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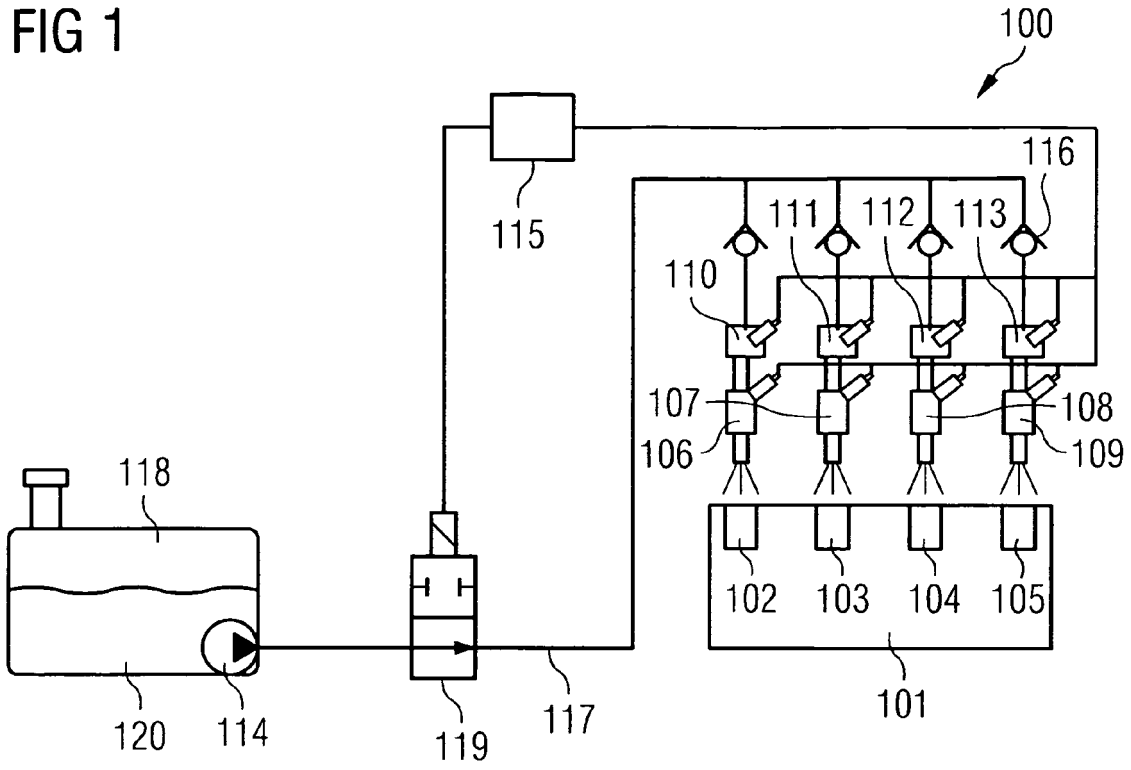
## (54) Fuel supply system and method for delivering fuel to a fuel injector

(57) A fuel supply system for a combustion engine (101) comprises a multitude of fuel injectors (106, 107, 108, 109) for providing fuel to the combustion engine (101) and a multitude of fuel pumps (110, 111, 112, 113) . Each fuel pump of the multitude of fuel pumps (110, 111, 112, 113) is hydraulically coupled with one fuel injector (106, 107, 108, 109) for providing fuel to the respective fuel injector (106, 107, 108, 109). The respective fuel pumps (110, 111, 112, 113) each comprise an electromagnetic or piezoelectric actuator for driving the respective fuel pump (110, 111, 112, 113). A Method for delivering fuel to the fuel injector (106, 107, 108, 109) of the combustion engine (101) comprises a controlling of a pump (110) to suck in fuel into a pump chamber when a fuel injector (106) that is hydraulically coupled to the pump (110) is in a closed state and a controlling of the fuel injector (106) to move to an open state as to inject the fuel of the pump chamber into a combustion chamber (102) of the combustion engine (101) , wherein the fuel out of the pump chamber is ejected out of the pump chamber only when the fuel is injected into a combustion chamber (102) via the fuel injector (106).

FIG 1

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## Description

**[0001]** The invention relates to a fuel supply system for a combustion engine. Furthermore, the invention relates to a method for delivering fuel to a fuel injector of a combustion engine.

**[0002]** Conventional fuel supply systems in vehicles comprise a high-pressure fuel pump that is connected to a high-pressure rail. The fuel rail is hydraulically connected a multitude of fuel injectors. The high-pressure fuel pump conventionally is driven by the camshaft of the combustion engine of the vehicle. Accordingly, the fuel pressure is only generated when the combustion engine is running, which is critical in particular during engine cranking. Conventionally, the fuel pressure is also a function of the revolutions per minute of the combustion engine because of the coupling of the high-pressure fuel pump with the camshaft of the combustion engine. Furthermore, the fuel injectors are all hydraulically coupled to one common high-pressure rail. Therefore, pressure waves are transmitted between the fuel injectors.

**[0003]** A further aspect of the conventional system is that the components such as the fuel pumps or the common fuel rail are relatively expensive components because they must handle high-pressure fuel and be properly sealed.

**[0004]** Additional engine management requirements like stop/start are look for a quick pressure build inside the injector to allow a quick injection to restart the engine. Also, engine cranking at low temperature requires high-pressure operating conditions to reduce engine emissions.

**[0005]** It is desirable to create a fuel supply system for a combustion engine that supplies the fuel reliably. Furthermore, it is desirable to create a method for delivering fuel to a fuel injector that works reliably. It is furthermore desirable that the system is cost-efficient.

**[0006]** According to one embodiment of the invention, the fuel supply system for a combustion engine comprises a multitude of fuel injectors for providing fuel to the combustion engine. The fuel supply system further comprises a multitude of fuel pumps. Each fuel pump of the multitude of fuel pumps is hydraulically coupled with one fuel injector for providing fuel to the respective fuel injector. The respective fuel pumps each comprise an electromagnetic or piezoelectric actuator for driving the respective fuel pump.

**[0007]** Each fuel pump delivers fuel to one single injector. Since each fuel pump provides fuel to only one fuel injector, the fuel injectors are hydraulically independent from each other downstream the fuel pumps. Therefore, no pressure waves are generated that impact other fuel injectors. Furthermore, since the fuel pumps each comprise an electromagnetic or piezoelectric actuator, they are cost-effective. Each fuel pump is arranged to provide the fuel with a pressure of about 50 to 200 bar. Furthermore, due to the coupling of one fuel pump to one single fuel injector, there is no need for a common high-pressure rail that is coupled to a multitude of fuel injectors.

**[0008]** According to two further aspects, the fuel pumps each are hydraulically directly coupled to the respective fuel injector. Thereby, high-pressure sealings are avoided and the system is reliable.

**[0009]** According to further aspects, each fuel pump is electrically coupled with an engine control unit for controlling the system. Each fuel pump is controllable by the engine control unit independent of the combustion engine. Furthermore, each fuel pump is controllable by the engine control unit independent of the other fuel pumps. Therefore, pressured fuel is provided by the fuel pumps for the fuel injectors reliably especially during engine cranking. Quick pressure build inside the fuel injector is realized and accordingly quick operation conditions to reduce engine emissions, especially in engine management requirements like stop/start. The fuel pressure is available and independent from the engine revolutions per minute. The fuel pressure is fitted to the actual demand. No higher pressure than actually demanded is needed to correctly operate the combustion engine such as in conventional systems. Stop/start operating mode and low temperature cranking do not require engine rotating to build up the fuel pressure.

**[0010]** According to one embodiment of the invention, a method for delivering fuel to a fuel injector of a combustion engine comprises a controlling of a pump to suck in fuel into a pump chamber when a fuel injector that is hydraulically coupled to the pump is in a closed state. The method further comprises a controlling of the fuel injector in an open state as to inject the fuel of the fuel chamber into a combustion chamber of the combustion engine. The fuel out of the pump chamber is injected out of the pump chamber only when the fuel is injected into a combustion chamber via the fuel injector.

**[0011]** Fuel is efficiently provided to the combustion chamber via the fuel injector. The pressurized fuel is only provided when needed. There is no need for redundant pressure as in conventional systems.

**[0012]** According to further aspects, one sucking in and one injecting is performed by one injection into the combustion chamber.

**[0013]** Reference will now be made in detail to the preferred embodiments, examples of which are illustrated in the accompanying drawings. Elements of the same design and function that appear in different drawings are identified by the same reference signs.

Figure 1 schematically shows a fuel supply system according to an embodiment,

Figure 2 schematically shows a fuel supply system according to a further embodiment.

**[0014]** Figure 1 schematically shows a fuel supply system 100. The fuel supply system 100 comprises a combustion engine 101. The combustion engine 101 is an internal combustion engine of a vehicle, in particular a

diesel gasoline combustion engine.

**[0015]** The system 100 further comprises a fuel reservoir 118 in which fuel 120 is stored. In particular, the fuel is diesel gasoline. The fuel reservoir 118 is hydraulically coupled via a pipe 117 to a multitude of fuel pumps 110, 111, 112, and 113. The fuel pumps are electrically driven by an electronic actuator. The electronic actuator is arranged to move a piston of the fuel pump in response to an electrical signal received by the fuel pump. The movement of the piston of the fuel pump forced by the electric actuator delivers fuel out of the reservoir 118 to the respective fuel injector. In particular the electronic actuator is an electromagnetic actuator. The electromagnetic actuator comprises a solenoid that interacts with the piston of the fuel pump. According to further embodiments, the electronic actuator is a piezoelectric actuator.

**[0016]** The fuel pumps each are hydraulically connected to one single fuel injector 106, 107, 108, and 109. The fuel injectors are arranged to inject fuel into combustion chambers 102, 103, 104, and 105 of the combustion engine 101.

**[0017]** The system 100 further comprises a low pressure pump 114 that is hydraulically arranged upstream the fuel pumps 110 to 113 and that provides fuel out of the fuel reservoir 118 to the fuel pumps 110 to 113. Furthermore, an on/off valve 119 is arranged at the pipe 117. An inlet valve 116 is arranged upstream of each fuel pump 110 to 113.

**[0018]** The system 100 further comprises an engine control unit 115 for controlling the system. The engine controlling unit 115 is electrically coupled to each of the fuel pumps 110 to 113 and to each of the fuel injectors 106 to 109. The engine control unit is further coupled to the on/off valve 119.

**[0019]** The engine control unit 115 is arranged to control the fuel pumps 110 to 113 to deliver fuel out of the fuel reservoir 118 to the fuel injectors 106 to 109. The engine control unit 115 is further arranged to control the fuel injectors between a closed state and an open state. In the closed state, the fuel injectors prevent fuel from being injected into the combustion chambers 102 to 105 of the combustion engine 101. In the open state, fuel provided by the fuel pumps 110 to 113 is injected into the combustion chambers via the fuel injectors 106 to 109.

**[0020]** The system 100 comprises as much fuel injectors as combustion chambers, for example four combustions chambers and four fuel injectors. The system 100 comprises as much fuel pumps as fuel injectors, for example four fuel pumps and four fuel injectors. According to further embodiments, the system 100 comprises more than four fuel injectors, combustion chambers and fuel pumps respectively, such as six fuel injectors, combustion chambers and fuel pumps respectively. According to further embodiments, the system 100 comprises less than four fuel injectors, combustion chambers and fuel pumps respectively, such as two fuel injectors, combustion chambers and fuel pumps respectively.

**[0021]** One fuel pump 110 delivers fuel to exactly one fuel injector. Downstream the fuel pumps, the fuel injectors 106 to 109 are hydraulically independent from each other. Upstream of each fuel pump, the inlet valve 116 is arranged. There are as many inlet valves 116 as fuel pumps 110 to 113. The inlet valve 116 is a one-way valve and prevents fuel from returning in the direction to the fuel reservoir 118.

**[0022]** During operation, the engine control unit 115 controls the valve 119 to open. Fuel is delivered out of the fuel reservoir 118 to the fuel pumps 110 to 113 by the low pressure pump 114 via the valve 119, the pipe 117, and the respective valves 116.

**[0023]** The engine control unit 115 controls the fuel pump 110 to suck in fuel only when the respective fuel injector 106 is in its closed state. After sucking in fuel into a pump chamber of the fuel pump 110, the fuel is provided under pressure in the pump chamber for being injected into the combustion chamber 102. The pump 110 does not eject the fuel out of the pump chamber as long as the fuel injector 106 is in its closed state.

**[0024]** When the engine control unit 115 controls the fuel injector 106 to open, the fuel is ejected under pressure out of the pump chamber and injected into the combustion chamber 102 via the fuel injector 106. Afterwards, the engine control unit 115 sets the fuel injector 106 again in its closed state and controls the pump 110 to suck in fuel.

**[0025]** There is only one sucking in and only one ejecting of fuel out of the pump 110 per one injection of fuel into the combustion chamber 102 via the fuel injector 106. Per one opening of the fuel injector 106 there is one ejecting of the fuel out of the pump chamber of the pump 110.

**[0026]** The functionality of the combination of the fuel pump 110, the fuel injector 106 and the combustion chamber 102 is transferable to the further combinations of the respective fuel pumps with the respective fuel injectors and combustion chambers, for example the combination of fuel pump 111, the fuel injector 107 and the combustion chamber 103.

**[0027]** Since each fuel pump 110 to 113 provides fuel to only one fuel injector 106 to 109 respectively, the fuel injectors 106 to 109 are hydraulically independent from each other downstream the fuel pumps 110 to 113. Therefore, no pressure waves are generated that impact other fuel injectors. Furthermore, since the fuel pumps each comprise an electromagnetic or piezoelectric actuator, they are cost-effective. Each fuel pump 110 to 113 is arranged to provide the fuel with a pressure of about 50 to 200 bar. Furthermore, due to the coupling of one fuel pump to one single fuel injector, there is no need for a common high-pressure rail that is coupled to a multitude of fuel injectors.

**[0028]** Figure 2 schematically shows the system 100 of Figure 1 according to a further embodiment. In contrast to the embodiment of Figure 1, according to the embodiment of Figure 2, the pumps 110 to 113 are hydraulically

coupled to the respective fuel injectors 106 to 109 via respective fuel pipes 121.

**[0029]** The system 100 according to the exemplary embodiments of Figure 1 and Figure 2 allows having the fuel pressure on demand and not only when the combustion engine 101 is running. Therefore, engine cranking is reliable because fuel pressure is readily available to allow proper storing conditions without turning the engine. This operation condition also supports a reliable stop/start function of the engine. The common high-pressure fuel rail is no longer required and the system 100 has a reduced number of components compared to conventional fuel supply systems. No fuel return line from the fuel pump to the fuel reservoir 118 is required. Since each fuel pump is responsible to supply high-pressure fuel to exactly one fuel injector, there are no or less pressure pulsations transmitted between the fuel pumps 110 to 113 and the fuel injectors 106 to 109. There is no influence from one fuel injector to the other fuel injectors. No pressure waves are transmitted between the fuel injectors due to any injection event.

**[0030]** The system 100 is reliable especially when there are multiple injections of fuel into one combustion chamber during one engine cycle. Since the fuel pumps 110 to 113 each are electrically driven, there is no longer a need for providing an overpressure of 30% of additional injector P-Max performance as in conventional systems with a common fuel high-pressure rail. By the fuel pumps according to the system 100, there is the fuel provided at the pressure needed without a redundant additional pressure for balancing pressure pulsations. If the system 100 includes the ballistic operating condition function, the complete flow range could be obtained with one pressure value only.

## Claims

1. Fuel supply system for a combustion engine (101), comprising:

   - a multitude of fuel injectors (106, 107, 108, 109) for providing fuel to the combustion engine (101),
   - a multitude of fuel pumps (110, 111, 112, 113), each fuel pump of the multitude of fuel pumps (110, 111, 112, 113) being hydraulically coupled with one fuel injector (106, 107, 108, 109) for providing fuel to the respective fuel injector (106, 107, 108, 109), wherein the respective fuel pumps (110, 111, 112, 113) each comprise an electromagnetic or piezoelectric actuator for driving the respective fuel pump (110, 111, 112, 113).

2. System according to claim 1, wherein the fuel pumps (110, 111, 112, 113) each are hydraulically directly coupled to the respective fuel injector (110, 111, 112, 113).

3. System according to claim 1, wherein the fuel pumps (110, 111, 112, 113) each are hydraulically coupled to the respective fuel injector (110, 111, 112, 113) via a fuel pipe (121).

4. System according to one of claims 1 to 3, comprising a low pressure pump (114) for delivering fuel out of a fuel reservoir (118) to the multitude of fuel pumps (110, 111, 112, 113) being arranged upstream of the multitude of fuel pumps (110, 111, 112, 113).

5. System according to one of claims 1 to 4, wherein each of the fuel pumps (110, 111, 112, 113) is electrically coupled with an engine control unit (115) for controlling the system and is controllable by the engine control unit (115) independent of the combustion engine (101).

6. System according to one of claims 1 to 5, with each fuel injector of the multitude of fuel injectors (106, 107, 108, 109) being attached to one combustion chamber of a multitude of combustion chambers (102, 103, 104, 105) of the combustion engine (101).

7. Method for delivering fuel to a fuel injector (106, 107, 108, 109) of a combustion engine (101), comprising:

   - controlling a pump (110) to suck in fuel into a pump chamber only when the fuel injector (106) that is hydraulically coupled to the pump (110) is in a closed state;
   - controlling the fuel injector (106) to move to an open state as to inject the fuel of the pump chamber into a combustion chamber (102) of the combustion engine (101), wherein the fuel out of the pump chamber is ejected out of the pump chamber only when the fuel is injected into a combustion chamber (102) via the fuel injector (106).

8. Method according to claim 7, wherein one sucking in and one ejecting is performed per one injection into the combustion chamber (102, 103, 104, 105).

FIG 1

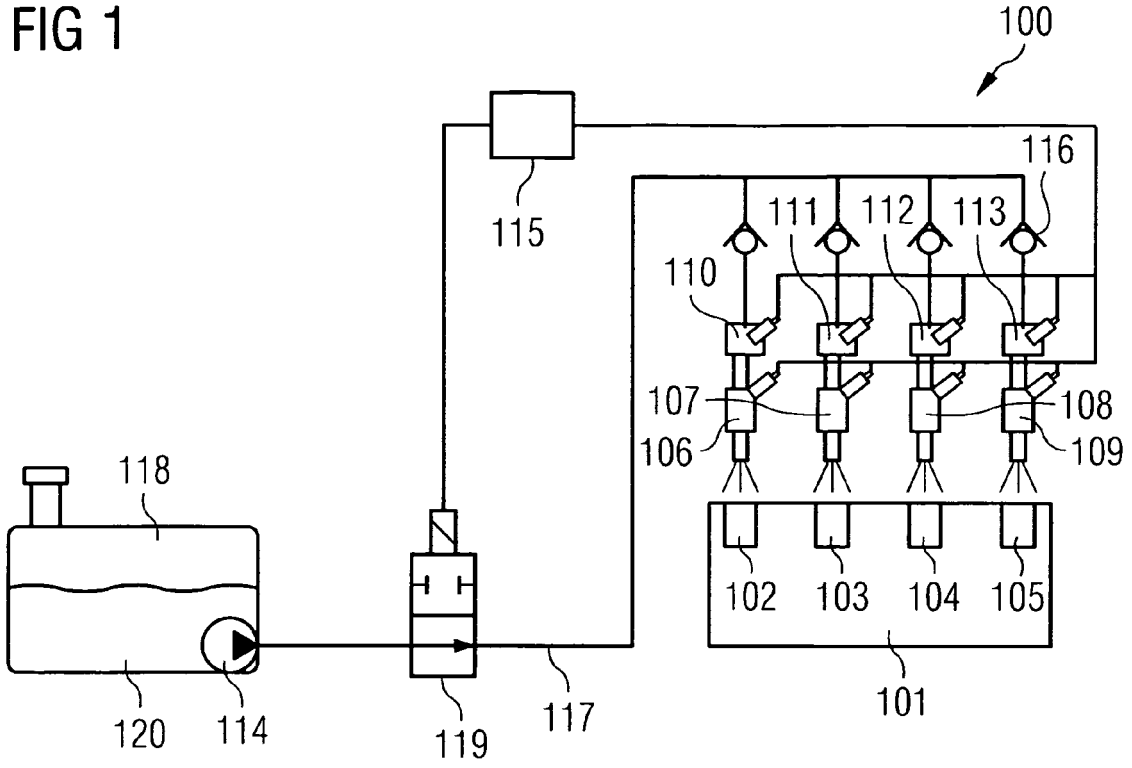
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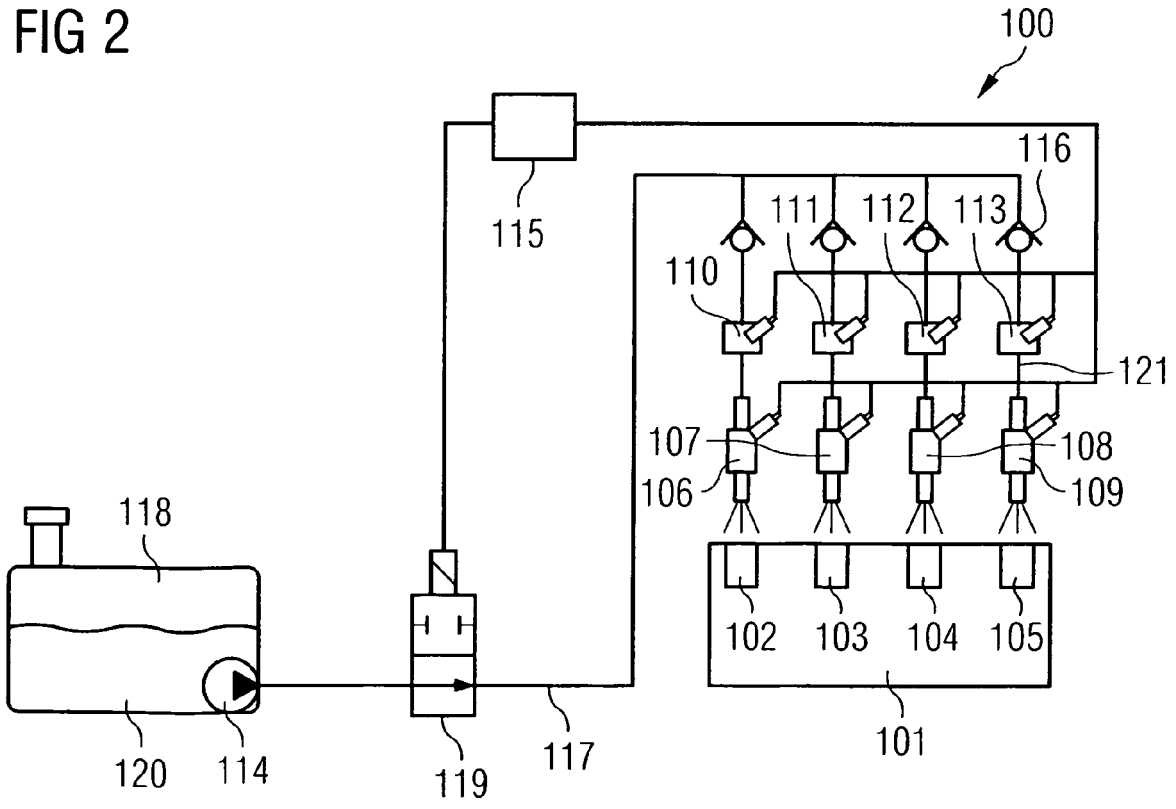
FIG 2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# EUROPEAN SEARCH REPORT

Application Number
EP 11 15 7020

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
|---|---|---|---|
| X<br>Y | DE 14 76 224 A1 (BOSCH GMBH ROBERT)<br>29 April 1971 (1971-04-29)<br>* page 5, line 23 - page 6, line 20; figures 1-5 * | 1,2,4,<br>6-8<br>3,5 | INV.<br>F02M57/02 |
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| X<br>Y<br>A | US 4 821 726 A (TAMURA HIROSHI [JP] ET AL)<br>18 April 1989 (1989-04-18)<br>* column 1, lines 13-26 *<br>* column 6, line 46 - column 7; figure 8 * | 7,8<br>5<br>1,2 | |
| X | US 2004/061478 A1 (FRENCH MICHAEL J [US] ET AL) 1 April 2004 (2004-04-01)<br>* paragraphs [0019] - [0035]; figures 1-3 * | 1,2,4-8 | |
| X<br>A | EP 0 055 116 A2 (FORD MOTOR CO [GB]; FORD WERKE AG [DE]; FORD FRANCE [FR])<br>30 June 1982 (1982-06-30)<br>* page 4, line 6 - page 5, line 26; figure 1 *<br>* page 6, line 19 - page 7, line 6; figure 2 *<br>* page 7, lines 18-24; figure 3 * | 1-3,5-8<br>4 | TECHNICAL FIELDS SEARCHED (IPC)<br>F02M |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 26 May 2011 | Kolland, Ulrich |

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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Application Number
EP 11 15 7020

## CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

## LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☒ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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## LACK OF UNITY OF INVENTION
## SHEET B

Application Number
EP 11 15 7020

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-6

Fuel supply system comprising
- a multitude of fuel injectors
- a multitude of fuel pumps driven by an electromagnetic or piezoelectric actuator
- each fuel pump being hydraulically coupled with one fuel injector

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2. claims: 7, 8

Method for delivering fuel to a fuel injector that is hydraulically coupled to the pump, by
- controlling a pump to suck in fuel into a pump chamber only when the fuel injector is in a closed state;
- controlling the fuel injector to open whereby the fuel out of the pump chamber is ejected out of the pump chamber only when the fuel is injected into a combustion chamber via the fuel injector.

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## ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 11 15 7020

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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26-05-2011

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
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| DE 1476224 A1 | 29-04-1971 | NONE | |
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82