July 4, 1967

P. PANHARD

3,329,133

REGULATION DEVICES FOR FREE PISTON INTERNAL COMBUSTION ENGINES

Filed Nov. 19, 1965

2 Sheets-Sheet 1

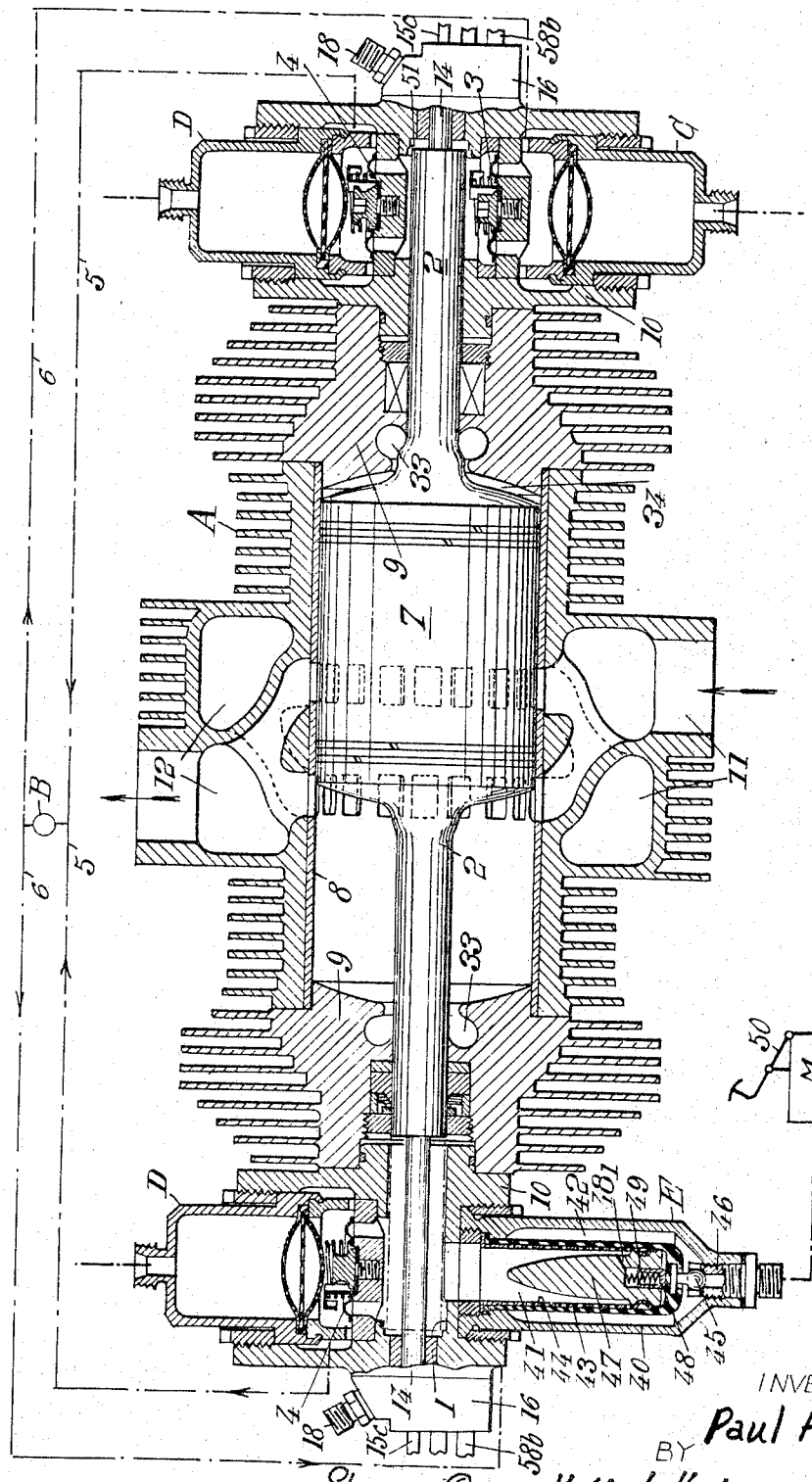


Fig. 1.

INVENTOR

Paul Panhard

BY

Stevens, Davis, Miller & Mosher ATTORNEYS

July 4, 1967

P. PANHARD

3,329,133

REGULATION DEVICES FOR FREE PISTON INTERNAL COMBUSTION ENGINES

Filed Nov. 19, 1965

2 Sheets-Sheet 2

Fig. 2.

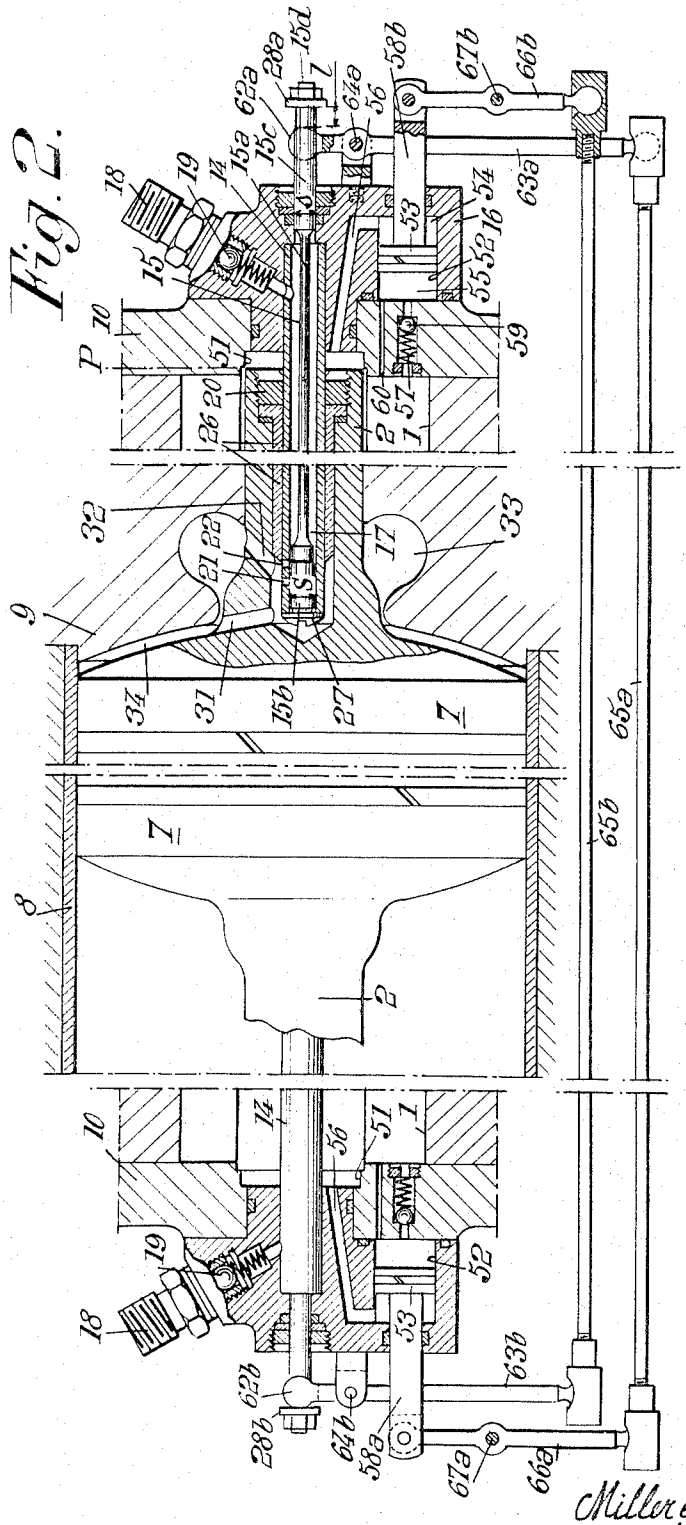
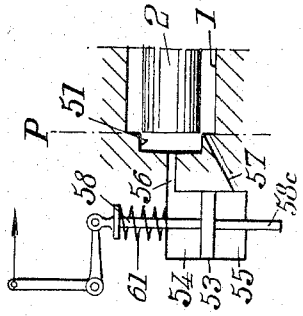


Fig. 3.



INVENTOR

Paul Panhard

BY Stevens, Davis, Miller & Mosher ATTORNEYS

United States Patent Office 3,329,133
Patented July 4, 1967

3,329,133

REGULATION DEVICES FOR FREE PISTON INTERNAL COMBUSTION ENGINES

Paul Panhard, Paris, France, assignor to Societe Anonyme Andre Citroen, Paris, France, a society of France

Filed Nov. 19, 1965, Ser. No. 508,670
Claims priority, application France, Nov. 25, 1964, 996,313
7 Claims. (Cl. 123—46)

The present invention relates to a regulation device for a free piston internal combustion engine provided with means for reducing the flow of fuel fed to the engine when the free piston tends to move beyond an outer dead center limit position thereof.

The invention is more especially concerned with a regulation device for a free piston internal combustion engine the piston of which is rigid with the plunger or piston of a hydraulic generator or pump connected through a closed circuit with at least one hydraulic receiver or motor so as to form a hydraulic transmission.

One object of the invention is to provide a device of this kind where the engine free piston is given a substantially uniform length of stroke by regulating the rate of feed of fuel to said engine.

The present invention further relates to a regulation device for a free piston internal combustion engine the piston of which is rigid with a plunger of a hydraulic generator connected through a closed circuit with at least one hydraulic receiver to form a hydraulic transmission, such a regulation device including means for reducing the flow rate of fuel fed to the internal combustion engine when the free piston of said engine tends to move beyond an outer dead center position thereof.

An object of the present invention is to provide a device of this kind such that it determines a substantially uniform length of stroke for the free piston by exactly regulating the fuel feed flow rate, account being taken of all the factors of operation and in particular of the number of reciprocations per unit of time, of the load of the engine, and possibly of the discharge pressure of the generator.

Preferred embodiments 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 represents, with portions shown in elevation and portions in axial section, a power plant with a hydraulic transmission made according to the invention;

FIG. 2 shows, on an enlarged scale, the regulation device of the free piston engine of FIG. 1; and

FIG. 3 shows a detail modification.

The following description will be supposed to apply to the case of a hydraulic transmission power plant for an automobile vehicle.

The system comprises the following elements:

(a) An internal combustion engine A;

(b) A hydraulic generator (or pump), preferably including two opposed groups each comprising a cylinder **1**, a plunger (or rod) **2**, a suction valve **3** and a delivery valve **4**, said hydraulic generator being driven by engine A, as it will be hereinafter explained;

(c) A receiver, or hydraulic motor, B, the intake of which is connected, through pipes **5**, with the delivery valves **4** of the hydraulic generator and the delivery of which is connected, through pipes **6**, with the suction valves **3** of said hydraulic generator, said receiver B being coupled with the delivery wheels (not shown) of the vehicle;

(d) Two damping chambers C and D communicating with each hydraulic generator cylinder **1**, respectively upstream of the suction valve **3** and downstream of the delivery valve **4** thereof; and

(e) A holding chamber E connected to each of the cylinders **1** of the hydraulic generator between valves **3** and **4** so as to receive a variable portion of the liquid delivered on every cycle from said cylinder **1**, thus determining the ratio of transmission between engine A and receiver B.

The axes of the three chambers C, D and E are disposed in star-shaped arrangement about the geometrical axis of each cylinder **1** and preferably, as shown, in a plane intersecting this cylinder. In FIG. 1 the cross section plane for the upper part of the drawing is the same vertical plane and therefore shows both of the chambers D located on the right hand side and on the left hand side, respectively, whereas the cross sections corresponding to the lower portion of FIG. 1 are made, respectively for the right hand side and the left hand side, through two planes symmetrical with respect to said vertical plane and making between them an angle of 120° so that the left hand portion shows a chamber E and the right hand portion a chamber C.

The internal combustion engine A is of the double action type and includes a single free piston **7** mounted in a cylinder **8** having two cylinder heads **9**. This piston **7** carries, fixed thereto on each opposite side thereof, a plunger or rod **2** and the hydraulic generator cylinders **1** cooperating with said plungers **2** are provided in blocks **10** rigid with cylinder heads **9**. The whole of cylinder **8**, cylinder heads **9** and blocks **10** is arranged to be freely oscillatable about its axis in a direction opposed to that in which oscillates the whole of piston **7** and plungers **2**. The internal combustion engine intake pipes are designated by reference numeral **11** and the exhaust pipes by **12**, the corresponding ports being controlled by piston **7**.

Each of the holding chambers E comprises a bell-shaped shell **40** and a movable or deformable partition **43** which separates the inside of said shell **40** into two chambers **41** and **42**, chamber **41** being connected permanently with the portion of the corresponding cylinder **1** between valves **3** and **4**, whereas chamber **42** is placed in communication, at the end of every suction stroke of plunger **2**, with a source M of gas under variable pressure, in a manner which will be hereinafter explained. Deformable partition **53** consists of a membrane engaged on a perforated rigid tube **44** fixed in shell **40** coaxially therewith. Membrane **43** carries, fixed to the bottom thereof, a check valve **45** the seat **46** of which is rigid with shell **40** and is interposed between chamber **42** and gas source M. To the bottom end of tube **44** there is fixed an ogive **47** in the bottom portion of which there is provided a cylindrical housing communicating through a passage 48_1 with chamber **41** and accommodating a piston **48** subjected to the action of a spring **49** and bearing against the bottom of membrane **43**, so that check valve **45** closes during the delivery stroke of plunger **2** as soon as the pressure of oil in chamber **41** is equal to that of the gas present in chamber **42** and reopens during the suction stroke of plunger **2**.

Thus, on every cycle, the first portion of the liquid delivered by a plunger **2** is admitted into chamber **41**, which causes membrane **43** to expand and compresses the gas present in chamber **42**, check valve **45** being then closed. Then the respective pressures on the opposed sides of delivery valve **4** become equal. Delivery valve **4** then opens and the second portion of the liquid driven by plunger **2** is discharged past said valve **4**. The power supplied to receiver B and the ratio of transmission depend upon the respective values of the two above mentioned liquid portions and therefore upon the pressure of source M. During the next suction stroke of plunger **2**, the energy corresponding to the compression of gas in chamber **42** is restored to said plunger **2**. Then check valve **45** reopens.

The fuel feed device of internal combustion engine A is made as follows:

On either side of piston **7** there is disposed, inside a tubular sheath **14**, fixed with respect to cylinder **8**, a metering member **15** consisting of a rod **15***a* provided with two heads **15***b* and **15***c* adapted to slide, with a limited amplitude, in fluidtight contact with the inner face of sheath **14** and with a surface in line therewith provided in a cap **16** fixed to block **10**. The cross section S of the head **15***b* nearer to cylinder **8** is greater than the cross section *s* of the other head **15***c* and it is acted upon, on its surface farthest to said other head (on the left hand side in FIG. 2) by the pressure existing in the compression chamber **34** of cylinder **8**.

A fuel feed pipe **18** for fuel under pressure, provided with a check valve **19**, opens into the annular space **17** between sheath **14** and the rod **15***a* of metering member **15** (extending between heads **15***b* and **15***c*).

Sheath **14** is located inside a tubular sleeve rigid with piston **7** and capable, when piston **7** is nearing its outer dead center position, of opening orifices **21** and **22** provided in sheath **14** so as thus to connect the annular space **17** with the internal combustion engine compression chamber **34**.

Said tubular plunger **2** includes, on its inner wall, a sleeve **26** secured thereto by means of a nut **20**, the inner edge of said sleeve **26** being located clearing orifices **21**, **22** when the internal combustion engine piston **7** is in its outer dead center position toward the right hand side of FIG. 2. Means are provided for making fluidtight, on the one hand, the surfaces of contact (without relative sliding displacement) between the inner wall of plunger **2** proper and the outer wall of sleeve **26** and, on the other hand, the surfaces of contact (with relative sliding displacement) between the inner wall of sleeve **26** and the outer wall of sheath **14**, so as thus to separate from each other the fuel circuit and the liquid transmission circuit.

In order to limit the displacement of metering member **15** with respect to fixed sheath **14**, there is provided, on the one hand, at the end of the big head **15***b*, a flange **27** projecting to the outside of sheath **14** and, on the other hand, at the end of the small head **15***c*, a washer cooperating with an abutment, said washer being designated in FIG. 2 by reference numeral **28***a* for the hydraulic generator on the right hand side and by reference numeral **28***b* for the hydraulic generator on the left hand side.

In order to permit the pressure existing in the compression chamber **34** of cylinder **8** to be transmitted to the big head **15***b*, there is provided at least one passage **31** connecting the external surface of piston **7** with the inside of tubular plunger **2**, this passage being provided in an axial plane and being slightly inclined, as shown by FIG. 2, so as to open tangentially to the curved end face of piston **7**.

As shown, there is further provided, in the wall of tubular plunger **2**, at least one fuel injection passage **32** positioned to open opposite orifices **21** and **22** when piston **7** is close to its outer dead center position. Passage **32** may open directly into chamber **34** but preferably, as shown by the drawings, it opens into an annular turbulence chamber **33** provided in cylinder head **9** and surrounding plunger **2**. Besides, the end **15***d* of metering member **15** may be pushed by a small spring if it is desired to reduce the pressure of the fuel arriving through pipe **18**.

When the pressure has dropped in chamber **34**, the pressure in pipe **18**, possibly with the addition thereto of the action of the last mentioned spring, opens check valve **19** and pushes metering member **15** toward piston **7** until washer **28***a* comes into contact with the above mentioned abutment. There is thus admitted into annular space **17** a volume of fuel proportional to the displacement *l* of metering member **15**, which displacement is adjusted as it will be hereinafter explained.

At the end of the movement of piston **7** toward the right, the pressure in compression chamber **34** is transmitted through passage **31** to the big head **15***b* of metering member **15**. As soon as the movement of piston **7** and plunger **2** causes the bevelled edge of sleeve **26** to clear orifice **21**, metering member **15**, which was kept in position by the column of fuel enclosed in annular space **17**, is released and driven toward the right by said pressure in chamber **34** until orifice **21** is closed.

A portion of said volume of fuel is injected. The injected fuel, driven by the air stream through passages **31** and **32**, mixes with air in turbulence chamber **33**, where it is ignited either by suitable ignition means, or, when the compression ratio is sufficiently high, by spontaneous ignition.

When orifice **22** is subsequently cleared (near the outer dead center position of FIG. 2, on the right hand side thereof), the remainder of said fuel volume is injected and, at this time, the combustion in chamber **33** reverses the direction of flow through passages **32** and **31** and causes an ignited fuel mixture to be injected into compression chamber **34** where it finds the amount of air necessary to finish its combustion.

According to a feature of the present invention, the driver, instead of directly controlling the flow rate of fuel fed to the engine to vary the power that is given off, acts upon the means for adjusting the power transmitted to receiver B, the flow rate of fuel fed to the engine being controlled by means responsive to the variation of the difference between the theoretical stroke of free piston **7** and the actual stroke thereof, the power absorbed by the receiver being greater or smaller than the power given off by the amount of fuel precedingly fed to the internal combustion engine.

According to the embodiment shown by the drawings, the powder delivered by receiver B may be adjusted by varying, by means of a pedal **50**, the pressure of the gas supplied from source M. This pedal may for instance control a distributing valve capable of connecting a reservoir of gas under pressure, corresponding essentially to source M, either with the delivery of a compressor or with the atmosphere.

In order to constitute the means responsive to the difference between the theoretical stroke of free piston **7** and its actual stroke, another feature of the present invention consists in causing free piston **7** positively to drive a rod cooperating with a capacity filled with a liquid, said capacity being provided at one end thereof with a cylindrical blind hole **51** in line with said rod and the diameter of which is equal, with a slight play, to that of said rod. Plane P in which is located the opening of this hole **51** is located in such manner that said rod penetrate into said hole **51** only when piston **7** tends to move beyond its theoretical stroke end. Finally, means responsive to the overpressure produced in said blind hole by the penetration of said rod thereinto control a part adapted to reduce the dose of fuel admitted into combustion chamber **34** during the next stroke of free piston **7**.

As shown by FIGS. 1 and 2 the above mentioned rod advantageously consists of plunger **2** which, in addition to its function of piston of the hydraulic generator, also serves to control the fuel injection. For this purpose, the blind hole **51** is disposed in line with the hydraulic generator cylinder **1**.

Furthermore, the above mentioned abutment adapted to come into contact with the washer, **28***a* or **28***b*, on one side is arranged to cooperate with means responsive to an overpressure occurring in the blind hole **51** on the other side.

For this purpose, there is provided, in each of the caps **16**, a cylinder **52** separated by a piston **53** into two chambers **54** and **55**. Chamber **54** is connected with blind hole **51** through a channel **56**, whereas chamber **55** is connected to cylinder **1** through a channel **57**.

In order to produce the desired return movement of piston **53** when there is no longer an overpressure in blind hole **51**, use is made, as shown by FIG. 2, of a differential piston **53** provided with a single rod which is designated by reference numeral **58***b* on the right hand side of the system and by **58***a* on the left hand side. Thus, if the same pressure exists in both of chambers **54** and **55**, piston **53** is pushed into the position corresponding to the minimum of volume of chamber **54**. In this case, channel **57** is provided with a check valve **59** and a passage **60** of small cross section is disposed in parallel with said channel **57**. In the modification illustrated by FIG. 3, use is made of a piston balanced by a double rod **58**, **58***c* and provided with a return spring **61**.

The abutment cooperating with washer **28***a* consists of a fork **62***a* integral with a lever **63***a* pivotable about a pin **64***a* fixed with respect to the corresponding cap **16**.

In a likewise manner, the abutment cooperating with washer **28***b* consists of a fork **62***b* integral with a lever **63***b* pivotable about a pin **64***b* fixed with respect to the corresponding cap **16**.

The lower end of lever **63***a* is hinged to the right hand end of a link **65***a* the other end of which is hinged to the lower end of a lever **66***a* pivoted at **67***a* and the upper end of which is hinged to rod **58***a*.

The lower end of lever **63***b* is hinged to the left hand end of a link **65***b* the other end of which is hinged to the lower end of a lever **66***b* pivoted at **67***b* and the upper end of which is hinged to rod **58***b*.

When a plunger **2** is moved outwardly by one stroke of the piston **7** of internal combustion engine **7–8**, a portion of the energy supplied by said stroke is accumulated in the holding chamber E corresponding to said plunger **2**.

When said plunger **2** next returns inwardly, this amount of energy is given back to said plunger **2**.

In other words, during the beginning of every inward stroke of said plunger **2**, a portion of cylinder **1** is filled up with liquid from holding chamber E, without having to collect energy from the internal combustion engine **7–8**.

As the energy available in holding chamber E at the beginning of the corresponding stroke of the internal combustion engine piston **7** (say toward the right) was determined during the preceding leftward stroke of said piston **7**, it may happen that this energy, added to that given back by holding chamber E (on the left) is too great, so that the outer end of the right hand plunger **2** engages into the corresponding blind hole **51**. As a consequence, the corresponding piston **53** is moved leftward, lever **66***b* is pivoted in anticlockwise direction, link **65***b* is pulled toward the right, lever **63***b* is pivoted in anticlockwise direction and its forked end **62***b* is moved toward the left.

Anyway, when piston **7** was at the end of its stroke toward the right (approximately as shown by FIG. 2), the left hand metering member **15** was moved toward the right by the pressure of fuel fed through the corresponding pipe **18**. But this movement toward the right was limited by the forked end **62***b* which, at this time, had been moved toward the left as above explained, so that the amplitude of the subsequent sliding displacement of metering member **15** toward the left is now smaller.

Therefore if the rightward stroke of the internal combustion engine piston **7** was of too great an amplitude (i.e. if the fuel injection into cylinder **8** on the left of piston **7** had been too great), the next fuel injection on the left of piston **7** will be reduced.

If the above considered rightward stroke of the internal combustion engine piston **7** was too long, of course the next leftward stroke of said piston was also too long (since no correction relative to fuel injection could take place between them). Therefore the left hand plunger **2** engaged the corresponding blind hole **51** and the liquid thus driven caused, through piston **53**, lever **66***a*, link **65***a* and lever **63***a* the forked end **62***a* of said lever **63***a*, the stroke of the right hand metering member **15** to be shortened as the stroke of the left hand metering member **15** was shortened.

It will now be noted that the regulation effect is practcially instantaneous since the injection after too long or too short a stroke of piston **7** is substantially immediately corrected. It suffices to choose the diameter of piston **53** and the arm ratios of levers **63** and **66** in such manner that too long or too short a stroke of piston **7** (for instance by 1 mm.) produces exactly the variation of fuel injection corresponding to the difference of energy to be supplied. It will be noted also that the regulation device according to the present invention is so efficient that it remedies all possible defects since it works in accordance with the effect and not in accordance with the cause. It would be possible to adjust the injection of fuel by means of a mere needle valve disposed between a source of fuel under sufficient pressure and combustion chamber **34**. Finally it is pointed out that the device according to this invention ensures perfect equality between the leftward and rightward strokes of the double action piston without any preliminary adjustment. The diameters of the injecting device and the leakages therein are without effect upon the accuracy of compensation.

If the action on the flow rate of fuel is insufficient to limit the stroke of piston **7**, pistons **53** may be made to control a mechanism (not shown) capable of reducing the pressure of source M, that is to say in chamber **42**, independently of the position of pedal **50**, so that the torque is reduced. Such a mechanism would prevent the internal combustion engine from stalling.

In a general manner, while the above description discloses what are deemed to be practical and efficient embodiments 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 combination,

an internal combustion engine comprising a cylinder and a piston freely slidable in said cylinder so as to form therewith two variable volume chambers located respectively on either side of said piston,

two rods rigid with said piston and coaxial therewith on either side thereof, respectively, said rods extending through the respective ends of said cylinder,

a cylindrical structure rigid with said cylinder adapted to accommodate each of said rods, slidable in said structure, said structure being filled with a liquid,

each of said structurse forming, at the outer end thereof a cylindrical blind hole in line with the corresponding rod and adapted to accommodate it with a sliding fit, said blind holes being so positioned that each of said rods engages thereinto only when the outer dead center of said piston is beyond a predetermined position,

regulatable means for feeding fuel into said cylinder in response to the reciprocating movements of said piston with respect to said cylinder,

and means responsive to overpressure produced in said blind hole when said rods engage thereinto, for operating said regulatable fuel feed means to reduce the rate of fuel feed ensured by said last mentioned means.

2. A combination according to claim **1**, further comprising a hydraulic receiver, a hydraulic generator, and a closed circuit connecting said receiver with said generator so as to form a hydraulic transmission between them, said generator including cylinders, fixed with respect to said engine cylinder and plungers adapted slidably to cooperate with said generator cylinders and integral with said rods, respectively.

3. In combination,

an internal combustion engine including a cylinder and a piston freely slidable in said cylinder,

a hydraulic generator including a cylinder rigid with said internal combustion engine cylinder and a piston rigid with said internal combustion engine piston,
a hydraulic receiver,
a closed hydraulic circuit between said hydraulic receiver and said hydraulic generator,
adjustable means for feeding fuel to said internal combustion engine,
hand operative means for controlling the power delivered to said hydraulic receiver by said hydraulic generator,
and means responsive to variations of the difference between the theoretical stroke of the internal combustion engine free piston and the actual stroke thereof for controlling said fuel feeding means to reduce the fuel feed rate in response to displacements of said internal combustion engine piston beyond a limit outer dead center position thereof.

4. A combination according to claim 3 comprising a holding capacity for receiving, on every cycle of said generator, a portion of the liquid delivered by said generator and a deformable partition adapted to divide the inside of said capacity into two chambers, a first one and a second one, said first chamber being in communication with said hydraulic generator cylinder, and a source of gas under adjustable pressure adapted to communicate with said second chamber, said hand operation means being arranged to vary the pressure of said gas source.

5. A combination according to claim 3 comprising a differential sliding rod operative by variation of the difference between the theoretical stroke and the actual stroke of said internal combustion engine piston, said adjustable fuel feeding means being operative by said rod.

6. A combination according to claim 3 wherein said internal combustion engine comprises a single free piston the meains responsive to variations of the difference between the theoretical stroke of said engine free piston and the actual stroke thereof in one direction being adapted to adjust the flow rate of fuel admitted into the cylinder during the following stroke of the piston in the other direction and vice versa.

7. In combination,
an internal combustion engine comprising a cylinder having a cylinder end and a piston freely slidable in said cylinder so as to form therewith a variable volume chamber on either side of said piston,
two hydraulic generators, respectively on opposite sides of said internal combustion engine, each of said generators comprising a tubular plunger rigid with said piston and coaxial therewith, said plunger extending through the corresponding cylinder end, and a cylinder rigid with said internal combustion engine cylinder adapted slidably to accommodate said plunger, said generator cylinder being filled with a liquid,
a delivery valve connected with each of said generator cylinders,
a suction valve connected with each of said generator cylinders,
a closed hydraulic circuit extending from each of said delivery valve to corresponding suction valve,
a hydraulic receiver in said hydraulic circuits,
a liquid holding device connected with each of said generator cylinders, said liquid holding device including:
a liquid-tight shell in permanent communication with said last mentioned cylinder,
a deformable partition in said shell dividing it into two

chambers, a first one and a second one, said first chamber being in permanent free communication with said last mentioned cylinder,
rigid means for limiting the deformations of said partition that reduce the volume of said first chamber,
a check valve carried by said shell and opening into said second chamber, and
means responsive to the pressure in said first chamber for opening said check valve in response to a suction in said first chamber,
a source of gas under pressure, common to both of said liquid holding devices, adapted to communicate with said second chambers through said check valves,
manually operative means for controlling the pressure of said source,
a tubular casing rigid with each of said cylinder heads and extending coaxially therein, said casing including, in line with each other, a sheath, the inner end of which opens into said compression chamber and at the outer end of said sheath, a cap provided with a bore the outer end of which opens into the atmosphere,
a metering member coaxially slidable in each of said casings, said metering member including at its respective ends two heads slidable with a fluid-tight fit in said casing, to wit a big head located in the inner end of said sheath and a small head located in said cap, the cross section area of said small head being smaller than that of said big head, the portion of said metering member between said heads being a rod leaving an annular space between itself and the inner wall of said sheath,
a fuel feed pipe opening into each of said annular spaces for the feed of fuel under pressure into the corresponding sheath,
a check valve in each of said fuel feed pipes to prevent the outflow of fuel therethrough,
a sleeve rigid with each of said tubular plungers and fitting slidably about the corresponding sheath,
each of said sheaths being provided with at least one orifice and the corresponding plunger with one passage adapted, when said piston is nearing its outer dead center position, to connect said annular space in said sheath with said internal combustion engine compression chamber,
whereby each of said metering members, after being fixed in position by the column of liquid in the corresponding annular space, can be displaced by the gaseous pressure applied on the big head thereof and thus inject into the engine cylinder a volume of fuel equal to the difference between the volumes displaced respectively by said two heads,
and means responsive to variations of the length of outward stroke of said plunger for adjusting the inward stroke of said metering member so as to reduce it when said plunger outward stroke exceeds a predetermined value.

References Cited

UNITED STATES PATENTS

3,065,703	11/1962	Harman	123—46 X
3,168,045	2/1965	Sebastiani	103—37
3,199,456	10/1965	Wachsmuth	103—37 X

MARK NEWMAN, *Primary Examiner.*

W. E. BURNS, *Assistant Examiner.*