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(54) **Title**: FUEL INJECTION EQUIPMENT AND CONTROL METHOD

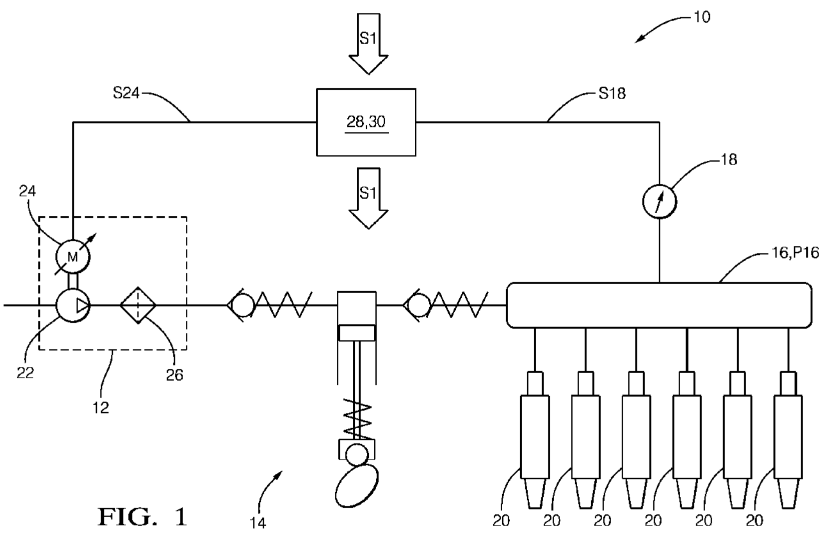

FIG. 1

(57) **Abstract**: A fuel injection equipment (10) comprising a transfer pump (22), a high pressure pump (14) wherein, in use, the fuel flow exiting the transfer pump (22) is integrally pressurized in the high pressure pump (14).

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Fuel injection equipment and control method

TECHNICAL FIELD

The present invention relates to a fuel injection equipment and to a method of operating such equipment.

BACKGROUND OF THE INVENTION

A fuel injection equipment comprises a low pressure (LP) system wherein a transfer pump (TP) sucking fuel from a low pressure tank flows said fuel toward a high pressure (HP) system wherein a high pressure pump (HPP) pressurizes said fuel and flows it toward a high pressure reservoir, also known as a common rail, prior to deliver the pressurized fuel to a plurality of fuel injectors that spray the pressurized fuel upon demand into combustion chambers of an internal combustion engine. The total quantity of fuel flowing from the HP system into the engine is dependent on the demanded engine power output. In conventional systems the transfer pump is mechanically driven from the HPP, or directly from the engine and, its delivery is not closely linked to the requirements of the HP system. Consequently the flow from the LP system to the HP system must be controlled to meet the HP system requirements and this is achieved with an inlet metering valve (IMV) arranged on the inlet of the HPP. A command unit generally controls the equipment and, in particular, it controls the IMV which varies the HPP inlet flow according to a command signal computed in consideration of the actual rail pressure measured by a sensor and, of the fuel pressure demanded by the engine. The surplus of fuel flown from the TP is sent back to the low pressure tank, this return representing an energy loss.

The function of the IMV causes pressure drop in the fuel that passes though it meaning that the pressure generated by the TP is higher than that required by the HPP, this results in more energy being lost in surplus of the fuel flowing back to the low pressure tank.

Furthermore the inclusion of the IMV represents additional cost.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to resolve the above mentioned problems in providing a fuel injection equipment comprising a transfer pump adapted to suck fuel from a low pressure tank and, a high pressure pump adapted to receive fuel from said transfer pump.

Advantageously, the fuel injection equipment is arranged so that, in use, the fuel flow exiting the transfer pump is integrally pressurized in the high pressure pump. Specifically, the transfer pump is actuated by an electrical motor and, in use, the electric transfer pump is operated and controlled to regulate the output flow of the high pressure pump.

The fuel injection equipment further comprises a high pressure reservoir, such as a well-known common-rail, adapted to store fuel received from the high pressure pump, a pressure sensor adapted to measure the pressure inside the high pressure reservoir and, an electronic command unit adapted to control the transfer pump as a function of the pressure information received from the pressure sensor.

The invention further extends to an electronic command unit adapted to control a fuel injection equipment as set in the preceding paragraphs.

The invention further extends to a method for controlling a fuel injection equipment when executed by an ECU as described in the previous paragraph, the method comprising the steps of:

a) determining the flow rate of fuel required to be injected in the engine and, the corresponding pressure required to be in the high pressure reservoir;

b) determining the necessary fuel flow required to enter the high pressure reservoir so the pressure in the rail matches said required pressure;

c) adjusting the actuation of the transfer pump so that said transfer pump adjusts to only suck and send to the high pressure pump the necessary fuel flow determined at step b).

The method may further comprise the following step:

d1) comparing the pressure required determined at step a to the actual pressure measured by the pressure sensor, wherein said step c) is performed in order to perform determining step b).

The method may further comprise the following step:

d2) with input of the pressure required determined at step a), executing a recorded equation

(eq.) FS = FI + L1 + L2, where

FS is the flow rate of fuel supplied by the transfer pump to the high pressure pump;

FI is the flow rate of fuel injected into the engine.

L1 is the pump leakage;

L2 is the injector leakage.

In a variant to the step d2), the determining step b) may be performed by executing the following step:

d3) with input of the pressure required determined at step a), searching in a reference map, recorded in a memory of the ECU, the necessary fuel flow required to enter the high pressure reservoir so the pressure in the rail matches said required pressure.

Also, the transfer pump is operated by a variable revolution speed electrical motor and wherein step c) is performed by tuning the electric power sent to the motor so that the revolution speed of the motor is adjusted.

The invention further extends to a software able to execute the steps of the previous method when said software is loaded onto an ECU as previously mentioned.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is now described by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic representation of a fuel injection equipment as per the invention.

Figure 2 is a diagram of a method controlling the equipment of figure 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In reference to figure 1 is described a fuel injection equipment 10 comprising a low pressure supply system 12, a high pressure pump 14, a high pressure reservoir 16, also known as a common rail, which internal pressure P16 is measured by a pressure sensor 18. Also, six fuel injectors 20 are connected to the common rail, each injector 20 being adapted to spray fuel in a combustion chamber of an internal combustion engine, not represented. Although the figure represents six injectors, the invention can perfectly be adapted to any other engine having another number of cylinders, three, four, eight…

The low pressure supply system 12 comprises a transfer pump 22 operated by an electric motor 24, said pump 22 sucking fuel from a general low pressure tank, not represented. The quantity of fuel exiting the transfer pump 22 is proportional, or at least directly linked, to the revolution speed RPM24 of the motor 24. The output flow exiting the transfer pump 22 is filtered through a filter 26 prior to delivery to the high pressure pump 14. As can be noted on the figure, the equipment 10 is not provided with any inlet metering valve controlling the high pressure pump inlet.

An electronic command unit (ECU) 28 receives from the engine a plurality of signals S1 informing the ECU 28 about the state of operation of the engine and about the performance expected from the engine..

Engine revolution speed, vehicle speed, throttle pedal position are examples of information signals S1 received by the ECU 28. In turn, the ECU 28 generates a plurality of command signals S2 sent to the components of the engine 10. In particular the ECU 28 determines the flow rate of fuel FI required to be injected into the engine in order in order for the engine to match said engine demand ED. Opening and closing of the injectors, fuel pressure are examples of command signals S2.

In particular, the ECU 28 permanently receives from the sensor 18 an information signal S18, that is one of the signals S1, corresponding to the rail pressure P16 also, the ECU 28 generates and sends to the electric motor 24 a command signal S24, that is one of the signals S2, adjusting the revolution speed RPM24 of the motor 24 to the engine demand ED.

More precisely, the ECU 28 performs a dynamic and permanent closed loop control between the rail pressure P16 and the electric motor revolution speed RPM24. The ECU 28 determines, as a function of the received information signals S1, S18, a flow rate FI of fuel required to be injected in the engine and the corresponding pressure required PR in the common rail 16 in order for the engine to match the engine demand ED. The ECU 28 compares said pressure required PR to the actual rail pressure P16 and, it calculates a necessary fuel flow that must be pressurized and that must enter the rail.

Alternatively the electric motor revolution speed RPM24 can be determined using an open loop method, whereby the information signals S1 are evaluated by the ECU 28. Information on the rail pressure P16, engine speed and injection delivery period are used to calculate flow from the high pressure pump 14.

In the high pressure pump 14, a plunger reciprocally translates in a bore therein performing a pumping cycle, between a bottom dead centre (BDC) position and a top dead centre (TDC) position, during which the volume of a compression chamber is varied and fuel is pressurized. During said pumping cycle the majority of the fresh fuel that has entered the compression chamber is pressurized and flown to the rail 16. A minor quantity of the fuel leaks between the plunger and the bore, said pump leakage L1 being collected and sent back to the low pressure tank.

The pump leakage L1 occurs when the pressure in the compression chamber rises and, said leakage L1 depends upon said pressure in the compression chamber, upon the fuel viscosity, which is temperature dependent and, upon the pumping period. Indeed if the pump operates at full capacity, the compression chamber is totally filled with fuel and, the pressure rises as soon as the plunger lifts from BDC toward TDC and, if the pump only operates at half capacity, the compression chamber is only half filled with fuel and, the pressure starts rising after the plunger has already lifted for half the stroke between BDC and TDC.

Furthermore, due to manufacturing variations, the pump leakage L1 varies from one pump to another as being dependent upon the specific functional clearance between a plunger and its bore.

Also, after the rail, the pressurized fuel enters the injector 20 and, part of said fuel is not injected and is returned, via a return line, to the low pressure tank. This represents injector leakage L2 from control valve clearances and control flow. The pressurized fuel entering in the injector flows directly back to an outlet. This injector leakage L2 is typically function of the pressure of the entering fuel and also of the operational temperature of said fuel.

Should the pump or injector be individually characterized at the end of the production line, the individual leakages L1, L2, of each unit can be measured under a full range of operational conditions and can be recorded for future use in the ECU 28.

Should the pump or injector only be statistically characterized, pump leakage L1 or injector leakage L2 would be statistically determined and recorded for future use in the ECU 28.

Generally, injectors are individually characterized and pump are statistically characterized.

Consequently, a flow rate FS of fuel supplied by the transfer pump to the high pressure pump can be determined by adding the pump leakage L1 and the injector leakage L2 to the flow rate FI of fuel injected into the engine required to match the engine demand ED. This can be expressed in the following equation:

(eq.) $FS = FI + L1 + L2$

This equation (eq.) or, alternatively a map M wherein are pre-recorded the results of the equation (eq.), can be recorded in the ECU 28. Consequently, the speed of the electric motor RPM24 can be rapidly calculated and, even if this may not be perfectly accurate it may be of use for transient operation where important adjustments in motor speed RPM24 are rapidly required. Once said transient situation resumed, engine speed and load have substantially stabilized, the ECU 28 reverts back to the closed loop process.

Once the flow rate FI of fuel required to be injected into the engine is determined, the ECU 28 generates the adapted electric motor command signal S24 ordering to adjust the revolution speed RPM24 of the motor 24 so that the transfer pump 22 adjusts and only sucks from the low pressure tank said necessary quantity of fuel and transfers it integrally to the high pressure pump 18. Since this is a dynamic closed loop process, the ECU 28 regulates the rail pressure P16 by managing the electric motor 24 and, there is no need of any metering valve arranged on the inlet of the high pressure pump. The metering of the inlet flow is directly done by regulating the electric motor revolution speed. In other words, since the closed loop process operated by the ECU 28 is between the rail pressure P16 and the motor 24, one hundred percent (100%) of the fuel sucked by the transfer pump 22 enters the compression chamber of the high pressure pump 14.

Once said fuel quantity is pressurized and is flown into the rail 16, the rail pressure P16 equates the pressure required to fulfill the flow rate FI of fuel to be injected in the engine and, the engine demand ED. Here above “integrally” or “100%” are mentioned to clearly distinguish the invention from the prior art equipment’s wherein a large portion of the flow exiting the transfer pump is deviated by a metering valve and is returned to the general low pressure tank. The pipe joining the transfer pump to the high pressure pump may be provided with a small hole enabling air to evacuate. Through said small hole may leak a very small quantity of the fuel exiting the transfer pump. Therefore, “integrally”, “100%” or other words such “all the flow” are mentioned, and have to be understood, in the present disclosure “to the exception of minor leaks”.

The ECU 28 performs this dynamic closed loop control by running a software 30 embedded into the ECU 28, the software 30 executing the steps of a method 100 now described in reference to figure 2.

The method 100 comprises the steps:

- determining 110 the flow rate FI of fuel required to be injected in the engine and the pressure required PR in the high pressure reservoir so the engine demand ED is met. This determination is done upon reception of a plurality of information signals S1, S18, informing about the state of operation of the engine and about the performance demanded to the engine. The signal S18 informing about the actual pressure P16 in the high pressure reservoir 16 is one of the information signals S1;

- comparing 120 the required pressure PR to the actual pressure P16 measured by the pressure sensor 18;

  - if, said required pressure PR equates the actual pressure P16, no adjustment is needed and the method returns to the previous determining 110 step;

  - if, said required pressure PR does not equate the actual pressure P16, an adjustment is necessary, the method 100 continues to the following step:

- determining 130 the necessary fuel quantity required to enter the high pressure reservoir 16 so the pressure P16 in the rail 16 matches said required pressure PR and;

- determining 140 the necessary revolution speed RPM24 of the electric motor 24 so that the transfer pump 22 adjusts to said necessary fuel quantity previously determined, the transfer pump 22 sucking and transferring only the necessary quantity of fuel;

- generating 150 a command signal S24 for piloting the electric motor 24 to the revolution speed determined at the previous step;

- sending 160 to the electric motor 24 said command signal S24.

In an alternative, determining the necessary fuel flow FF is done by the method 100 in adding a third alternative to the comparing step 120, said third alternative being:

- if the required pressure PR and the actual pressure P16 largely differ, a major adjustment is necessary, the method 100 continues to the following step:

- with input of the pressure required PR determined at the determining step 110, the method executes the equation (eq.), this is calculation step 122, and rapidly determines a good approximate of the electric engine speed RPM24.

In a variant to this alternative, instead of the calculation step, the method can perform a searching step 124 where the necessary fuel flow FF required to enter the high pressure reservoir 16 is searched in the computed map M recorded in a memory of the ECU 28, so that the pressure P16 in the rail 16 matches said required pressure PR.

LIST OF REFERENCES

P16	rail pressure
S1	information signal
S2	command signal
S18	information signal from the pressure sensor
S24	command signal to the electric motor
PR	pressure required
QF	quantity of fuel
RPM24	revolution speed of the electric motor
M	map
VE	volumetric efficiency equation of the transfer pump
BDC	bottom dead centre position
TDC	top dead centre position
FI	flow rate of fuel required to be injected in the engine
FS	flow rate of fuel supplied by the TP to the HPP;
L1	pump leakage
L2	injector leakage
ED	engine demand
10	fuel injection equipment
12	low pressure supply system
14	high pressure pump - HPP
16	high pressure reservoir - common rail
18	pressure sensor
20	fuel injector
22	transfer pump - TP
24	electric motor
26	filter
28	electronic command unit - ECU
30	software
100	method
110	determining step

120	comparing step
122	searching
124	executing and calculating
140	determining step
150	generating step
160	sending step

CLAIMS

1. Fuel injection equipment (10) comprising a transfer pump (22) adapted to suck fuel from a low pressure tank and, a high pressure pump (14) adapted to receive fuel from said transfer pump (22), characterized in that,

the fuel injection equipment (10) is arranged so that, in use, the fuel flow exiting the transfer pump (22) is integrally pressurized in the high pressure pump (14) and wherein,

the transfer pump (22) is actuated by an electrical motor (24) and wherein,

in use, the electric transfer pump (22) is operated and controlled to regulate the output flow of the high pressure pump (14).

2. Fuel injection equipment (10) as claimed in the preceding claim further comprising a high pressure reservoir (16) adapted to store fuel received from the high pressure pump (14), a pressure sensor (18) adapted to measure the pressure (P16) inside the high pressure reservoir (18) and, an electronic command unit (28) adapted to control the transfer pump (22) as a function of the pressure information received from the pressure sensor (18).

3. Electronic command unit (28) adapted to control a fuel injection equipment (10) as set in any one of the preceding claims.

4. Method (100) for controlling a fuel injection equipment when executed by an ECU (28) as claimed in claim 3, the method comprising the steps of:

a) determining (110) the flow rate (FI) required to be injected in the engine and, the corresponding pressure (PR) required to be in the high pressure reservoir (16);

b) determining (130) the necessary fuel flow (FF) required to enter the high pressure reservoir (16) so the pressure (P16) in the rail (16) matches said required pressure (PR);

characterized in that the method (100) further comprises the step:

c) adjusting (140, 150, 160) the actuation of the transfer pump (22) so that said transfer pump (22) adjusts to only suck and send to the high pressure pump (14) the necessary fuel flow (FF) determined at step b).

5. Method (100) as claimed in claim 4 further comprising the following step:

d1) comparing (120) the pressure required (PR) determined at step a) to the actual pressure (P16) measured by the pressure sensor (18),

and wherein said step c) is performed in order to perform determining (130) step b).

6. Method (100) as claimed in claim 4 wherein the determining (130) step b) is performed by executing the following step:

d2) with input of the flow rate (FI) required to be injected in the engine and of the corresponding pressure (PR) required to be in the high pressure reservoir (16) as determined at step a) executing a recorded equation

(eq.) FS = FI + L1 + L2, where

FS is the flow rate of fuel supplied by the transfer pump to the high pressure pump;

FI is the flow rate of fuel injected into the engine.

L1 is the pump leakage;

L2 is the injector leakage.

7. Method (100) as claimed in claim 4 wherein the determining (130) step b) is performed by executing the following step:

d3) with input of the flow rate (FI) of fuel required to be injected in the engine, and of the pressure required (PR) determined at step a),

searching (122) in a reference map (M), recorded in a memory of the ECU (28), the necessary fuel flow (FF) required to enter the high pressure reservoir (16) so the pressure (P16) in the rail (16) matches said required pressure (PR).

8. Method (100) as claimed in any one of the claims 5 or 6 wherein the transfer pump (22) is operated by a variable revolution speed electrical motor (24) and wherein step c) is performed by tuning the electric power sent to the motor (24) so that the revolution speed (RPM24) of the motor is adjusted.

9. Software (30) able to execute the steps of the method (100) as claimed in any one of the claims 4 to 8 when said software (30) is loaded onto an ECU (28) as claimed in claim 3.

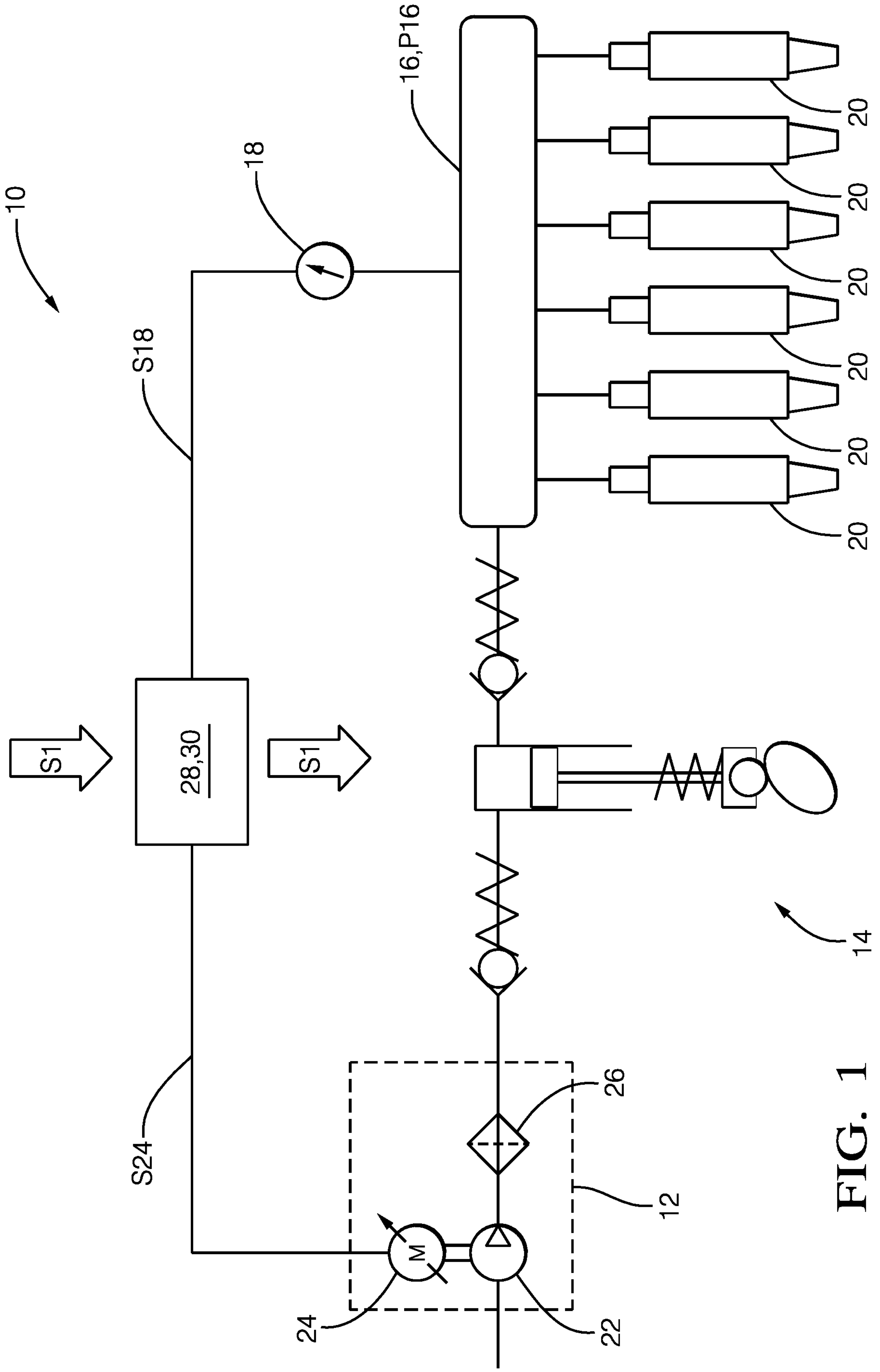

FIG. 1

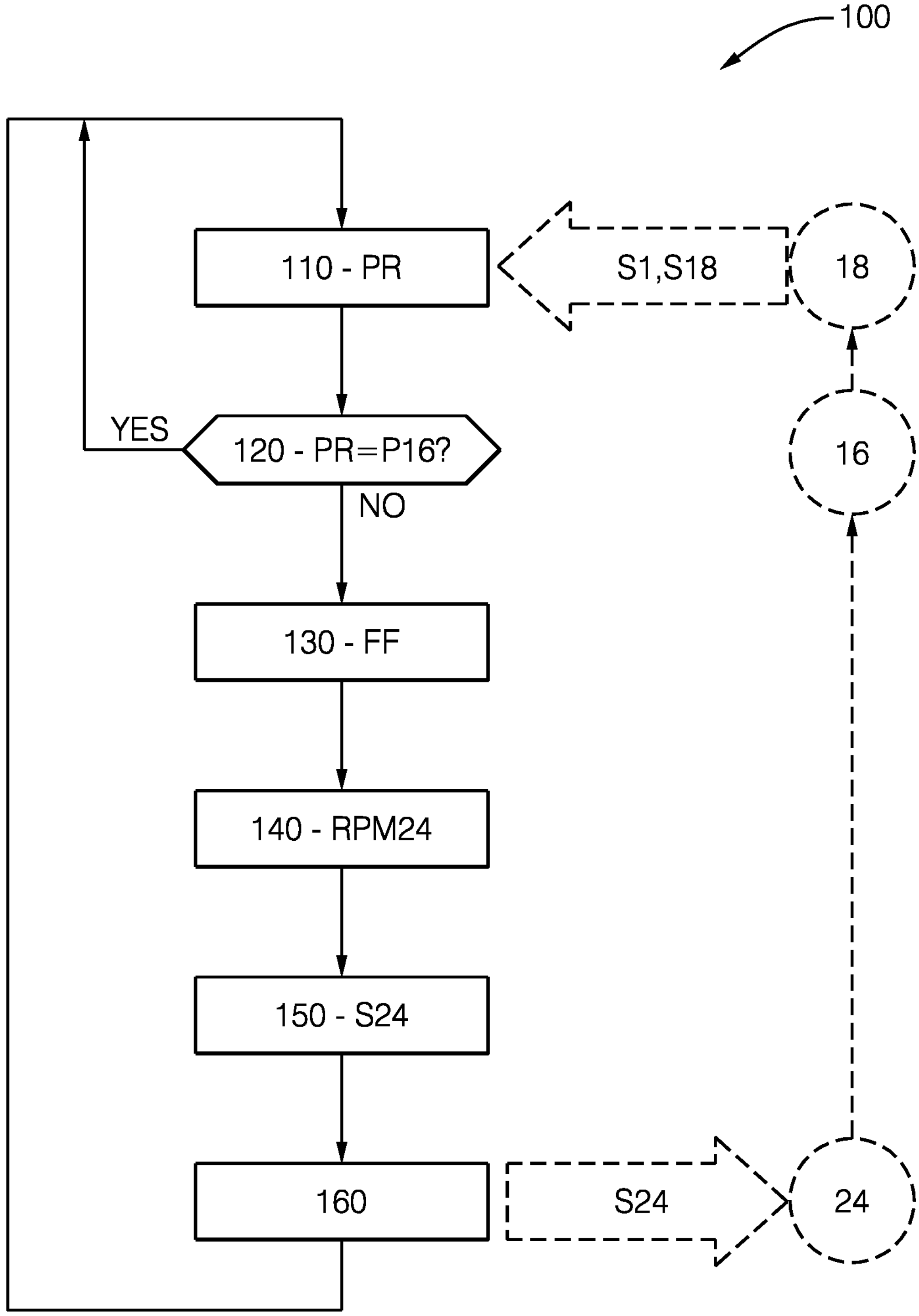
100
110 - PR
S1,S18
18
YES
120 - PR=P16?
NO
16
130 - FF
140 - RPM24
150 - S24
160
S24
24

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. F02M63/02 F02D41/38
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F02M F02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 April 2017	11/05/2017

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INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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