning of this return stroke, a spring 40, bearing on one side upon the edge of the fixed injection conduit 16, and on the other side upon an abutment 41 rigid with needle 19, causes injection orifice 20 to be closed. As shown by FIG. 2, space 25 belongs to a chamber 42 provided in block 29 at the end of bore 32 and containing spring 40 and abutment 41, this chamber 42 communicating with conduit 26 through slots 43 provided at the end of conduit 16 and a groove 44 provided in piece 28 at the outlet of conduit 26.

In order to control the position of abutment 39, it is advantageous to make use, as disclosed in French Patent No. 1,428,516 of Nov. 25, 1964, of a rod or plunger positively driven by free piston 7 and cooperating with a chamber filled with liquid and followed by a blind bore in line with said rod and the diameter of which is substantially equal to the diameter of said rod. This blind bore is disposed so that the end of said rod penetrates thereinto only when piston 7 tends to exceed an optimum length of stroke. Means responsive to the overpressure that may occur in said blind bore as a result of the penetration thereof of the rod at the end of a stroke thereof control the abutment 39 provided on the other side of the engine so as to reduce the return stroke of the piston 15 23 cooperating with this last mentioned abutment.

In particular, according to the embodiment shown by the drawings, the portion of plunger 2 immediately adjacent to the end 22 of smaller diameter thereof cooperates with a blind bore 45 formed in piece 28 and in line with bore 21, said bore 45 communicating with cylinder 1 as long as plunger 2 is not moving outwardly beyond a normal outer position. As for the means responsive to overpressure in bore 45, they include a piston 46 moving in a cylinder 47 which is connected on one side of said piston 46 with bore 45 through a channel 48, whereas the portion of cylinder 47 on the other side of piston 46 is connected directly with cylinder 1 through a channel 49. The rod 50 of piston 46 extends through the frame of the device. Advantageously channel 48 communicates with passage 35.

FIG. 3 shows the means for connecting the rod 50 of piston 46 on the right hand side of engine A with the abutment 39 on the left hand side of said engine. To differentiate the symmetrical elements from one another they are followed by letters *a* and *b* according as they are associated with the abutment 39 on the right hand side of the engine or with the abutment 39 on the left hand side of said engine. The rod of piston 50a (on the left) is linked with a lever 51a pivotable about an axis 52a and connected, beyond the point where it is pivoted to rod 50a, with a link 53a. This last mentioned link is pivotally connected with one end of a lever 54a pivotable about an intermediate axis 55a, the other end of said lever 54a carrying abutment 39a. The displacements of the various elements of link systems 51a, 53a, 55a that correspond to too great a displacement of piston 7 and to a reduction of the fuel injected during the next stroke have been indicated by arrows in FIG. 3. Any other link system capable of moving the abutment 39 for the extension 37 of auxiliary piston 23 when there is an overpressure in bore 45 might be used. The link system associated with piston rod 50b is symmetrical with respect to that associated with piston rod 50a and need not be described.

The feed device above described works as follows: In the position of piston 7 corresponding to the beginning of injection on the right hand side of this piston, the end 22 of plunger 2 enters bore 21. The liquid present in said bore, flowing through channels 33 and 34, acts upon the face of the portion 23a of piston 23 that is located in space 24. When the pressure of this liquid is sufficient to overcome the resistance of springs 40 and 36, piston 23 is moved toward the left and its portion 23b delivers fuel from space 25. Fuel, which cannot flow back due to the action of check valve 27, moves needle 19 toward the left and is injected into chamber 17 through orifice 20. If the ratio of the respective cross sections of piston portions 23a and 23b averages two or three, the injection pressure is multiplied in the same ratio with respect to the pressure of the liquid compressed in bore 21. Fuel injection stops when passage 35 is cleared by the portion 23a of piston 23 (position shown by the drawing).

When piston 7 moves toward the left of FIG. 2 (suction of the liquid in cylinder 1), the action of spring 36, added to the pressure of the fuel fed through conduit

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26 and acting upon the free face of piston portion 23b, pushes piston 23 toward the right until extension 37 is brought into contact with abutment 39.

It will be seen that the beginning of injection always takes place for the same position of piston 7 but that the end of injection takes place the earlier as the amount of fuel that is injected is smaller. As a matter of fact, it is possible to determine the speed of injection by choosing the ratio of the annular cross section of the end 22 of plunger 2 and of the cross section of the portion 23a of piston 23, the cross section of portion 23b being determined in accordance with the length of stroke that is to be obtained for full admission and accuracy of regulation.

In order to have a sharper beginning of injection, it may be advantageous to place under pressure the fuel about needle 19. To obtain this result it suffices to give extension 37 a cross section slightly smaller than that of the portion 23b of piston 23. As a consequence, from the beginning of the delivery stroke of plunger 2 in cylinder 1 (toward the right hand side of FIG. 2), the liquid pressure in this chamber (which may range from some kgs./cm.² to 300/400 kgs./cm.²) acts upon both sides of the portions 23a of piston 23 because it is transmitted on the right hand side through channels 33 and 34 and on the left hand side through channel 48 and passage 35. This pressure tends to push piston 23 toward the left of FIG. 2 due to the fact that extension 37 and portion 23b of said piston 23 have different respective cross sections. Piston 23 is therefore pushed in the direction that places under pressure around needle 19 the fuel. In all cases it is imperative that, under the maximum hydraulic delivery pressure (pressure in cylinder 1), needle 19 does not open.

If piston 7 moves beyond the optimum end stroke position thereof, plunger 2 penetrates into bore 45 and delivers liquid through channel 48 to the right hand face of piston 46, which moves rod 50 toward the center of the engine, into a position from which its return stroke is braked by a calibrated orifice provided in channel 49, as indicated in the above mentioned French Patent No. 1,428,516. It follows that the abutment 39 located on the other side of the internal combustion engine is also moved toward the center of said engine, which reduces the return stroke of piston 23 and, consequently, the amount of fuel injected on the next stroke.

It is also to be noted that when plunger 2 penetrates into bore 45 fuel injection stops since both faces of the portion 23a of piston 23 are subjected to the same pressure. However, this might be modified by connecting passage 35 directly with cylinder 1 instead of through bore 45.

Injection device 19, 20 might be disposed in a position where it is not coaxial with plunger 2 but would open into any part of cylinder head 9. In this case space 25 should be connected to the body of the injecting means through suitable pipes.

In a general manner, while the above description discloses what is deemed to be a practical and efficient embodiment of the present invention, said invention is not limited thereto as there might be changes made in the arrangement, disposition and form of the parts without departing from the principle of the invention as comprehended within the scope of the appended claims.

What I claim is:

1. In an internal combustion engine comprising, on the one hand, a cylinder with at least one cylinder head at one end thereof and, on the other hand, a freely movable piston slidable in this cylinder, a fuel feed device which comprises, in combination,

a structure fixed with respect to said cylinder and forming a chamber filled with liquid,

a rod fixed to said piston coaxially thereto and slidable in a fluidtight manner through said cylinder head to extend into said chamber,

said fixed structure being provided with a bore in communication with said chamber and arranged for slidably accommodating the free end of said rod at the end of the outward stroke thereof, said bore being arranged so that said free end of said rod cuts off the communication between said chamber and said bore when said piston is near its outer dead center position,

means belonging to said fixed structure forming an auxiliary cylinder,

an auxiliary piston slidable in said auxiliary cylinder for dividing it into two spaces, a first one and a second one,

said fixed structure being provided with a fuel feed conduit opening at the downstream end thereof into said second space,

a check valve at the upstream end of said fuel feed conduit opening toward the downstream end thereof,

a fuel inlet valve movable in said fixed structure adapted to connect said second space with the inside of said engine cylinder in response to a given rise of pressure in said second space, and

conduit means extending between said bore and said auxiliary cylinder first space so that the liquid compressed in said bore by the free end of said rod at the end of the outer stroke thereof pushes said auxiliary piston in the direction which causes fuel to be delivered through said fuel inlet valve.

2. A fuel feed device according to claim 1 wherein said auxiliary piston is made of two portions of different respective diameters cooperating with corresponding portions, of different respective diameters, of said auxiliary cylinder forming said two chambers respectively, the first chamber being of greater diameter than the second chamber, whereby the fuel injection pressure is correspondingly increased with respect to the liquid pressure in said bore.

3. A power plant which comprises,

a fixed structure,

an internal combustion engine including on the one hand a cylinder fixed with respect to said structure and having a cylinder head at one end thereof, and, on the other hand a freely movable piston slidable in said cylinder,

a hydraulic pump including a cylinder formed in said fixed structure and full of liquid and a piston adapted to cooperate with said pump cylinder, said pump piston being rigid with said engine piston coaxially thereto and slidable in a fluidtight manner through said cylinder head,

said fixed structure being provided with a bore in communication with said cylinder and arranged for slidably accommodating the free end of said pump piston at the end of the outward stroke thereof, said bore being arranged so that said free end of said pump piston cuts off the communication between said cylinder and said bore when said engine piston is near its outer dead center position,

means belonging to said fixed structure forming an auxiliary cylinder,

an auxiliary piston slidable in said auxiliary cylinder for dividing it into two spaces, a first one and a second one,

said fixed structure being provided with a fuel feed conduit opening at the downstream end thereof into said second space,

a check valve at the upstream end of said fuel feed conduit opening toward the downstream end thereof,

a fuel inlet valve movable in said fixed structure adapted to connect said second space with the inside of said engine cylinder in response to a given rise of pressure in said second space,

conduit means extending between said bore and said auxiliary cylinder first space so that the liquid compressed in said bore by the free end of said pump piston free end at the end of the outer stroke thereof

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pushes said auxiliary piston in the direction which causes it to deliver fuel through said fuel inlet valve, and

a hydraulic motor fed with liquid from said hydraulic pump.

4. A power plant according to claim 3 including an injection conduit carried in fixed position by said fixed structure so that said pump piston is coaxially slidable therein, said fuel inlet valve being provided at the end of said injection conduit.

5. A power plant according to claim 4 wherein said auxiliary piston is made of two portions of different respective diameters cooperating with corresponding portions of different respective diameters of said auxiliary cylinder forming said two chambers respectively, the first chamber being of greater diameter than the second chamber, auxiliary piston carries on the side opposed to its portion of smaller cross section, a rod extending in a fluid-tight manner through the end of the first space, whereby the pressure of the control liquid fed from the hydraulic pump or generator cylinder which is transmitted to both faces of the portion of greater cross section of the auxiliary piston pushes the latter in the direction that increases the pressure of the fuel filling the second space.

6. A power plant according to claim 5 wherein the rod

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of said auxiliary piston includes a portion that projects to the outside of said fixed structure, said power plant further comprising, to cooperate with said rod portion, an abutment movable in accordance with the operation of said hydraulic motor.

7. A power plant according to claim 6 wherein said internal combustion engine is of double acting construction, further comprising a second hydraulic pump identical with the first one and the piston of which is rigid with the internal combustion engine piston, said abutment being responsive to a pressure which may be produced on the other side of said engine in the bore provided on said other side.

References Cited

UNITED STATES PATENTS

2,274,683	3/1942	Fraser	123—139.9
2,537,371	1/1951	Petersen	123—139.9
3,106,896	10/1963	Van der Lely et al.	103—54
3,110,152	11/1963	Johnson et al.	60—14

FOREIGN PATENTS

1,428,516	1/1966	France.
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WENDELL E. BURNS, *Primary Examiner*.