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FUEL INJECTION EQUIPMENT

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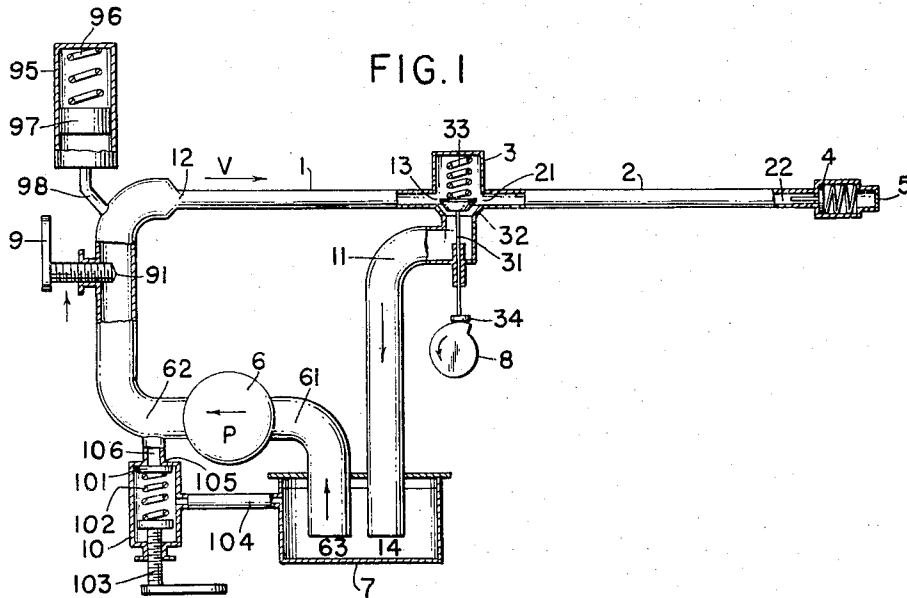
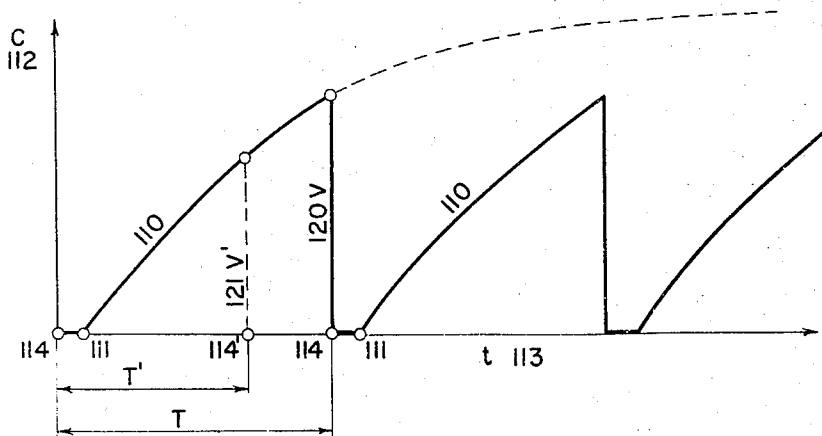


FIG. 2



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FUEL INJECTION EQUIPMENT

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The known types of fuel injection equipment for internal combustion engines are mostly based on the principle that a pressure or pressure wave is set up by the displacement of a piston in a fuel injection pump. Equipment of this type possesses the following disadvantages. Firstly, the quantity of fuel injected by the pump in this manner is a function of the speed of rotation, which does not correspond to the output characteristic of the engine, so that intricate regulating devices are required, secondly, some important difficulties are encountered with the feeding of the fuel when only small quantities are passing through the pump, thirdly, some difficulties are encountered at higher speeds of rotation, and fourthly, these fuel injection pumps must be made with great accuracy and very small tolerances, which has the effect of increasing the cost of manufacture.

Equipment is already known where the injection pressure is set up by the deceleration of a column of liquid under pressure, moving in a primary circuit. The deceleration of this column of liquid is effected by closing the primary circuit by means of a rotary slide valve. In this case the quantity to be injected is regulated by variation of the pressure in the entire primary circuit, effected by means of an over-pressure valve in series with the rotary slide valve but following the latter valve in the direction of the flow of the liquid; while the pressure due to the retardation remains constant.

But the rotary slide valve used in conjunction with this equipment has that disadvantage that the equipment cannot operate at the lower end of the range of speeds in the case of engines with a wide range of speeds, since the slow motion of the closing device causes the deceleration of the column of liquid in the primary circuit to take place too slowly, so that the resulting pressure is too low to inject any fuel at all. Also, the rotary slide valve does not at all overcome the disadvantages of the piston pump, owing to the delicate fits in the casing, necessary to achieve a uniform injection, and the ensuing sensitivity of the sliding sealing faces to wear. Also, with this equipment, as with the displacement pumps, an intricate regulating device is necessary to obtain an injection characteristic corresponding to that of the engine.

These disadvantages are avoided by the injection equipment described below; important components and the method of adjustment being objects of the invention.

In order that the invention may be clearly understood and readily carried into effect, the same will now be described more fully with reference to the accompanying drawings, in which:

Figure 1 shows diagrammatically fuel injection equipment;

Figure 2 is a graph, as explained below.

A fuel injection equipment shown in its simplest form in Figure 1 consists of a primary circuit comprising a low-pressure pump 6, for instance, a gear pump or a centrifugal pump, a primary pipe 1 and a closing device 3 in series, in the direction of the flow of the liquid, together with further components, such as a regulating

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device, fuel supply pipes, and so on. Also, a secondary pipe is connected to the primary pipe, with an injection valve 4 and an injection nozzle 5 at its end. The connection of the secondary pipe 2 to the primary pipe 1 is made in front of the closing device 3. This device is a valve which is controlled by mechanical, electrical, or hydraulic means according to the rhythm of the required injection sequence.

The operation of the plant is as follows:

Pump 6 sucks fuel at 63 from fuel tank 7 and delivers it from pressure side 62 to the front end of primary conduit 1 at 12. The fuel flows in primary conduit 1 at speed v from 12 to 13, then through main valve 3 between valve 31 and valve seat 32 to return conduit 11 in order to get back at 14 into tank 7. The closing pressure of injection valve 4 is high enough so that there cannot be any flow in secondary conduit 2. If snapping cam 8 keeps on turning in the direction of the arrow, valve 31 is no longer lifted at 34 (valve stem) by cam 8 (spot 114, Fig. 2). The valve spring 33 moves valve 31 downwardly against valve seat 32. By this motion a space becomes free behind valve 31. Into this place the fuel flows from primary conduit 1 keeping the space full. During this flow the valve 31 seats on valve seat 32 and interrupts the connection 13 to 11. Since the space which became free behind the valve is filled up by the fuel flowing from primary conduit 1, the fuel tends to flow on from 13 to 11 and then into tank 7, yet finds the connection 13 to 11 closed and is decelerated to speed o . Thereby the injection pressure builds up.

Since in liquids pressures propagate at the speed of sound, a pressure wave of value p travels at the speed of sound past point 21 into and along secondary conduit 2 to 22 where it opens the injection valve 4 and the fuel is injected into the engine through aperture 5. From the main valve 3 a pressure wave of pressure value p travels through 13 along primary conduit 1 to 12. At 12 this pressure wave encounters a relatively large volume and is therefore reduced. According to the above statement this reduction of the pressure wave runs at the speed of sound from 12 through 1 to 13, then to 21, on through secondary conduit 2 to 22 which ends the injection. The fuel in the secondary conduit 2 and primary conduit 1 is then at rest, the speed is zero. The fuel delivered by pump 6 can return through overflow valve 10, further through return conduit 104 to fuel tank 7. The snap action cam 8 keeps on turning and owing to the cam shape after some time (spot 114, Fig. 2) valve 31 is lifted by stem 34 whereby the connection between 13 and 11 is reestablished. Propelled by the pump 6 the fuel again begins to flow through the primary conduit, its speed v rising from zero at 111 in Fig. 2. This increase of speed 112 is represented in Fig. 2 as curve 110 in time 113. At 114 the cam 8 again releases the valve stem 34 with a snap action and the process is repeated as described above.

In order to obtain a pressure wave which is always suitable for the purpose, the closing device is designed according to the invention as a valve and controlled by a rotating cam. In order to make the entire kinetic energy available for the production of a pressure wave and to make this wave as short as possible, the valve is loaded by means of a spring with a pressure sufficient to ensure that its closing speed is such that the volume released during the closing motion of the valve is equal to or greater than the volume flowing in from the primary pipe. A change in the pressure wave due to any wear which may take place is also avoided; this is achieved according to the invention by using a valve as the closing device, since in this case the closing effect is obtained by two sealing surfaces at rest.

The faster the snap action cam 8 rotates, i. e., the

higher the speed of the motor, the shorter is the time T for the operation (compare Fig. 2). If in Fig. 2 T is the time for an operation at low motor speed and T' the time at higher motor speed, one sees in the first case the speed of fuel in the primary conduit 1 in the instant of braking (114) as v (120), in the other case at 114' as v' (121), v' being much smaller than v . Since, as shown above, the injection pressure and thus the injected quantity depends on this speed, the result for this plant is that at higher motor speed the injected quantity becomes smaller. This corresponds to the characteristic of the combustion motors, i. e., a plant according to the invention has per se, without any additional installations, the consumption characteristics of the combustion motor.

The increase of speed in primary conduit 1 shown in Fig. 2 by curve 110 proceeds according to the following equation:

$$V = V_{st} \frac{e^{tXv_{st}/l} - 1}{e^{tXv_{st}/l} + 1}$$

In this equation v_{st} is the speed of the fuel in the primary conduit which occurs after time $t = \infty$, otherwise expressed v_{st} is the velocity indicated by the asymptote of the curve 110 in Fig. 2. e is the base of the natural logarithm 2.71828. X is the length of the primary conduit (the distance from 12 to 13). The value X is the resistance factor (a dimensionless factor which represents the losses of a flowing liquid in a pipe and mostly is ascertained by test) of the conduits from gear pump 6 to primary conduit 1, through this primary conduit 1, through main valve 3, through return conduit 11 to tank 7. One can control this value very simply, e. g., by a throttle which in Fig. 1 is represented as setting screw 9 and which affects a narrowing of the cross section at 91. Thereby the shape of curve 110 in Fig. 2 can be so determined that the injection device with its injected quantity precisely or in a high degree of precision agrees with any connected motor.

As already mentioned above, the injected quantity is regulated by regulating speed v of the fuel in the primary conduit. This can be brought about by making a part of the fuel delivered by pump 6 flow back through pressure relief valve 10 consisting of valve 101, spring 102 and regulating rod 103, through the return conduit 104 into tank 7. In comparison with the quantity injected at 5 the fuel quantity passing through the overflow valve 10 is very large and is subject to a low pressure which is generated by pump 6 so that this regulation is very simple and can be carried out with most inexpensive means. A regulation is also possible by decreasing the quantity delivered by pump 6, something which can be effected, for example, by changing the rotary speed of the pump 6 or by throttling of the fuel quantity sucked in from tank 7.

If the pump 6 runs at a speed which corresponds to the motor rotary speed, at low speeds the fuel quantity delivered by pump 6 gets too small in order to create the necessary speed v in the primary conduit. Therefore, a pressure accumulator 95 can be connected in the pump discharge pipe, preferably near point 12. The pump 6 delivers fuel into this accumulator during the time that the main valve 3 is closed during the first part of an operation. Plunger 97 is moved upwardly under the discharge pressure from pump 6 against spring 96. At the instant of opening main valve 3 plunger 97 tends to be again moved downwardly by spring 96 and so presses the fuel through 98 into the primary conduit 1. Since this occurs in addition to the continuing delivery of pump 6, it is possible to attain the desired speed v in the instant of closing the main valve 3 (at 114, Fig. 2). The overflow valve 10 and this pressure accumulator 95 can be united structurally, whereby valve 101 is replaced by piston 97.

In contradistinction with known types of injection equipment, the injection equipment according to the inven-

tion has the characteristic feature that the quantity emitted by the injection nozzle 5 depends substantially on the energy and shape of the pressure wave set up in any given case by the deceleration of the velocity in the primary circuit, on the characteristics of the injection valve 4 and, if an open nozzle is provided, on the effective cross-section of the injection nozzle 5; all these factors can be employed to vary the injected quantity and also the injection pressure. Furthermore, the energy of the pressure wave is a function of the velocity of the fuel in the primary pipe 1 at the instant where the closing device 3 is being closed. But since this velocity is governed by the feed pressure and the output of the low-pressure pump 6, it is possible to regulate the injected quantity within very wide limits by an adjustment of the said feed pressure or output, for instance, by means of an adjustable by-pass valve in the primary circuit between the low-pressure pump and the primary pipe, or by means of a change in the speed of rotation of the low-pressure pump 6 and thus in the output of this pump.

Summarising, the injection equipment and method of regulation described here have compared with the known injection pumps the following advantages in their function, control and manufacture. Even very small quantities for injection, down to a cubic millimeter, can be dosed very accurately and, owing to the characteristic property of the equipment of producing very brief pressure-waves, free from reflection, up to speeds of fifteen thousand revolutions per minute, the fuel can be emitted accurately and without secondary emissions from closed or open nozzles. The shapes of the characteristics of the injection quantities of the installation can be varied by simple means to a considerable extent, as far as their dependence on the engine speed is concerned, and can be adapted to the given charging characteristic of the engine, taking the best mixture ratio of fuel to air into account. Since the feeding and control devices act on quantities of liquid amounting to a multiple of the injected quantity and whose pressure is only a fraction of the injection pressure, and since the parts of the equipment under the effect of the injection pressure do not require any sealing by sliding sealing surfaces, the components can be manufactured with less accuracy.

We claim:

1. A fuel injection device for intermittent injection of fuel into a combustion chamber, comprising a primary fuel circulating circuit including a pump having a suction, and a discharge discharging into a conduit and from thence into at least one primary pipe, a return pipe returning the fuel from the end of said primary pipe remote from the pump to the pump suction, a quick closing valve in said primary circuit at the junction of said primary and said return pipes to control flow of fuel to said return pipe, a secondary pipe connected to said primary pipe at said quick closing valve, injection means operated by impact pressure at the end of said secondary pipe, and means to intermittently close said quick closing valve to create an impact pressure within said secondary pipe whereby said injection means is operated.

2. A fuel injection device according to claim 1, including an adjustable throttle at the pump discharge adapted to be coordinated with the delivery pressure of the pump to ensure that the increase of the speed of flow due to the characteristics of the throttled flow of fuel, with respect to time, of the column of liquid in the said conduit and therefore in the primary pipe occurs after each injection, whereby at the instant when this speed is suddenly reduced by the closing of the valve the speed required for the desired characteristic of the injected quantities is reached.

3. A fuel injection device according to claim 1, including a pressure operated accumulator connected to the conduit in such a way that it accumulates the fuel fed by the low pressure pump during the first part of a cycle and returns the fuel to the conduit just before the quick

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closing valve closes so as to assure a sufficient speed of fuel flow in said primary pipe to cause a sufficient quantity of fuel to be injected.

4. A fuel injection device for internal combustion engines, comprising a constant output pump having a suction and discharge, a conduit receiving the discharge of said pump, a pipe of reduced diameter to provide a high velocity of flow of fuel therethrough connected to said conduit, a quick operating valve at the end of said portion of reduced diameter remote from said conduit and a pipe of larger diameter extending from said valve to the suction of said pump, a branch pipe extending from said portion of reduced diameter to deliver fuel to said engine, an injection valve operated by hydraulic impact at the end of said branch pipe, and means operating to open said quick operating valve and to close said valve in timed relation to the operation of the internal combustion engine on which the injection device is used, said means closing said valve very rapidly so as to cause a hydraulic hammer to create an impact to operate said injection valve.

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5. The fuel injection device of claim 1, in which throttling means are provided to control the flow of fuel in the said primary circuit whereby the quantity of fuel injected is controlled.

6. The fuel injection device of claim 1, in which means are provided to control the volumetric output of the pump whereby the quantity of fuel injected is controlled.

7. The fuel injection device of claim 1, in which means are provided to control the pressure of fuel delivered by said pump whereby the quantity of fuel injected is controlled.

8. The fuel injection device of claim 1, in which a bypass from the pump discharge to the pump suction is provided, said bypass including an adjustable bypass valve whereby the quantity of fuel injected may be controlled.

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