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Remarks:
Amended claims in accordance with Rule 137(2) EPC.

(54) **Fuel-injection system for an internal-combustion engine**

(57) The fuel-injection system comprises a variable-capacity high-pressure pump (7), having at least one pumping element (18) provided with an intake valve (25) in communication with an intake duct (10) and with a delivery valve (30) in communication with a delivery duct (8). A dosage device (27) is designed to dose the flow rate of the pump (7) as a function of the running conditions of the engine and is associated with a pressure regulator (32) designed to discharge the excess fuel into a compartment (35) of a sump (33) of the high-pressure pump (7) for lubricating the usual actuation mechanism (26) of the pumping element (18). The dosage device (27) is provided with two outlets (29, 39), of which one outlet (29) supplies the delivery valve (25), whilst the other outlet (39) is in communication with a discharge duct (12), through a compartment (35) of the sump (33) of the pump (7). A control unit (16) activates the two outlets (29, 39) alternately in a complementary way, so that the formation of any pressure wave on the intake duct (10) is prevented when the outlet (29) towards the pumping element (18) is deactivated.

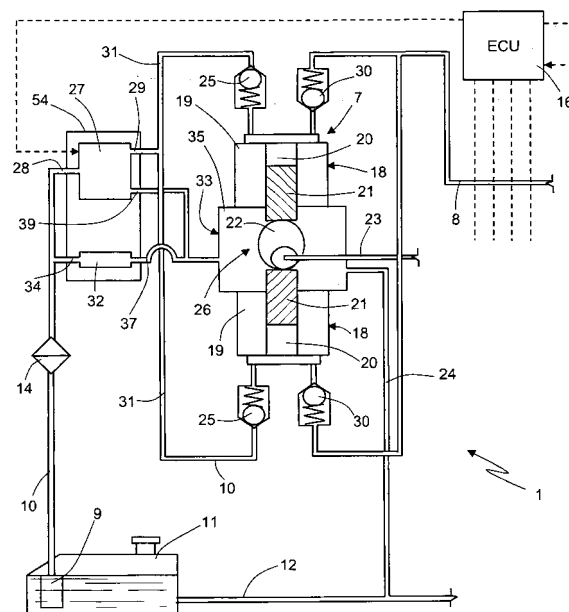


Fig.1

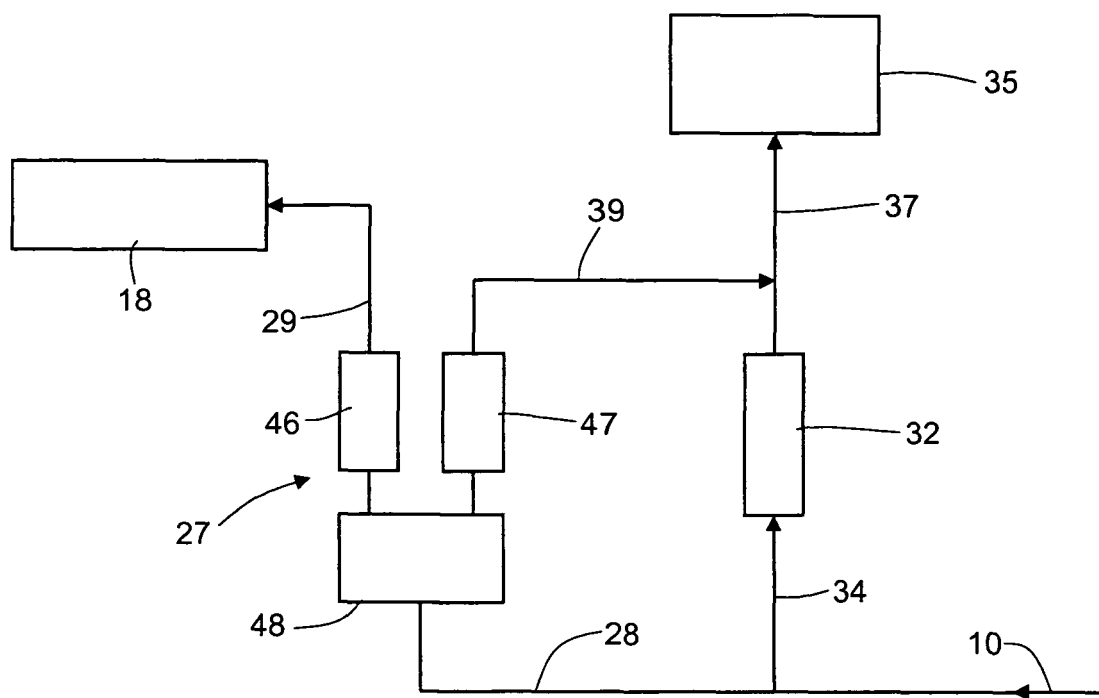


Fig.4

Description

[0001] The present invention relates to a fuel-injection system for an internal-combustion engine, comprising a variable-capacity high-pressure pump having at least one pumping element.

[0002] In known high-pressure pumps of the aforesaid type, the pump capacity must be regulated as a function of the running conditions of the engine so as to prevent fuel in excess from being sent to the usual common rail for supply of the injectors so that the work of compression of said pressure pump is reduced. In general, the high-pressure pump is supplied with the fuel by a low-pressure electric pump, actuated at a constant voltage, so that it supplies a constant flow rate of fuel.

[0003] Consequently, the low-pressure electric pump must be sized in such a way that its constant flow rate is equal to the highest flow rate required by the engine, multiplied by an appropriate safety coefficient higher than unity. In addition, the high-pressure pump comprises an actuation mechanism enclosed in a sump, said mechanism being lubricated and cooled by a flow rate of fuel, which is subtracted from the flow supplied by the low-pressure electric pump.

[0004] Fuel-injection systems are known in which the flow rate of the high-pressure pump is dosed by means of a dosage device formed by a shut-off solenoid valve, which is located on the usual intake duct and is controlled by an electronic control unit. Moreover, a pressure regulator is located on said intake duct and discharges any possible excess fuel into the tank, maintaining the pressure of the fuel upstream of the shut-off solenoid valve at a constant value.

[0005] The electronic control unit, by determining the times of opening of the solenoid valve carries out dosage of the amount of fuel to be sent to the pumping elements of the high-pressure pump, which thus takes in only the fuel to be compressed required by the running conditions of the engine. The solenoid valve thus remains closed for longer periods when the engine operates at low r.p.m. since it requires a smaller amount of fuel. Instead, with the engine at low r.p.m., the pressure regulator must send to the sump a greater amount of fuel, equal to the complement of the amount sent to the high-pressure pump, than that delivered by the low-pressure electric pump.

[0006] In a known fuel-injection system of the aforesaid type, the shut-off solenoid valve is located on the intake duct of the high-pressure pump, downstream of the pressure regulator. Consequently, when the solenoid valve is closed, in the stretch of intake duct between the inlet of the pressure regulator and the solenoid valve, the flow of fuel is stopped. In another known fuel-injection system, the shut-off solenoid valve is, instead, set upstream of the pressure regulator in order to create a flow of fuel at the inlet of the solenoid valve even when it is closed.

[0007] In both of these systems, the shut-off solenoid valve is of the on-off type and is actuated by the electronic control unit in chopped mode. Said mode may be asyn-

chronous with operation of the pumping elements or synchronous with the suction stroke of each pumping element. Consequently, the shut-off solenoid valve is opened and closed repeatedly, and its flow rate passes substantially from a maximum to zero. In the duct upstream, closing of the solenoid valve, as a result of the so-called fluid hammer causes a train of pressure waves, which cannot be either eliminated or damped by the normal supply ducts of the high-pressure pump. The train of waves is hence transmitted to the bodywork, to which the fuel-injection system is in any case constrained, generating acoustic discomfort and noise.

[0008] The train of pressure waves due to the fluid hammer also occurs in the presence of the pressure regulator set in the intake duct upstream of the solenoid valve. In fact, the pressure regulator has a dynamics of intervention slower, by at least one order of magnitude, than the dynamics of the fluid hammer due to closing of the solenoid valve. In any case, the train of pressure waves rebounds towards the low-pressure pump also in the presence of the damping action of the possible fuel filter located between said low-pressure pump and the dosage device of the high-pressure pump.

[0009] The aim of the invention is to provide a fuel-injection system of the aforesaid type, which will eliminate any acoustic discomfort due to the dosage and will present a high reliability and a limited cost, eliminating the drawbacks of the fuel-injection systems of the known art.

[0010] According to the invention, the above purpose is achieved by a fuel-injection system for an internal-combustion engine, as defined in Claim 1.

[0011] For a better understanding of the invention, described herein is a preferred embodiment, provided by way of example with the aid of the annexed drawings, wherein:

Figure 1 is a partial diagram of a fuel-injection system, with a dosage device according to the invention; Figures 2 and 3 show the time plots of the control signals of the dosage device; Figure 4 and 5 are two partial diagrams of two variants of the dosage device of the invention; Figure 6 is a diagram of a variant of the fuel-injection system of Figure 1.

[0012] With reference to Figure 1, designated as a whole by 1 is a fuel-injection system for an internal-combustion engine, for example, a four-stroke diesel engine, not illustrated in the diagram. The engine comprises a plurality of cylinders, for example four, associated to which are corresponding electrically controlled injectors, which are designed to inject the fuel therein at a high pressure, said fuel being normally accumulated in an accumulation space, for example, formed by the usual common rail (not illustrated in the figures either).

[0013] The common rail is supplied with fuel at a high pressure by a high-pressure pump, designated as a

whole by 7, via a delivery duct 8. In turn, the high-pressure pump 7 is supplied by a low-pressure pump, for example an electric pump 9, via an intake duct 10 of the pump 7. The electric pump 9 is in general located in the usual fuel tank 11, into which a discharge duct 12 for the excess fuel of the fuel-injection system 1 gives out. A filter 14 is located on the intake duct 10 and is designed to prevent entry into the pump 7 of any possible impurities present in the fuel pumped by the electric pump 9.

[0014] Each injector is designed to inject, in the corresponding cylinder, an amount of fuel that can vary between a minimum value and a maximum value under the control of an electronic control unit 16, which can be formed by the usual microprocessor control unit for control of the engine. The control unit 16 is designed to receive signals indicating the running conditions of the engine, as well as the pressure of the fuel in the common rail, which are generated by corresponding sensors (not shown). The discharge duct 12 conveys towards the tank 11 the fuel discharged by the injectors and by other devices of the fuel-injection system 1 that will be described hereinafter.

[0015] The high-pressure pump 7 comprises at least one pumping element 18 formed by a cylinder 19 having an intake/compression chamber 20, in which there slides a piston 21 that moves with a reciprocating motion constituted by a suction stroke and a delivery stroke. In particular, the pump 7 of Figure 1 comprises two pumping elements 18, each having an intake/compression chamber 20 provided with a corresponding intake valve 25 and a corresponding delivery valve 30. The valves 25 and 30 can be of the ball type and can be provided with respective return springs. The two intake valves 25 are in communication with the intake duct 10 common to said intake valves, whilst the two delivery valves 30 are in communication with the delivery duct 8 common to said delivery valves.

[0016] The pistons 21 are actuated by an actuation mechanism 26 housed in a compartment 35 enclosed in a pump casing or sump 33. In Figure 1, the two pumping elements 18 are coaxial and opposite to one another, i.e., they are in line with one another, and the actuation mechanism comprises a single eccentric 22 carried by a shaft 23 so that the pumping elements are actuated with a phase offset of 180° with respect to one another. The shaft 23 can be actuated in any known way, for example by the usual crankshaft, via a device for transmission of the motion, which is in itself known.

[0017] The capacity of the pump 7 is controlled exclusively by a dosage device, designated as a whole by 27, which is provided with an inlet 28 in communication with the intake duct 10. The dosage device 27 has an outlet 29 in communication with the intake valves 25, via corresponding connection segments 21. The dosage device 27 is designed to be actuated, in a synchronous or asynchronous way with respect to the suction stroke of the pumping elements 18, by the electronic control unit 16 as a function of the running conditions of the engine, by

means of chopped control signals, modulated in frequency and/or in duty cycle. Said running conditions determine the amount of fuel that the pump 7 must take in through the duct 10 to maintain an adequate pressure of the fuel in the accumulation space. Advantageously, said control is performed both during the suction stroke and during the compression stroke of the piston 21 of each pumping element 18.

[0018] Moreover, a pressure regulator 32 is located on the intake duct 10 and has the function of maintaining constant the pressure of the fuel to be taken in, pumped continuously by the low-pressure electric pump 9. In particular, the pressure regulator 32 is provided with an inlet 34 in communication with the intake duct 10, set upstream of the inlet duct 28 of the dosage device 27, and with an outlet 37 in communication with the compartment 35 of the sump 33 of the pump 7. The pressure regulator 32, through the outlet 37, sends the excess fuel into the compartment 35 in order to cool and lubricate the actuation mechanism 26 contained in the sump 33. The fuel of the compartment 33 returns then to the tank 11 through a duct 24 in communication with the discharge duct 12.

[0019] The inlet 28 of the dosage device 27 has a relatively small effective section of passage, so as to enable dosage of the fuel before it is compressed and brought to the desired pressure by the pump 7. Preferably, said section of passage is such that, as a result of the difference of pressure between upstream and downstream of said section of passage (in particular, the pressure upstream is defined by the pressure regulator 32), the dosage device 27 presents an instantaneous maximum flow rate lower than the instantaneous maximum flow rate that can be taken in through each intake valve 25. For example, the instantaneous maximum flow rate of the dosage device 27 can be up to 10% lower than the instantaneous maximum flow rate of the intake valve 25 of each pumping element 18.

[0020] In the tank 11, the fuel is at atmospheric pressure. In use, the electric pump 9 compresses the fuel to a low pressure, for example in the region of 3-5 bar. In turn, the high-pressure pump 7 compresses the fuel dosed by the dosage device 27 so as to send, via the delivery duct 8, the fuel at a high pressure, for example in the region of 1600 bar, to the common rail for pressurized fuel. Consequently, the dosage device 27 must frequently close and open the outlet 29 and hence the intake duct 10 of the high-pressure pump 7. However, the low-pressure electric pump 9 must have a flow rate such as to guarantee both circulation of the fuel in the sump 33 and the maximum amount of fuel that can be required by the engine.

[0021] According to a first control strategy, the electronic control unit 16 is designed to control the dosage device 27 by means of a chopped electrical signal 41 (Figure 2), formed by a series of control signals A of constant duration t_1 , of which the frequency is modulated, according to the PFM (pulse-frequency modulation) strategy. Consequently, to vary the amount of fuel to be

pumped, the time interval B between the signals A is varied.

[0022] According to another control strategy, the electronic control unit 16 is designed to control the dosage device 27 by means of another chopped electrical signal 42 (Figure 3) formed by a series of control signals C of constant frequency, the duty cycle of which is modulated, according to the PWM (pulse-width modulation) strategy. The constancy of the frequency is indicated in Figure 3 by the constancy of the distance of the dashed lines G. Consequently, the duration of the signals C is varied, but also the interval D between said signals varies. In both cases of Figures 2 and 3, the time interval T, indicated by two dashed and dotted lines, is a multiple of the time t_1 and G. Obviously, in Figures 2 and 3, the number of signals A and C in the time interval T is purely indicative. It is obviously possible to control the dosage device 27 by modulating both the frequency of the signals and the corresponding duty cycle. In any case, the frequency of opening of the outlet 29 of the dosage device 27 is correlated to the speed of rotation of the pump 7.

[0023] According to the invention, the dosage device 27 comprises another outlet 39, which is in communication with the discharge duct 12. In particular, the outlet 39 is set in parallel with the pressure regulator 32 and gives out into the outlet 37 of said pressure regulator 32. Consequently, the outlet 39, through the compartment 35 and the outlet duct 25 from the compartment 35, is in communication with the discharge duct 12 and hence with the tank 11.

[0024] The two outlets 29 and 39 of the dosage device 27 are activated by the electronic control unit 16 alternately, i.e., in a complementary way. Consequently, when the outlet 29 is blocked, the outlet 39 that delivers the fuel into the compartment 35 is activated so that the flow of fuel of constant flow rate generated by the electric pump 9 is not altered, thus preventing any pressure wave or fluid hammer.

[0025] In particular, in the case of the PFM control represented in Figure 2, the electronic control unit 16, in addition to generating the chopped signal 41 for activating the outlet 29, generates another chopped signal 43, having a pattern perfectly complementary to the corresponding chopped signal 41. In the case of the PWM control represented in Figure 3, the electronic control unit 16, in addition to generating the chopped signal 42 for activating the outlet 29, generates another chopped signal 44, having a pattern perfectly complementary to that of the corresponding chopped signal 42.

[0026] According to the variant of Figure 4, the dosage device 27 is formed by two solenoid valves 46 and 47 of an on-off type, which are substantially the same as one another and are controlled by the electronic control unit 16 by means of the complementary signals 41 and 43 or the complementary signals 42 and 44, respectively. In this way, when one of the solenoid valves 46 and 47 is closed, the other of the two solenoid valves 47 and 46 is opened. In a position corresponding to the two solenoid

valves 46 and 47 there can be provided an accumulation space 48 for supply of the solenoid valves 46 and 47 themselves in communication with the inlet 28 and hence with the intake duct 10 of the pump 7.

[0027] According to the variant of Figure 5, the dosage device 27 is formed by a three-way solenoid valve 49, having the two outlets 29 and 39 and a single inlet 51 in communication with the intake duct 10, possibly through an accumulation space 48. The three-way solenoid valve 49 has a two-position control element 51, designed to be actuated by the control unit 16, by means of the complementary signals 41, 43 or 42, 44 (Figures 2 and 3). In this way, the inlet 51 is set in communication alternately, i.e., in a complementary way, with the two outlets 29 and 39, so that the flow of fuel of constant flow rate does not undergo any discontinuity as in the case of the variant of Figure 4.

[0028] In the variant of the fuel-injection system of Figure 6, the elements similar to those of the variant of Figure 1 are designated by the same reference numbers and will not be described any further herein.

[0029] According to the variant of Figure 6, the pressure regulator 32 is located on the intake duct 10 downstream of the dosage device 27, preferably separated by a stretch 53 of the intake duct 10, having a pre-set volume, which has the same function as the accumulation space 48 of Figures 4 and 5. In the case of Figure 6, the pressure regulator 32 sends continuously a certain amount of fuel into the compartment 35 of the sump 33, so that in the branching between the duct 10 and the inlet 28 of the dosage device 27 there is always a certain flow of fuel. At the moment when the outlet 29 of the dosage device 27 is opened, in the stretch 53 of the intake duct 10, comprised between the inlet 28 of the dosage device 27 and the inlet 34 of the pressure regulator 32, there exists a certain flow of fuel, which, however, does not manage to prevent formation of a pressure wave on the duct 10.

[0030] According to the variant of the invention of Figure 6, the second outlet 39 of the dosage device 27 is in communication with the outlet of the pressure regulator 32 so that it is in communication with the compartment 35 of the sump 33. Also in this case, the second outlet 39 is activated alternately in a complementary way to activation of the outlet 29, as in the case of the variant of Figure 1, so that the flow of fuel on the intake duct 10 does not undergo any variation at all.

[0031] From what has been seen above, the advantages of the fuel-injection system according to the invention as compared to the known art emerge clearly. In particular, thanks to the complementary actuation of the outlets 29 and 39 of the dosage device 27, at the intake duct 10 there is always a constant flow of fuel so that the formation of any pressure wave is prevented, as likewise prevented is any reduction of the service life of the electric pump 9.

[0032] It may be understood that various modifications and improvements may be made to the fuel-injection sys-

tem described above, without this implying any departure from the sphere of protection of the claims. For example, in the variants of Figures 4 and 5 the accumulation space 48 of the fuel to be taken in can be eliminated. In addition, on the outlet 29 of the dosage device 27 there can be provided a further accumulation space. In the case of pumps with a number of pumping elements 18, there can also be provided a dosage device for each pumping element 18.

[0033] Another variant envisages that the flow rate at the outlet 39, i.e., the flow rate that is complementary to the one required by the common rail, will not traverse the sump 33 of the pump 7 but will follow an alternative path, i.e., a by-pass path that will finish directly in the discharge duct 12 or in other recirculation ducts.

[0034] In addition, the device 27 and the pressure regulator 32 can be inserted or integrated in the cartridge of the filter 14 set upstream of the high-pressure pump 7; in this case, two pipes depart from the filter 14: one supplies the intake valves of the pump 7, and the other supplies and lubricates the sump 33 of the pump 7; the advantage of this alternative architecture lies in the fact that the casing of the pump 7 is rendered lighter.

[0035] Finally, a common regulation body 54 may be provided (Figures 1 and 6), which will include both the dosage device 27 and the pressure regulator 32.

Claims

1. A fuel-injection system for an internal-combustion engine, comprising a variable-capacity high-pressure pump (7), having at least one pumping element (18) provided with an intake valve (25) in communication with an intake duct (10) and provided with a delivery valve (30) in communication with a delivery duct (8); and comprising a dosage device (27) located on said intake duct (10) and designed to be controlled by a control unit (16) so as to dose the flow rate of said pump (7) as a function of the running conditions of the engine; said fuel-injection system being **characterized in that** said dosage device (27) comprises two outlets (29, 39), of which one outlet (29) supplies said delivery valve (25), whilst the other outlet (39) is in communication with a discharge duct (12).
2. The fuel-injection system according to Claim 1, wherein said pump (7) comprises an actuation mechanism (26) housed in a compartment (35) of a sump (33), **characterized in that** said other outlet (39) is in communication with said discharge duct (12) through said compartment (35).
3. The fuel-injection system according to Claim 2, comprising a pressure regulator (32) located between said intake duct (10) and said compartment (35) for lubricating said mechanism (26), **characterized in**

that said other outlet (29) is set in parallel with said pressure regulator (32).

4. The fuel-injection system according to Claim 3, **characterized in that** said pressure regulator (32) is in communication with said intake duct (10) upstream of said dosage device (27).
5. The fuel-injection system according to Claim 3, **characterized in that** said pressure regulator (32) is in communication with said intake duct (10) downstream of said dosage device (27).
6. The fuel-injection system according to any one of the preceding claims, **characterized in that** said dosage device (27) is designed to be controlled by said electronic control unit (27) by means of chopped electrical signals (41-44).
7. The fuel-injection system according to Claim 6, **characterized in that** said dosage device (27) is formed by two solenoid valves (46, 47) which are designed to be controlled by said electronic control unit (16) in such a way that, when one of the two solenoid valves (46, 47) is open, the other of said two solenoid valves (46, 47) is closed.
8. The fuel-injection system according to Claim 6, **characterized in that** said dosage device (27) is formed by a three-way solenoid valve (49) having a two-position control element (52) for setting in communication an inlet (51) of said three-way solenoid valve (49) alternately with said two outlets (29, 39).
9. The fuel-injection system according to any one of the preceding claims, **characterized in that** said electronic control unit (16) controls said dosage device (27) in an asynchronous way with respect to the actuation of said pumping element (18).
10. The fuel-injection system according to any one of Claims 1 to 8, **characterized in that** said electronic control unit (16) controls said dosage device (27) in a synchronous way with the compression stroke of said pumping element (18).
11. The fuel-injection system according to any one of the preceding claims, wherein said pump (7) comprises at least two pumping elements (18) carried by a common pump casing (33), **characterized in that** said pressure regulator (32) and said dosage device (27) are integrated in a regulation body (54) separate from said pump casing (33).

Amended claims in accordance with Rule 137(2) EPC.

1. A fuel-injection system for an internal-combustion engine, comprising a variable-capacity high-pressure pump (7), having at least one pumping element (18) provided with an intake valve (25) in communication with an intake duct (10) and provided with a delivery valve (30) in communication with a delivery duct (8); and comprising a low-pressure electric pump (9) supplying a constant fuel flow rate to said intake duct (10), a metering device (27) located on said intake duct (10) and designed to be controlled by a control unit (16) so as to meter the flow rate of said high-pressure pump (7) as a function of the running conditions of the engine; said high-pressure pump (7) comprising an actuation mechanism (26) housed in a compartment (35) of a sump (33); said metering device (27) comprising two outlets (29, 39), of which one outlet (29) supplies said intake valve (25), whilst the other outlet (39) is in communication with a discharge duct (12) through said compartment (35); said fuel-injection system being **characterized in that** said outlets (29, 39) are activated by said control unit (16) alternately in a complementary way, whereby when one of said outlets (29, 39) is blocked the other of said outlets (29, 39) is activated, so that said constant flow rate generated by said low-pressure electric pump (9) is not altered.

2. The fuel-injection system according to Claim 1, comprising a pressure regulator (32) located between said intake duct (10) and said compartment (35) for lubricating said mechanism (26), wherein said other outlet (39) is set in parallel with said pressure regulator (32).

3. The fuel-injection system according to Claim 2, wherein said pressure regulator (32) is in communication with said intake duct (10) upstream of said metering device (27).

4. The fuel-injection system according to Claim 2, wherein said pressure regulator (32) is in communication with said intake duct (10) downstream of said metering device (27).

5. The fuel-injection system according to any one of the preceding claims, wherein said electronic control unit (27) is designed to control said metering device (27) by means of chopped electrical signals (41-44).

6. The fuel-injection system according to Claim 5, wherein said metering device (27) is formed by two solenoid valves (46, 47), and wherein said electronic control unit (27) is designed to control said solenoid valves (46, 47) in such a way that, when one of the two solenoid valves (46, 47) is open, the other of

said two solenoid valves (46, 47) is closed.

7. The fuel-injection system according to Claim 5, wherein said metering device (27) is formed by a three-way solenoid valve (49) having a two-position control element (52) for setting in communication an inlet (51) of said three-way solenoid valve (49) alternately with said two outlets (29, 39).

8. The fuel-injection system according to any one of the preceding claims, wherein said electronic control unit (16) is designed to control said metering device (27) in an asynchronous way with respect to the actuation of said pumping element (18).

9. The fuel-injection system according to any one of Claims 1 to 7, wherein said electronic control unit (16) is designed to control said metering device (27) in a synchronous way with the compression stroke of said pumping element (18).

10. The fuel-injection system according to any one of the preceding claims, wherein said pump (7) comprises at least two pumping elements (18) carried by a common pump casing (33), and wherein said pressure regulator (32) and said metering device (27) are integrated in a regulation body (54) separate from said pump casing (33).

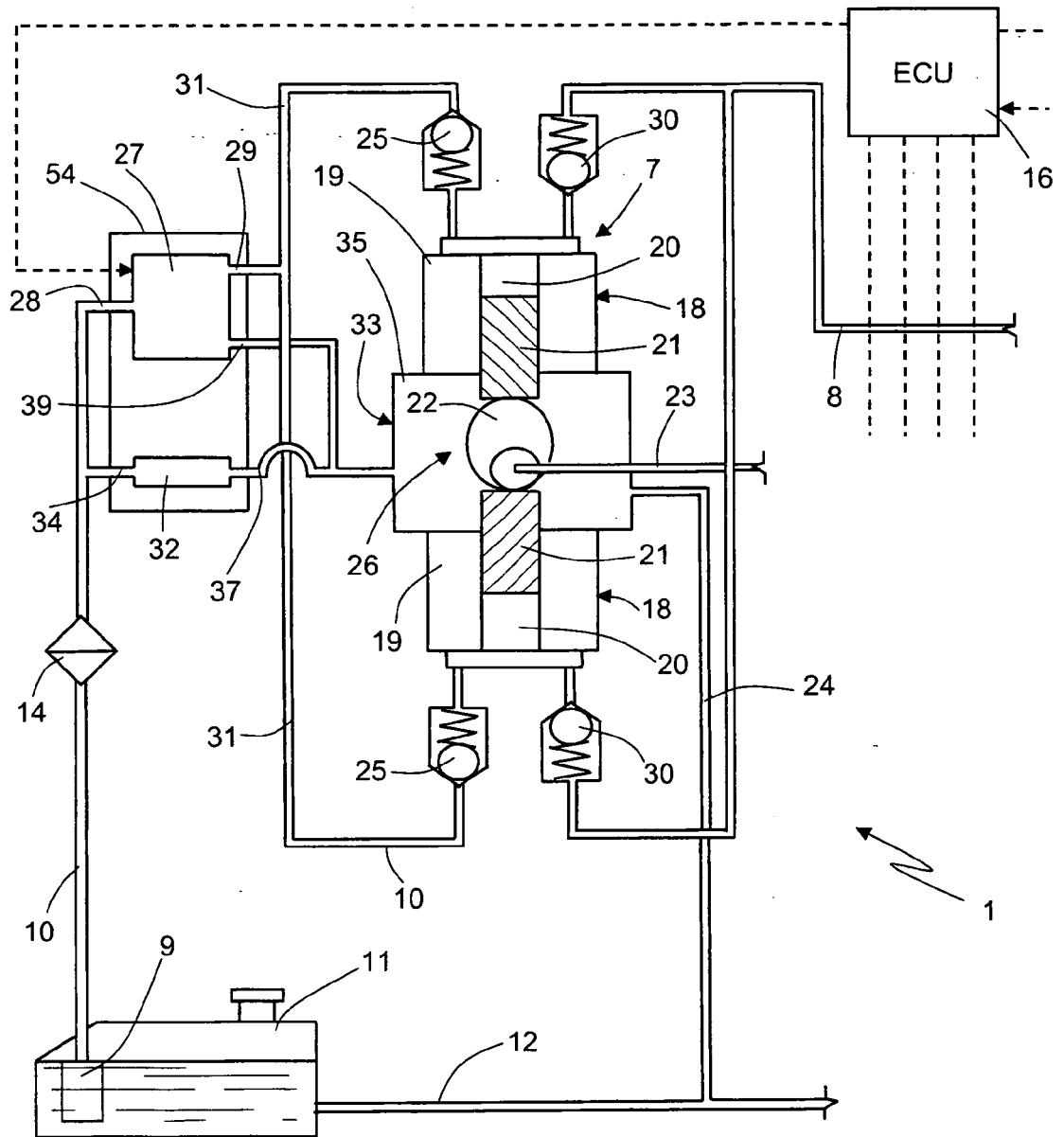


Fig.1

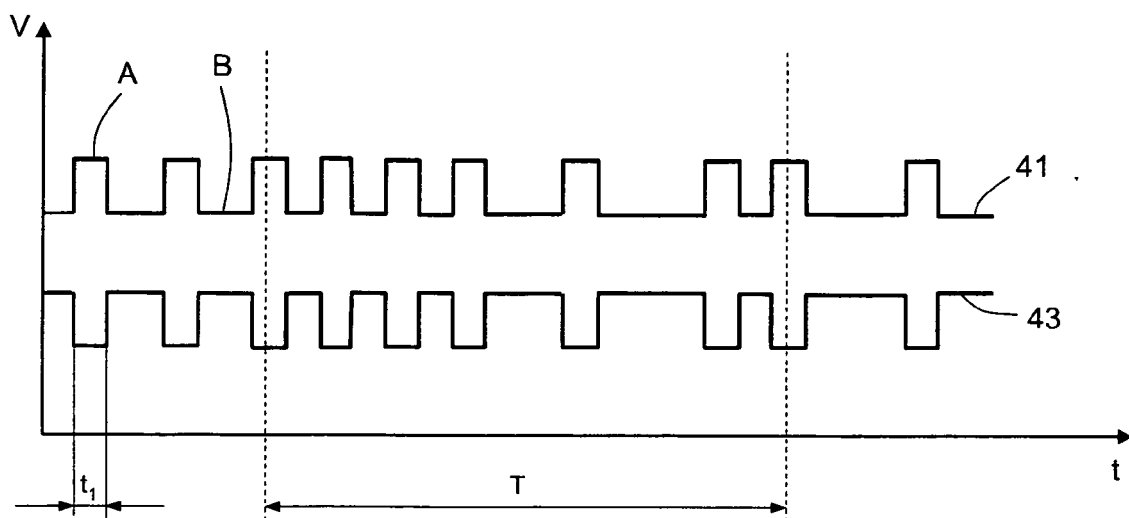


Fig.2

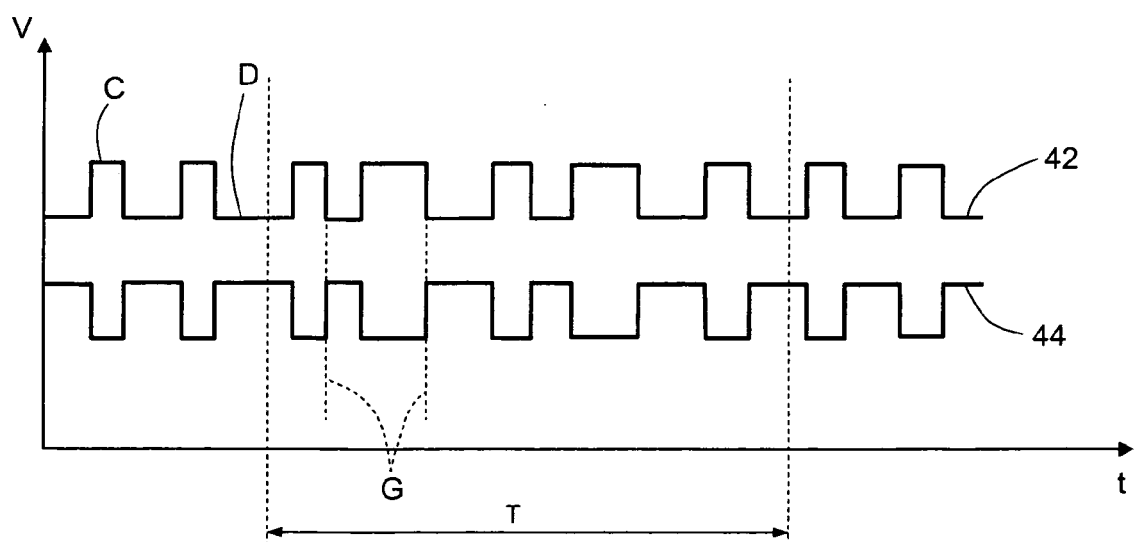


Fig.3

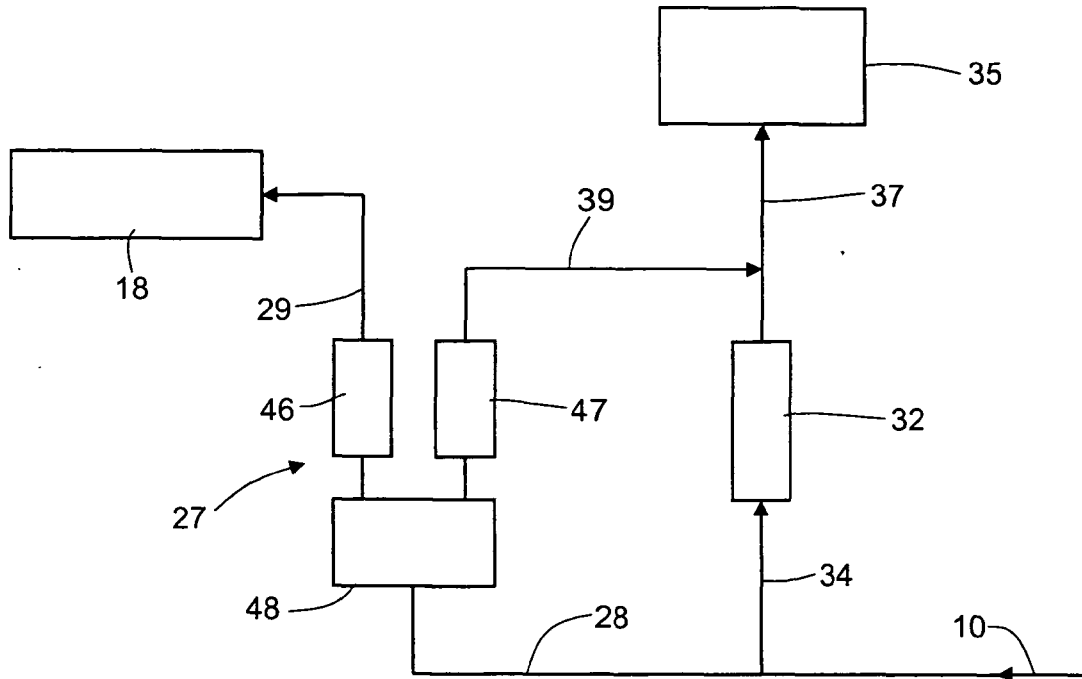


Fig.4

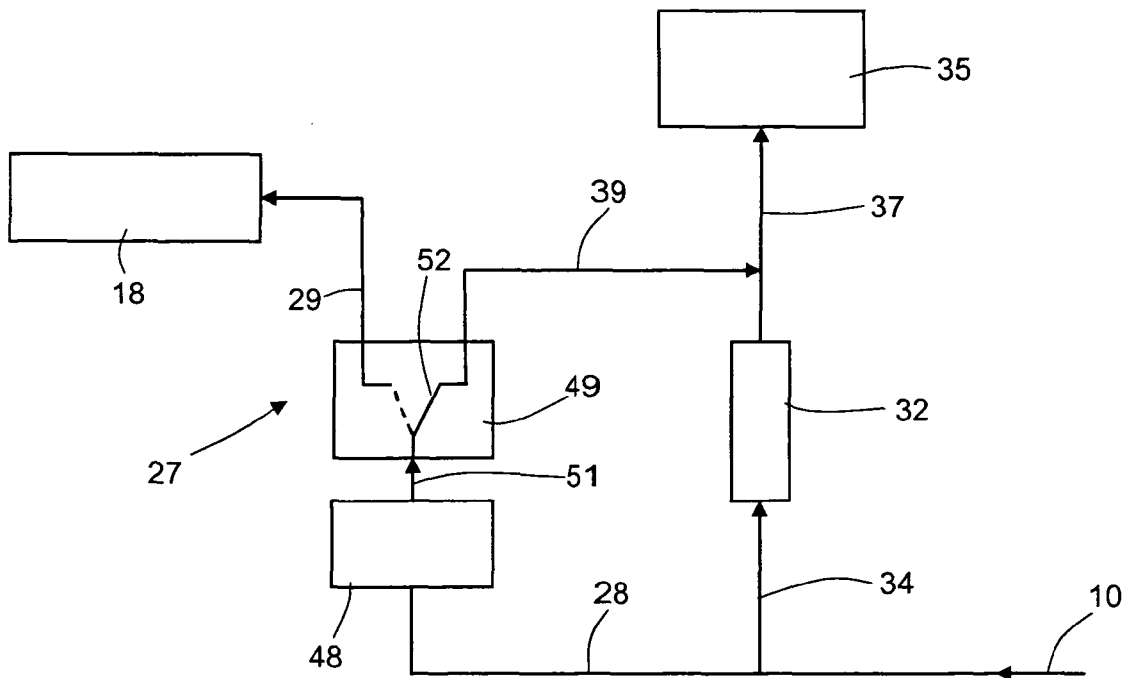


Fig.5

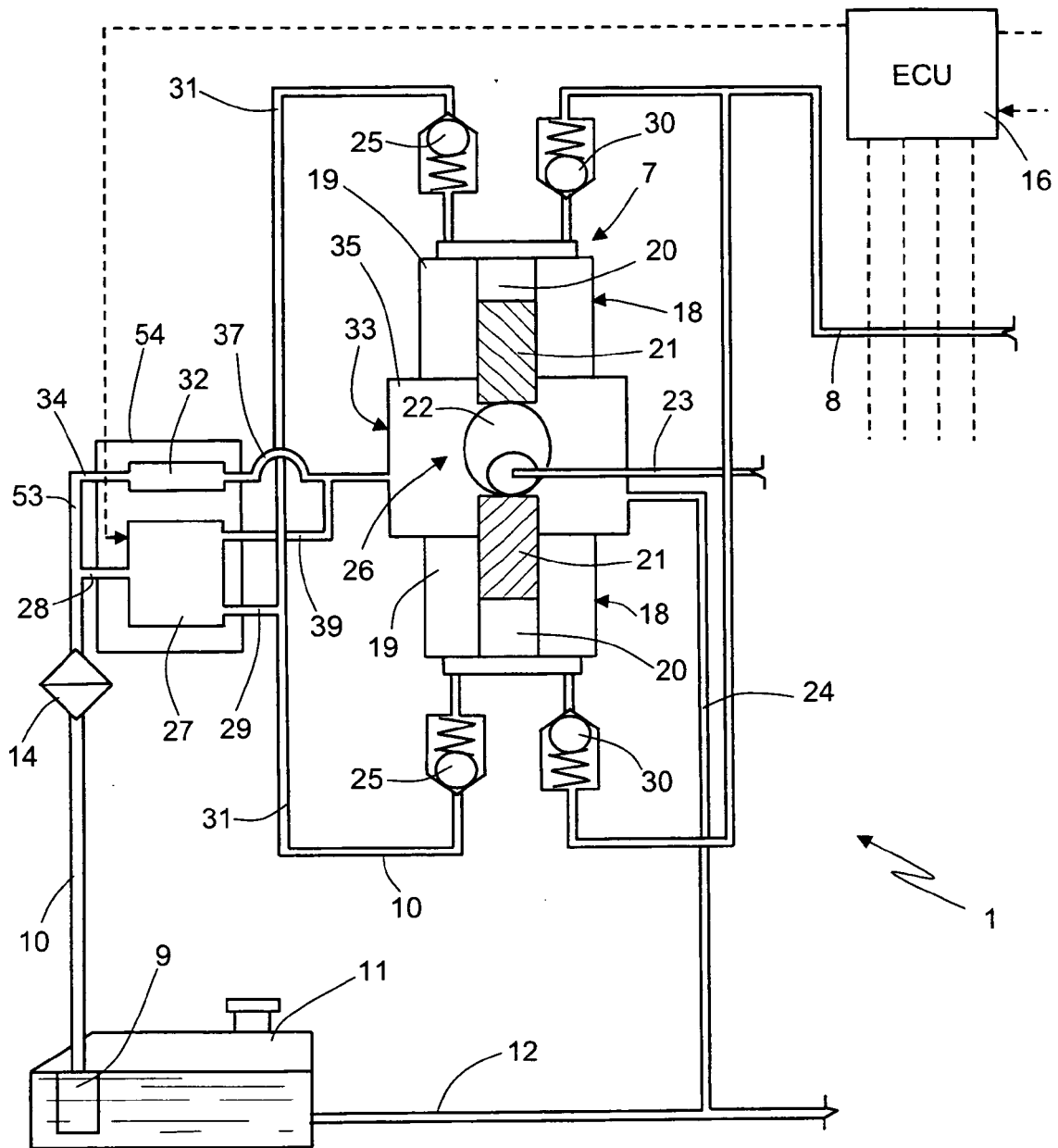


Fig.6



EUROPEAN SEARCH REPORT

Application Number
EP 09 42 5060

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Place of search		Date of completion of the search	Examiner
Munich		8 July 2009	Etschmann, Georg
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 09 42 5060

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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