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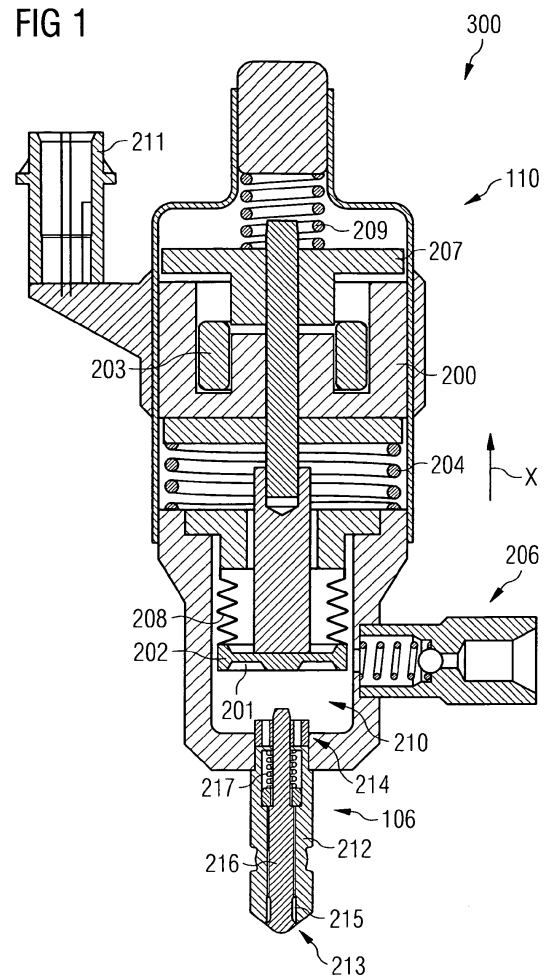
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(54) **Apparatus for delivering fuel and fuel supply system**

(57) An apparatus for delivering fuel to a combustion engine comprises a fuel pump (110) with an electromagnetic or piezoelectric actuator (203) for driving the piston (202) and a fuel injector (106) that is hydraulically and mechanically coupled to an outlet (210) of the fuel pump (110). The fuel injector (106) comprises an open state in which a flow-through of the fuel through the fuel injector (106) is enabled and a closed state in which the flow-through of the fuel through the fuel injector (106) is prevented, wherein the fuel injector is designed to be shifted from the closed state to the open state due to the pressure affected by the pressurised fuel of the fuel pump (110).



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## Description

**[0001]** The invention relates to an apparatus for delivering fuel to a combustion engine. Furthermore, the invention relates to a fuel supply system that comprises a multitude of such apparatuses.

**[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 to 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 an apparatus for delivering fuel to a combustion engine that works reliably and is cost-effective. Furthermore, it is desirable to create a fuel supply system that works reliably and is cost-effective.

**[0006]** According to an embodiment of the invention, an apparatus for delivering fuel to a combustion engine comprises a fuel pump. The apparatus further comprises a fuel injector that is hydraulically and mechanically coupled to an outlet of the fuel pump. The fuel pump comprises a pump housing with a pump chamber and a piston. The piston is arranged in the fuel pump such that it is axially movable in the pump chamber in order to provide a pressurization of the fuel within the pump chamber. The fuel pump further comprises an electromagnetic or piezoelectric actuator for driving the piston. The fuel injector comprises an open state in which a flow-through of the fuel through the fuel injector is enabled. The fuel injector further comprises a closed state in which the flow-through of the fuel through the fuel injector is prevented. The fuel injector is designed to be shifted from the closed state to the open state due to the pressure affected by the pressurized fuel of the fuel pump.

**[0007]** The fuel pump is arranged to deliver fuel out of a fuel reservoir to exactly one fuel injector. Since the fuel pump is electrically driven, it is cost-effective. The fuel

pump is arranged to be operated independent of the combustion engine since it is electrically driven and not driven by the camshaft of the combustion engine. The fuel pump is arranged to provide the fuel with a pressure of about 50 to 200 bar.

**[0008]** The fuel injector is arranged to shift from the closed state to the open state only due to the force affected by the pressurized fuel of the fuel pump. The fuel injector comprises an outward opening design. The fuel injector comprises no separate electrical actuator and, therefore, no additional electrical signal to correctly open the fuel injector is necessary.

**[0009]** According to further aspects, the electromagnetic or piezoelectric actuator is arranged to drive the piston in a first direction in order to provide the pressurization of the fuel and the fuel pump comprises a spring coupled to the piston for driving the piston in a second direction opposite the first direction to suck in the fuel into the pump chamber. The spring is arranged to apply a force to the piston that is as strong as needed to suck in the fuel into the pump chamber. The actuator is designed to apply a force that is strong enough to overcome the force of the spring and to pressurize the fuel with the pressure needed.

**[0010]** According to further aspects, the apparatus further comprises a magnet that is coupled with the pump housing for driving the piston in the second direction. For example, the magnet is a permanent magnet. The magnet supports the spring in moving the piston in the second direction.

**[0011]** According to further aspects, the fuel injector comprises an injector body including a central longitudinal axis. The injector body comprises a cavity with a fuel inlet portion and a fuel outlet portion.

**[0012]** The fuel injector further comprises an injector needle axially movable in the cavity. The injector needle is designed to prevent a fuel flow through the fuel outlet portion in the closed state and releasing the fuel flow through the fuel outlet portion in the open state. The fuel injector further comprises an injector spring which is coupled to the injector needle. The injector spring is arranged to force the injector needle to move in the closed state.

**[0013]** The fuel injector is controlled by the pressure of the fuel provided by the fuel pump. The fuel injector releases the fuel flow through the fuel outlet portion when the pressure of the fuel provided by the fuel pump is greater than the force of the injector spring.

**[0014]** According to a further embodiment of the invention, a fuel supply system for a combustion engine comprises a multitude of apparatuses as described above. The combustion engine comprises a multitude of combustion chambers. The system comprises as much apparatuses as the combustion engine comprises combustion chambers and each apparatus of the multitude of apparatuses is arranged to deliver fuel to one combustion chamber of the multitude of combustion chambers, respectively.

**[0015]** Reference will now be made in detail to embod-

iments of the invention, examples of which are illustrated in the accompanying drawings. Elements of the same design and function that appear in different figures are identified by the same reference signs.

Figure 1 schematically shows an apparatus according to an embodiment, and

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

**[0016]** Figure 1 schematically shows an apparatus 300 for delivering fuel to a combustion engine 101 (Figure 2). The apparatus 300 comprises a fuel pump 110 and a fuel injector 106.

**[0017]** The fuel pump 110 comprises a pump housing 200. The pump housing 200 surrounds a pump chamber 201. A piston 202 is axially movably arranged in the pump chamber 201. The piston 202 is coupled to an actuator 203. The piston is further coupled to a spring 204. The pump housing 200 has a spring rest and the piston 202 comprises a spring rest. The spring 204 is arranged between the two spring rests. In particular, the piston 202 is coupled to an armature 207. The armature 207 is arranged to interact with the actuator 203. A bellow 208 surrounds the piston as to separate the piston 202 from the magnetic circuit and, accordingly, the actuator 203 to protect the magnetic circuit from the fuel. The pump 110 further comprises an inlet valve 206 through which fuel is sucked into the pump chamber 201 during operation of the fuel pump. The fuel is ejected out of the pump chamber 201 through an outlet 210. The inlet valve 206 and the outlet 210 are hydraulically coupled with the pump chamber 201. The fuel pump 110 further comprises a connector 211 for connecting the pump with an engine control unit 115 (Figure 2). In particular, the actuator 203 is electrically coupled to the engine control unit 115.

**[0018]** The fuel injector 106 comprises an injector body 212. The injector body 212 surrounds a cavity 213 with a fuel inlet portion 214 and a fuel outlet portion 215. The fuel injector 106 further comprises an injector needle 216 which is axially movable in the cavity 213. The fuel injector further comprises an injector spring 217 which is coupled to the injector needle 216 and the injector body 212. The injector spring 217 forces the injector needle to a closed state in which a fuel flow through the fuel outlet portion 215 is prevented. The injector needle 216 is movable out of the closed state against the force of the spring 217 in an open state in which the fuel flow through the fuel outlet portion 215 is released.

**[0019]** The fuel injector 106, in particular the injector body 212, is coupled to the fuel pump 110, in particular to the pump housing 200. The fuel injector 106 is directly coupled to the fuel pump 110. The injector body 212 is in contact with the pump housing 200. The fuel injector 106 is hydraulically coupled with the pump 110. The outlet 210 of the pump 110 is hydraulically coupled with the inlet portion 214 of the injector 106. Fuel is deliverable

out of the pump chamber 201 through the outlet 210 to the cavity 213.

**[0020]** The fuel pump 110 comprises a second spring 209 which is coupled to the piston, in particular to the armature 207. The second spring 209 is a calibration spring for calibrating the pressure that is provided by the pump 110. In further embodiments, the second spring 209 is arranged for calibrating the force applied to the piston when sucking in fuel into the pump chamber.

**[0021]** According to further embodiments, the pump 110 comprises a magnet that is coupled with the pump housing for driving the piston in the x-direction of Figure 1. The magnet in particular is a permanent magnet and supports the spring 204 in moving the piston in the x-direction. When the solenoid of the actuator 203 is energized, the magnet exerts a force in the opposite x-direction and supports the pressurization of the fuel. This allows to have a stronger spring 204 which acts against the movement in the opposite x-direction. This leads to a quicker sucking in of the fuel.

**[0022]** For delivering fuel to a combustion chamber 102 of the combustion engine 101 (Figure 2), the engine control unit 115 controls the pump 110, especially the actuator 203, to move the piston axially in the pump chamber 201 in the opposite x-direction of Figure 1. This movement is against the force of the spring 204. Due to the movement of the piston, fuel that is in the pump chamber 201 is pressurized by the piston. The pressurized fuel exerts a force on the injector needle 216. Due to the force applied by the pressurized fuel, the injector needle is moved against the force of the spring 217 in the opposite x-direction. Therefore, the fuel injector 106 has an outward opening injector design.

**[0023]** When enough fuel is injected into the combustion chamber 102, the energizing of the actuator 203 is stopped. Therefore, no force in the opposite x-direction is applied to the piston 202 and the fuel in the pump chamber is no longer pressurized. At the same time, the spring 204 moves the piston 202 in the x-direction. Furthermore, the injector needle 216 moves in its closed state. The closing of the injector needle 216 is supported by the injector needle 216 after the fuel pressure in the cavity 213 and the pump chamber 201 is reduced. When the force of the spring 217 in the x-direction is higher than the fuel pressure force, the closing of the fuel injector 106 begins. Due to the low displacement and due to the fact that no high residual fuel pressure is to be overcome, the closing will be very fast.

**[0024]** During the movement of the piston 202 in the x-direction, fuel that may be provided by a low-pressure pump 114 (Figure 2) is suck into the pump chamber 201 via the inlet valve 206. The inlet valve 206 is a one-way valve which prevents fuel from flowing out of the pump chamber 201 into the regions of the fuel supply system upstream the pump 110.

**[0025]** The volume of the pump chamber 202 is higher than the maximum fuel quantity that the apparatus 300 is supposed to deliver during one cycle of the combustion

engine. More fuel may be stored in the pump chamber 202 than the apparatus 300 is supposed to deliver during one engine cycle.

**[0026]** The pump 110, which is electronically driven by the electromagnetic or piezoelectric actuator 203, is only driven by electric energy during the fuel outtake phase when pressurized fuel is injected into the combustion chamber of the combustion engine. The energy to suck in fuel into the pump chamber is coming from the spring 204. The energy stored in the spring 204 is the only energy to perform the fuel intake. No additional energy is needed to suck in the fuel into the pump chamber. Electronic energy is only required to eject fuel out of the pump chamber.

**[0027]** Therefore, energy is saved and the efficiency of the apparatus is improved.

**[0028]** In the pump 110, no pressure pulsations are generated during the ejecting phase of the fuel. Further, the pump 110 with the electric actuator 203 is arranged to provide pressurized fuel to the fuel injector independent from the combustion engine 101, especially independent from the revolutions per minute of the combustion engine. The pump 110 is not coupled to the camshaft of the combustion engine and therefore is arranged to provide pressurized fuel also when the camshaft is not turning.

**[0029]** During cranking of the combustion engine or by a stop/start function of the combustion engine, the pump 110 is arranged to pressurize the fuel without engine rotation since the electrical signal to control the pump 110 can be sent to the pump by the engine control unit 115 at any time regardless of the engine rotation speed. The pump 110 is also arranged to pressurize only the fuel required by the fuel injector 106 by the next injection and there is no large waste or inefficiency as per the conventional mechanically driven high-pressure pumps.

**[0030]** The fuel pump 110 and the fuel injector 106 are part of the same product. The fuel pump 110 comprises a single piston, is electrically driven and allows to be driven only during the injection event to generate the fuel pressure and to deliver the required fuel quantity to the combustion engine. The energy required to pressurize the fuel and to perform the injection event is significantly reduced in comparison with the current system design with a mechanically driven high pressure pump and a common rail high pressure rail. Furthermore, since the fuel injector opening is generated by the fuel pressure, it does not require a separate electrical signal to correctly open the fuel injector. The apparatus 300 comprising the fuel pump 110 and the fuel injector 106 needs one single electrical signal to control the pumping and to perform the fuel injection into the combustion chamber. The required fuel pressure values are achieved with less energy consumption with respect to the current systems that comprise a high-pressure pump driven by the camshaft of the combustion engine and that comprise a single high-pressure rail to which all of the fuel injectors are connected.

**[0031]** Figure 2 schematically shows a fuel supply system 100. The fuel supply system 100 comprises the combustion engine 101. The combustion engine 101 is an internal combustion engine of a vehicle, in particular a diesel gasoline combustion engine.

**[0032]** 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 apparatuses 300 with respective fuel pumps 110, 111, 112, and 113 and respective fuel injectors 106, 107, 108, and 109 as explained with respect to Figure 1. The fuel pumps each are electrically driven by the electronic actuator 203. The electronic actuator is arranged to move the piston 202 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 the solenoid that interacts with the piston 202 of the fuel pump. According to further embodiments, the electronic actuator is a piezoelectric actuator.

**[0033]** 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, respectively.

**[0034]** 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.

**[0035]** The system 100 further comprises the 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. 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.

**[0036]** The system 100 comprises as much apparatuses 300 as combustion chambers, for example four combustions chambers and four apparatuses. 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 apparatuses 300 as well as combustion chambers and fuel pumps respectively, such as six apparatuses and combustion chambers respectively. According to further embodiments, the system 100 comprises less than four apparatuses 300, such as two apparatuses and combustion chambers respectively.

**[0037]** One fuel pump 110 delivers fuel to exactly one fuel injector 106. Downstream the fuel pumps, the fuel injectors 106 to 109 are hydraulically independent from each other. Upstream of each fuel pump, the inlet valve 206 is arranged. There are as many inlet valves 206 as fuel pumps 110 to 113. The inlet valve 206 is a one-way valve and prevents fuel from returning in the direction to

the fuel reservoir 118.

**[0038]** During operation, fuel is delivered out of the fuel reservoir 118 to the fuel pumps 110 to 113 by the low pressure pump 114 via the pipe 117, and the respective valves 206.

**[0039]** After sucking in fuel into the pump chamber 201 of the fuel pump 110 by moving the piston 202 in the x-direction due to the force of the spring 204, the fuel is provided under low-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 actuator 203 is not energized by the motor control unit 115. The injector spring 217 is strong enough to hold the fuel injector in its closed state against the low pressure as long as the actuator 203 is not energized.

**[0040]** When the engine control unit 115 controls the actuator to move in the opposite x-direction to eject the fuel out of the pump chamber, the respective fuel injector 106 opens and 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 stops the movement of the piston in the negative x-direction and therefore the fuel injector 106 moves again in its closed state and the pump 110 sucks in fuel.

**[0041]** 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 ejecting of the fuel out of the pump chamber of the pump 110 there is one opening of the fuel injector 106.

**[0042]** 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 and the fuel injector 107 which form a further apparatus 300 as well as the combustion chamber 103.

**[0043]** 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 apparatus 300 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.

**[0044]** The system 100 with the apparatus according to Figure 1 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 starting 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. No on/off digital valve in the pipe 117 between the low pressure pump 114 and the apparatuses 300. 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 apparatus to the other apparatuses. No pressure waves are transmitted between the fuel injectors due to any injection event.

**[0045]** 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.

## 30 Claims

1. Apparatus for delivering fuel to a combustion engine, comprising:

- a fuel pump (110),
- a fuel injector (106) that is hydraulically and mechanically coupled to an outlet (210) of the fuel pump (110), with
- the fuel pump (110) comprising a pump housing (200) with a pump chamber (201) and a piston (202), with the piston (202) being arranged in the fuel pump such that it is axially moveable in the pump chamber (201) in order to provide a pressurisation of the fuel within the pump chamber (201) and an electromagnetic or piezoelectric actuator (203) for driving the piston (202) and
- the fuel injector (106) comprising an open state in which a flow-through of the fuel through the fuel injector (106) is enabled and a closed state in which the flow-through of the fuel through the fuel injector (106) is prevented, wherein the fuel injector is designed to be shifted from the closed state to the open state due to the pressure affected by the pressurised fuel of the fuel pump (110).

2. Apparatus according to claim 1, wherein the actuator

(203) is arranged to drive the piston (202) in a first direction in order to provide the pressurisation of the fuel and the fuel pump comprises a spring (204) coupled to the piston (202) for driving the piston (202) in a second direction opposite to the first direction to suck in the fuel into the pump chamber (201). unit (115).

3. Apparatus according to claim 2, comprising a magnet that is coupled with the pump housing for driving the piston (202) in the second direction. 5 10
4. Apparatus according to one of claims 1 to 3, wherein the fuel injector (106) comprises
  - an injector body (212) including a central longitudinal axis (L), the injector body (212) comprising a cavity (213) with a fuel inlet portion (214) and a fuel outlet portion (215), 15
  - an injector needle (216) axially movable in the cavity (213), the injector needle (216) preventing a fuel flow through the fuel outlet portion (215) in the closed state and releasing the fuel flow through the fuel outlet portion (215) in the open state, and 20
  - an injector spring (217), with the injector spring being coupled to the injector needle (216), the injector spring (217) being arranged to force the injector needle (216) to move in the closed state. 25
5. Apparatus according to one of claims 1 to 4, with the fuel injector (106) being directly coupled to the fuel pump (110). 30
6. Apparatus according to one of claims 1 to 5, with the fuel pump being arranged to be operated independent of the combustion engine (101). 35
7. Fuel supply system for a combustion engine (101), with the combustion engine (101) comprising a multitude of combustion chambers (102, 103, 104, 105), comprising: 40
  - a multitude of apparatuses (300) according to any of claims 1 to 6, wherein the system comprises as much apparatuses as the combustion engine (101) comprises combustion chambers (102, 103, 104, 105) and wherein each apparatus of the multitude of apparatuses is arranged to deliver fluid to one combustion chamber (102) of the multitude of combustion chambers (102, 103, 104, 105) respectively. 45 50
8. Fuel supply system according to claim 7, further comprising an engine control unit (115) for controlling the multitude of apparatuses (300), with each apparatus (300) being arranged to pressurize the fuel and inject the fuel one time in response to one single common control signal from the engine control 55

FIG 1

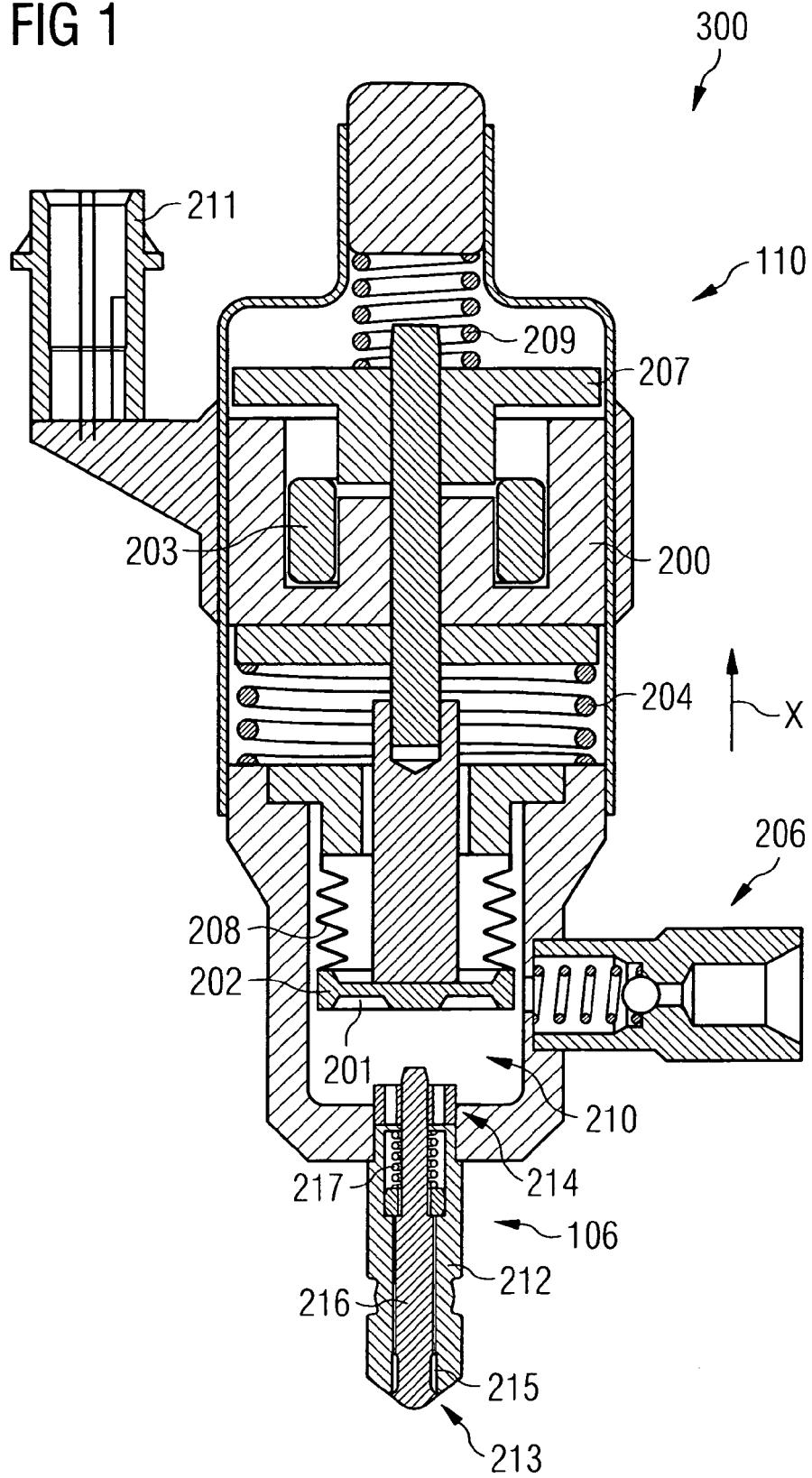
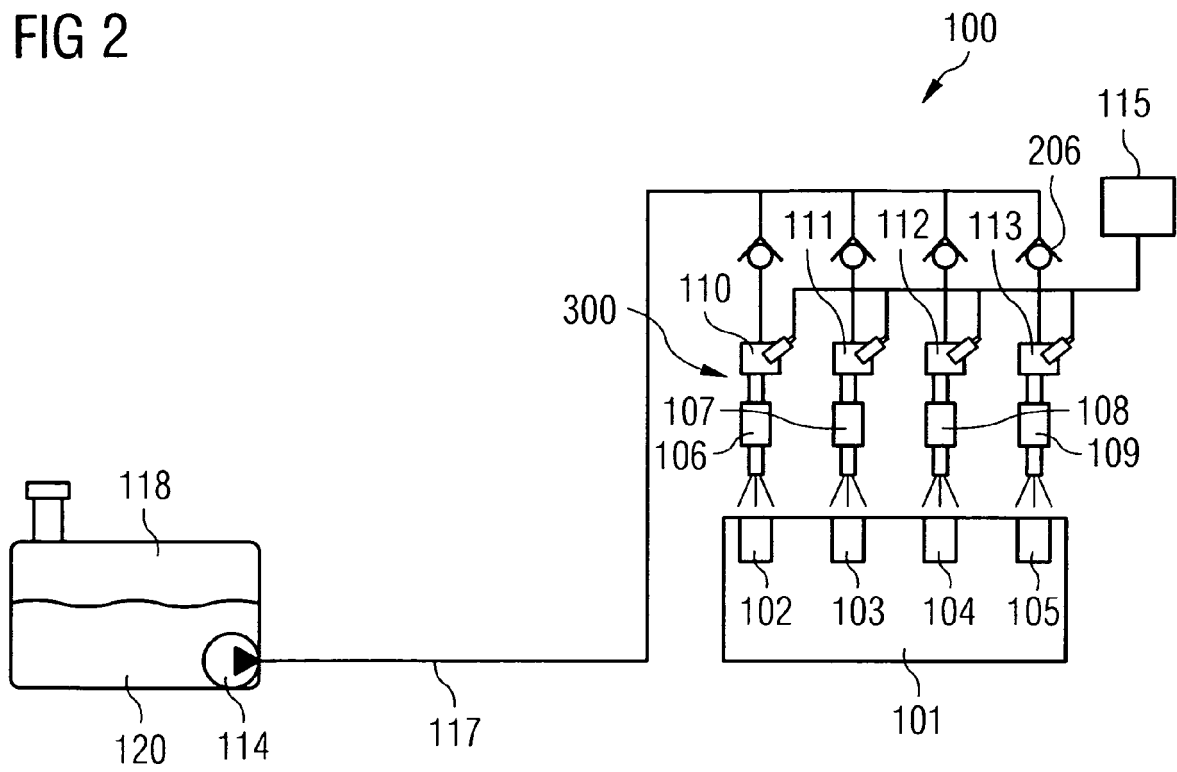


FIG 2





## EUROPEAN SEARCH REPORT

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 26 May 2011	Examiner Etschmann, Georg
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**ANNEX TO THE EUROPEAN SEARCH REPORT  
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