



- (51) **International Patent Classification:**
F02M 63/00 (2006.01) *F02M 61/20* (2006.01)
F02M 55/00 (2006.01)
- (21) **International Application Number:**
PCT/EP2013/002861
- (22) **International Filing Date:**
24 September 2013 (24.09.2013)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
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tion, Volvo Corporate Intellectual Property, Dept.B-
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- (81) **Designated States** (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM,
TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM,
ZW.

- (84) **Designated States** (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

- (54) **Title:** A FUEL INJECTION SYSTEM FOR AN INTERNAL COMBUSTION ENGINE AND A METHOD OF CON-
TROLLING FUEL INJECTION INTO AN INTERNAL COMBUSTION ENGINE

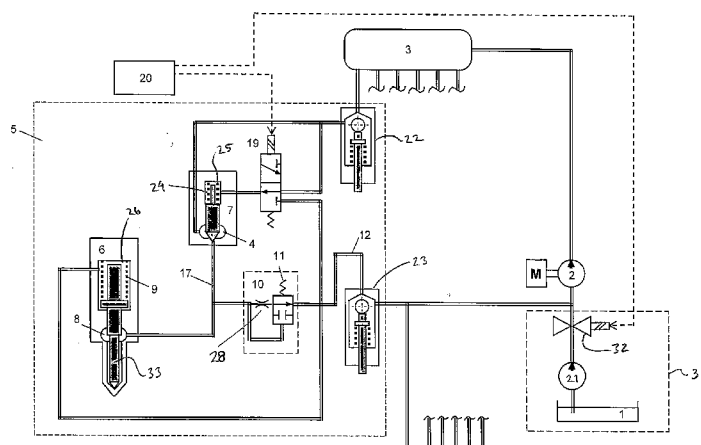


Fig. 1

- (57) **Abstract:** The invention relates to a fuel injection system for an internal combustion engine. The system comprises a nozzle (6) for injecting fuel into a combustion chamber of the engine. The nozzle (6) comprises a fuel chamber (8). The system comprises a line (17) connected to the fuel chamber for distributing fuel to the fuel chamber for an injection, a return line (12) connected to the fuel chamber (8) for distributing residual fuel from the fuel chamber (8) and a first valve (10) arranged for controlling fuel flow in the return line. The first valve (10) is a pressure relief valve configured to be controlled by a pressure upstream of the first valve (10) for opening between injection events and thereby relieving the pressure in the fuel chamber (8) of the nozzle (6).

**A fuel injection system for an internal combustion engine
and a method of controlling fuel injection into an internal
combustion engine**

5 TECHNICAL FIELD

The present invention relates to a fuel injection system for an internal combustion engine and especially a diesel engine. The present invention also relates to a method of controlling fuel injection into an internal combustion
10 engine and especially a diesel engine. The invention can for example be applied in heavy-duty vehicles, such as trucks, buses and construction equipment.

BACKGROUND

15 WO2007/046733 discloses a Common Rail (CR) injection system for low-viscosity fuels such as Dimethyl ether (DME). The system comprises one three-way solenoid-actuated valve and a two-way solenoid-actuated valve per injector and is configured for electronic control for relieving the pressure
20 from the nozzle between injection events to limit possible leakages, and to purge the system of vapour that may form in certain conditions. This is a relatively expensive and complex solution. Another disadvantage of this system is the relatively high electrical power consumption. This can in
25 certain conditions lead to overheating of the solenoid actuators and cause a malfunction.

SUMMARY

One object is to achieve a cost-efficient fuel injection
30 system for low-viscosity fuels, which is configured for an efficient relief of the pressure from the nozzle between consecutive injection events.

This object is achieved by a fuel injection system according to claim 1. Thus, it is achieved by a fuel injection system for an internal combustion engine, wherein the system comprises a nozzle for injecting fuel into a combustion
5 chamber of the engine, wherein the nozzle comprises a fuel chamber and wherein the system comprises a line connected to the fuel chamber for distributing fuel to the fuel chamber for an injection, a return line connected to the fuel chamber for distributing residual fuel from the fuel
10 chamber, and a first valve arranged for controlling fuel flow in the return line. The system is characterized in that the first valve is a pressure relief valve configured to be controlled by a pressure upstream of the pressure relief valve for opening between injection events and thereby
15 relieving the pressure in the fuel chamber of the nozzle.

Thus, the actuation of the first valve is automatically (or directly) controlled by the pressure upstream of the first valve. In other words, the pressure in the line upstream of
20 the first valve acts directly on the first valve for closing it. Thus, no active pressure relief control is required, such as electronic, separate hydraulic or mechanical control.

25 Preferably, the first valve is controlled by the pressure in the fuel chamber of the nozzle. More preferably, the first valve is controlled by the pressure in the return line between the fuel chamber and the first valve itself and just upstream of the first valve.

30

Further, it has the advantage that the actuation of the nozzle pressure relief effects a minimum disturbance of the fuel injection process.

A further advantage is that the electrical power consumption is reduced in relation to the two-valve injector solution according to prior art and therefore the durability of the 5 injectors is improved.

According to a preferred embodiment, the first valve comprises a valve member and a first seat, that the valve member is movably arranged in relation to the first seat 10 between a contact position relative to the first seat and a non-contact position relative to the first seat for preventing a fuel flow through the first valve when the valve member is in the contact position and allowing a fuel flow through the first valve when the valve member is in the 15 non-contact position. Such a design of the first valve creates conditions for achieving the pressure relief function in a robust and cost-efficient way.

According to a further development of the last-mentioned 20 embodiment, the first valve comprises a second seat on an opposite side of the valve member in relation to the first seat, that the valve member and/or the second seat is configured so that a fuel flow is allowed through the first valve when the valve member is in a contact position 25 relative to the second seat. Preferably, the valve member and/or the second seat is configured so that a certain, relatively small fuel flow is allowed through the first valve when the valve member is in a contact position relative to the second seat. Such a design of the first 30 valve creates conditions for achieving the pressure relief function in a simple way. For example, contact surfaces of the valve member and/or the second seat are configured in such a manner in relation to each other that partly there is

a space therebetween for a communication between the fuel chamber of the nozzle and a part of the return line downstream the first valve when the valve member is in a contact position relative to the second seat.

5

According to a further development of the last-mentioned embodiment, the second seat comprises a recess for allowing a fuel flow past the valve member when the valve member is in a contact position relative to the second seat. Such a
10 design of the first valve creates conditions for achieving the pressure relief function in a cost-efficient way. The recess may be achieved via a cut-out in the surface of the second seat. Further, the recess may extend transversely with regard to a movement direction of the valve member.
15 Further, the recess may extend over a limited angular section, especially significantly less than 180 degrees. For example, the recess may be elongated, for example in the form of a valley. The surface of the valve member facing the recess may be plane for achieving the gap therebetween.

20

According to a further development of one of the last-mentioned embodiments, the first valve is configured for allowing a substantially smaller fuel flow through the first valve when the valve member is in the contact position
25 relative to the second seat than a fuel flow to the fuel chamber of the nozzle for an injection. The magnitude of the fuel flow to the fuel chamber of the nozzle for an injection is governed by the system configuration upstream of the fuel chamber of the nozzle. In the case of a system of the common
30 rail type, the magnitude of the fuel flow to the fuel chamber of the nozzle for an injection is governed by the configuration and functioning of a valve positioned between the common rail and the fuel chamber of the nozzle.

Especially, the first valve is configured to keep the flow area between the first seat and the valve member relatively small even in the fully open state of the first valve.
5 Still, fuel is able to escape the fuel chamber between the first seat and the valve member and further out via the return line.

A further object is to achieve a method of controlling fuel
10 injection into an internal combustion engine for low-viscosity fuels, which creates conditions for an efficient relief of the pressure from the injection nozzle between consecutive injection events in an efficient manner.

15 This object is achieved by a method according to claim 23. More specifically, it is achieved by the steps of
- closing a first valve in a return line connected to a fuel chamber of a fuel injection nozzle before an injection of fuel is commenced,
20 - commencing injection of fuel via the nozzle, and
- reducing the closing force on the first valve shortly after the injection is commenced and well before the injection needs to be terminated.

25 According to a preferred embodiment, the method comprises the step of reducing the closing force on the first valve shortly after the injection is commenced and well before the injection needs to be terminated to a level where a resilient means is able to close the first valve in the
30 absence of the pressure differential between the fuel chamber and the return line.

According to a preferred embodiment, the closing of the first valve in the return line is performed via an electrical actuator.

Further embodiments and advantages thereof will be apparent
5 from the detailed description and associated drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the appended drawings, below follows a more detailed description of embodiments of the invention
10 cited as examples.

In the drawings:

Fig. 1 is a schematic view of a fuel injection system according to a preferred embodiment,

15

Fig. 2 is a detailed cross sectional view of a fragment of injector and nozzle in figure 1,

Fig. 3 is a detailed cross sectional view of a pressure
20 relief valve in the injector according to figure 2, and

Fig. 4 is an alternative embodiment example of the pressure relief valve in figure 3.

25 DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS OF THE INVENTION

Figure 1 shows a fuel injection system according to a first embodiment example. The fuel injection system comprises a nozzle 6 for injecting fuel into a combustion chamber of the engine, especially a diesel engine (not shown). The nozzle 6
30 comprises a fuel chamber 8. The nozzle 6 further comprises a resilient means 9 biasing it towards its closed position. The nozzle 6 comprises a needle 33 and a control chamber 26 opposite a point of the needle directed towards the engine

combustion chamber. The resilient means 9 is located in the control chamber 26. The side surface of the needle 33 is angled towards the point and acts against a needle seat. The fuel chamber 8 is located around a step in the needle 33, 5 wherein a fuel pressure can effect a movement of the needle against the force effected by the resilient means 9. Thus, the nozzle 6 can open when the pressure in the nozzle is built up sufficiently high to overcome the force of the resilient means 9 and the force of backpressure acting on 10 the nozzle needle from the control chamber 26 side.

The fuel injection system further comprises a line 17 connected to the fuel chamber 8 of the nozzle 6 for distributing fuel to the fuel chamber 8 for an injection. 15 The fuel injection system further comprises a high-pressure pump 2 and a common rail 3, wherein the high-pressure pump 2 is adapted for supplying fuel to the common rail 3. The fuel injection system further comprises an electronically controlled shut-off valve 7 that is installed in the line 17 20 between the common rail 3 and the nozzle 6 to control a hydraulic communication between the common rail 3 and the fuel chamber 8 of the nozzle 6.

The electronically controlled shut-off valve 7 has a 25 precision-matched stem and comprises an outlet chamber 4 and a control chamber 24, and is preferably biased towards its closed position by a resilient means 25. The fuel injection system further comprises an electronically operated pilot valve 19 adapted to control the position of the shut-off 30 valve 7. The electronically operated pilot valve 19 is in this embodiment formed by a three-way pilot valve. The control chamber 24 of the valve 7 can be connected by the three-way pilot valve 19 to either the common rail 3 or a

source of a relatively low pressure such as a return line 12, depending on commands from an Engine Management System (EMS) 20.

- 5 The fuel injection system further comprises a first differential hydraulic valve 22 positioned in the line 17 between the common rail 3 and the electronically controlled shut-off valve 7.
- 10 The fuel injection system further comprises a return line 12 connected to the fuel chamber 8 of the nozzle 6 for distributing residual fuel from the fuel chamber 8. The fuel injection system further comprises a first valve 10, or spill valve, arranged for controlling fuel flow in the
- 15 return line 12. The first valve 10 is a pressure relief valve configured to be controlled by a pressure upstream of the first valve 10 for opening between injection events and thereby relieving the pressure in the fuel chamber 8 of the nozzle 6. The first valve 10 comprises a resilient means 11
- 20 in the form of a return spring.

The first valve 10 is designed in such a way that the pressure in the fuel chamber 8 tends to keep the valve closed, wherein the return spring 11 of the first valve 10

25 tends to open the valve.

The fuel injection system further comprises a second differential hydraulic valve 23 positioned in the return line 12.

30

Each of the first and second differential hydraulic valves 22,23 is designed such that, once it is open, the area of the valve that is exposed to the pressure of the fuel is

sufficiently big to hold the valve open against the force of the valve's return spring when the pressure in the valve is anywhere from slightly below the feed pressure in the system or above that level. In case of engine being stopped and the
5 feed pressure falling below a predetermined level, the valve 22,23 closes and the area of the valve exposed to the pressure upstream of the valve becomes relatively small, such that a pressure above the feed pressure level is required to re-open the valve 22,23.

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The fuel injection system further comprises a fuel tank 1 and a feed pump 21 for pumping fuel from the tank 1 to the high-pressure pump 2. The differential hydraulic valve 23 is positioned between the first valve 10 and the tank 1.

15

The return line 12 takes any fuel leaked from the injector 5 back to the fuel tank 1. A pressure regulator (not shown) may be installed in the return line to control the fuel pressure there to a desired level.

20

Fig. 2 shows a detailed cross sectional view of the nozzle 6 in figure 1. The arrangement of the first valve 10 in connection with the fuel chamber 8 of the nozzle 6 is also shown. More specifically, the first valve 10 comprises a
25 valve member 14 and a first seat 15 (see figure 3). The valve member 14 is movably arranged in relation to the first seat 15 between a contact position relative to the first seat and a non-contact position relative to the first seat for preventing a fuel flow through the first valve when the
30 valve member 14 is in the contact position and allowing a fuel flow through the first valve when the valve member 14 is in the non-contact position. Further, the first valve 10

comprises a resilient means 11 biasing the first valve to an open state.

The first valve 10 is operationally connected to the fuel chamber 8 of the nozzle 6 via a line 27. More specifically, the valve member 14 is arranged so that a pressure in the control chamber 8 acts on a first side of the valve member 14 and the valve member 14 then tends to move towards the first seat 15 while the resilient means 11 is arranged to act on the valve member 14 in the opposite direction.

Fig. 3 is a detailed cross sectional view of the first valve 10 in the nozzle according to figure 2. The first valve 10 comprises a second seat 13 on an opposite side of the valve member 14 in relation to the first seat 15. The valve member 14 and/or the second seat 13 is configured so that a fuel flow is allowed through the first valve 10 when the valve member 14 is in a contact position relative to the second seat 13. More specifically, the second seat 13 comprises a recess 18 for allowing a fuel flow past the valve member 14 when the valve member is in a contact position relative to the second seat 13.

The valve seats 13, 15 and the valve member 14 are designed to keep the flow area between the first seat 15 and the valve member 14 relatively small even in the fully open state of the first valve 10. Still, fuel is able to escape the fuel chamber 8 between the first seat 15 and the valve member 14 and further out via the return line 12.

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The first valve 10 comprises a flow restriction means 28 for restricting the flow from the fuel chamber 8 via the return line 12. The flow restriction is achieved via a gap between

the valve member 14 and the first seat 15 and/or the second seat 13 when the first valve 10 is in an open state. More specifically, the flow restriction is achieved via a gap between the valve member 14 and the first seat 15 when the
5 valve member 14 is in contact with the second seat 13.

The resilient means 11 is configured for biasing the valve member 14 towards the second seat 13. Further, the resilient means 11 is pre-loaded to such an extent that the valve
10 member 14 is moved from its contact position relative to the second seat 13 when the pressure in fuel chamber upstream of the first valve 10 reaches a predetermined pressure level.

More specifically, the first valve 10 comprises a chamber
15 housing the valve member with a slightly larger extension than the valve member in a direction transverse to the movement direction of the valve member 14. Further, the chamber has an extension in the movement direction of the valve member defined by the first and second seat 15,13. The
20 height of the valve member 14 in the movement direction is somewhat smaller than the distance between the seats 13,15 for achieving said flow restriction in the valve open state. The recess 18 extends from an inlet 29 of the valve 10 in a lateral direction to the lateral gap between the interior
25 wall of the chamber and the valve member 14.

Fig. 4 shows a first valve 110 according to an alternative embodiment example of the first valve 10 in figure 3. The first valve 110 differs from the first valve 10 in figure 3
30 in that it comprises an electric actuator 116 arranged to close the first valve 110. The first valve 110 is designed in such a way that the pressure in the fuel chamber 8 of the

nozzle 6 tends to keep the valve closed, wherein the return spring 111 of the valve tends to open the valve.

Such an actuator 116 may be realised in the form of a solenoid actuator, or a piezo-electric actuator, or other type of electro-mechanical actuator. In case it is a solenoid actuator, it would generally comprise an electric stator with a coil and an armature that is attracted by the electromagnetic force to the stator upon energizing the coil. The valve member 114 would then represent the armature, or be a part of the armature built into its other part which would then have a design and composition advantageous for efficiently performing the function of a solenoid armature, for example as regards a better generation and distribution of the magnetic flux.

The following description of the function of the system is made with reference to figures 1 to 4. The system works in the following way:

20

The fuel from the fuel tank 1 (Fig.1) is fed into the high-pressure pump 2 by means of a feed pressure supply system 31. The feed pressure supply system 31 comprises the feed pump 21 and a valve 32 between the feed pump 21 and the high-pressure pump 2, which is electronically controlled by means of the EMS 20. The high-pressure pump 2 raises the pressure and supplies it to the common rail 3. The common rail 3 is connected to the outlet chamber 4 of the shut-off valve 7 of an injector 5. The shut-off valve 7 is able to hydraulically open and close a line 17 between the common rail 3 and the fuel chamber 8 of the nozzle 6, depending on the commands from the engine management system (EMS) 20.

In the initial position, the shut-off valve 7 is kept closed by the EMS 20, preventing the high pressure of the common rail 3 from reaching the fuel chamber 8 of the nozzle 6. The nozzle 6 is closed by its resilient means 9. The first valve 5 10 is open by the resilient means 11, thereby hydraulically connecting the nozzle fuel chamber 8 to the injector return line 12. In the open position of valve 10, the resilient means 11 keeps the valve member 14 at its second seat 13 which is designed to expose the valve member 14 to the 10 pressure in the fuel chamber 8 and to allow access of the fuel from the fuel chamber 8 to the first valve seat 15 and further to the downstream part of the return line 12.

When an injection is to take place, the EMS 20 opens the 15 shut-off valve 7, then the pressure in fuel chamber 8 of the nozzle 6 begins to rise due to the high-pressure fuel flow into this chamber from the common rail 3. The rate of fuel flow into the fuel chamber 8 via the opening shut-off valve 7 is far greater than the relief flow of fuel from fuel 20 chamber 8 out to the return line 12 via the first valve 10, due to the relatively small flow area as defined by the valve member 14 and the first 15 and second 13 seats. Thus, a pressure differential develops across the valve member 14, which overcomes the force of the resilient means 11 and 25 moves the valve member 14 towards its first seat 15 and further restricts the relief flow from the fuel chamber 8 to the return line 12. This creates even greater pressure differential and quickly closes the first valve 10. At the same time, the rising pressure in the fuel chamber 8 of the 30 nozzle 6 eventually overcomes the force of the resilient means 9 and opens the nozzle 6, initiating the injection. During the injection, the high pressure in the fuel chamber 8 keeps the first valve 10 closed, so that no leakage of the

high-pressure fuel out to the downstream part of the return line 12 is allowed.

When the injection needs to be terminated, the EMS 20 closes the shut-off valve 7 and thereby stops high-pressure fuel supply to the fuel chamber 8. With the nozzle 6 being still open at this time, the pressure in the fuel chamber 8 decays and eventually reaches a low enough level when the resilient means 9 can overcome the force of that pressure acting on the nozzle in the direction of its opening. During the following nozzle closing motion, the pressure in the fuel chamber 8 may continue to drop due to the fuel still escaping the fuel chamber 8 into the combustion chamber of the engine. At a certain lower pressure in the fuel chamber 8, the resilient means 11 becomes able to re-open the first valve 10. This establishes a hydraulic connection between the fuel chamber 8 and the downstream part of the return line 12, making the pressure in the fuel chamber 8 of the nozzle 6 to equal the relatively low pressure in the injection return line 12, and thereby reduces the risk of the fuel leaking past a worn nozzle into the engine combustion chamber when the nozzle is closed.

The present invention also acts to automatically prevent leakage of fuel into the engine past a worn nozzle in the event of the shut-off valve 7 losing its hydraulic tightness, which may happen in use due to for instance wear. This is because the first valve 10 remains open from the moment it opened at the end of one injection and until the start of another injection, when an opening shut-off valve 7 quickly raises pressure in the fuel chamber 8 and forces the closure of the first valve. A relatively small leakage from the common rail 3 into the fuel chamber 8 via a worn shut-

off valve 7 will not be able to create a pressure gradient across the valve member 14 that is sufficient to close it. By appropriately selecting the hydraulic flow area between the valve member 14 and the first seat 15 when valve 10 is 5 in the fully open position, an optimum performance of the first valve 10 can be achieved, such that it closes quickly enough in the beginning of an injection to not cause unwanted leakage increase from the injectors, but at the same time stays open and relieves the pressure in the fuel 10 chamber 8 in case of wear of the shut-off valve 7.

The invention according to the second example embodiment, see Fig.4, works in the same way, but the electrical actuator 116 of the first valve 110 closes this valve before 15 the shut-off valve 7 (Fig.1) begins to open, thereby further minimizing leakage. In other words, the method comprises the steps of actuating the electrical actuator 116 for closing the first valve 110 before an injection of fuel is commenced. Further, the electrical actuator is controlled to 20 reduce its closing force on the valve 110 shortly after the injection is commenced and well before the injection needs to be terminated, to a level where the spring 111 is able to close the first valve 110 in the absence of the pressure differential between the fuel chamber 8 and the return line 25 12. After the pressure in the fuel chamber 8 has risen, the control current is switched off from the electrical actuator 116, but the pressure in the fuel chamber 8 of the nozzle then keeps the valve 110 closed until an end of injection is initiated by the EMS 20 acting to close the shut-off valve 30 7. This allows to significantly shorten the duration of the electrical current supplied to the actuator 116, and therefore to reduce electrical power and heat-up of the actuator coil.

It is to be understood that the present invention is not limited to the embodiments described above and illustrated in the drawings; rather, the skilled person will recognize
5 that many changes and modifications may be made within the scope of the appended claims.

For example, the arrangement of the valves and the control thereof may differ from the one described above and shown in
10 the figures. For example, an injector may be arranged, which has a direct control of the shut-off valve by the EMS, ie no pilot valve.

CLAIMS

1. A fuel injection system for an internal combustion engine, wherein the system comprises a nozzle (6) for injecting fuel into a combustion chamber of the engine, wherein the nozzle (6) comprises a fuel chamber (8) and wherein the system comprises a line (17) connected to the fuel chamber for distributing fuel to the fuel chamber for an injection, a return line (12) connected to the fuel chamber (8) for distributing residual fuel from the fuel chamber (8) and a first valve (10) arranged for controlling fuel flow in the return line, **characterized in** that the first valve (10,110) is a pressure relief valve configured to be controlled by a pressure upstream of the first valve (10,110) for opening between injection events and thereby relieving the pressure in the fuel chamber (8) of the nozzle (6).

2. A fuel injection system according to claim 1, **characterized in** that the first valve (10,110) comprises a valve member (14,114) and a first seat (15,115), that the valve member is movably arranged in relation to the first seat between a contact position relative to the first seat and a non-contact position relative to the first seat for preventing a fuel flow through the first valve when the valve member (14,114) is in the contact position and allowing a fuel flow through the first valve when the valve member is in the non-contact position.

3. A fuel injection system according to claim 2, **characterized in** that the first valve (10,110) comprises a second seat (13,113) on an opposite side of the valve member (14,114) in relation to the first seat (15,115), that the valve member (14,114) and/or the second seat (13,113) is

configured so that a fuel flow is allowed through the first valve (10,110) when the valve member (14,114) is in a contact position relative to the second seat (13,113).

- 5 4. A fuel injection system according to claim 3, **characterized in** that the second seat (13,113) comprises a recess (18,118) for allowing a fuel flow past the valve member (14,114) when the valve member is in a contact position relative to the second seat (13,113).

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5. A fuel injection system according to claims 3 or 4, **characterized in** that the first valve (10,110) is configured for allowing a substantially smaller fuel flow through the first valve (10,110) when the valve member (14,114) is in
15 the contact position relative to the second seat (13,113) than a fuel flow to the fuel chamber of the nozzle required for an injection.

6. A fuel injection system according to any preceding claim,
20 **characterized in** that the first valve (10,110) comprises a flow restriction means (28) for restricting the flow from the fuel chamber (8) to a part of the return line (12) downstream of the first valve (10,110).

- 25 7. A fuel injection system according to claims 2 and 6, **characterized in** that the flow restriction is achieved via a gap between the valve member (14,114) and the first seat (15,115) and/or the second seat (13,113) when the first valve (10,110) is in an open state.

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8. A fuel injection system according to claims 2, 3 and 6, **characterized in** that the flow restriction is achieved via a gap between the valve member (14,114) and the first seat

(15,115) when the valve member (14,114) is in contact with the second seat (13,113).

9. A fuel injection system according to any preceding claim,
5 **characterized in** that the first valve (10,110) comprises a resilient means (11,111) biasing the first valve to an open state.

10. A fuel injection system according to claims 3 and 9,
10 **characterized in** that the resilient means (11,111) is configured for biasing the valve member (14,114) towards the second seat (13,113).

11. A fuel injection system according to claim 9 or 10,
15 **characterized in** that the resilient means (11,111) is preloaded to such an extent that the valve member (14,114) is moved from its contact position relative to the second seat (13,113) when the pressure in fuel chamber (8) upstream of the first valve (10,110) reaches a predetermined pressure
20 level.

12. A fuel injection system according to any preceding claim, **characterized in** that the system comprises a common rail (3) and a shut-off valve (7) connected operationally
25 between the common rail (3) and the nozzle (6).

13. A fuel injection system according to claim 12, **characterized in** that the system comprises an electrically operated pilot valve (19) adapted to control the position of
30 the shut-off valve (7).

14. A fuel injection system according to claim 12 or 13, **characterized in** that the shut-off valve (7) comprises an

outlet chamber (4) connected to the common rail (3), wherein said outlet chamber (4) can also be connected to the nozzle (6) depending on the position of the valve (7).

5 15. A fuel injection system according to any one of claims 12-14, **characterized in** that the shut-off valve (7) being designed such that, in its closed position, the valve disconnects the outlet chamber (4) from the nozzle (6).

10 16. A fuel injection system according to any preceding claim, **characterized in** that the nozzle (6) is provided with a resilient means (9) that biases the nozzle towards closing.

15 17. A fuel injection system according to claims 14 and 16, **characterized in** that the nozzle (6) is connected to the outlet chamber (4) of the shut-off valve (7) in such a way that pressure at the outlet chamber (4) of an open shut-off valve (7) tends to overcome the force of the resilient means
20 (9) and to open the nozzle (6).

18. A fuel injection system according to any preceding claim, **characterized in** that the system comprises a high-pressure pump (2) configured for supplying fuel under
25 pressure to the common rail (3).

19. A fuel injection system according to claim 18, **characterized in** that the system comprises a fuel feed pump (21) for supplying fuel from a fuel tank (1) to the high-
30 pressure pump (3).

20. A fuel injection system according to claim 12, **characterized in** that the system comprises an Engine

Management System (EMS) (20) for controlling the electrically operated pilot valve (19) and/or the shut-off valve (7).

5 21. A fuel injection system according to any of the above claims, **characterized in** that the first valve (110) comprises an electrical actuator (116), wherein the actuator (116) is designed in such a way that it can overcome the force of the resilient means (111) and close the first valve
10 (110) upon a command from the EMS (20).

22. A heavy-duty vehicle characterized in that it comprises a fuel injection system according to any one of the preceding claims.

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23. A method of controlling fuel injection into an internal combustion engine comprising the steps of
- closing a first valve (10,110) in a return line (12) connected to a fuel chamber (8) of a fuel injection
20 nozzle (6) before an injection of fuel is commenced,
- commencing injection of fuel via the nozzle (6), and
- reducing the closing force on the first valve (10,110) shortly after the injection is commenced and well before the injection needs to be terminated.

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24. A method of controlling fuel injection into an internal combustion engine according to claim 23, comprising the steps of reducing the closing force on the first valve (10,110) shortly after the injection is
30 commenced and well before the injection needs to be terminated to a level where a resilient means (11) is able to close the first valve (10) in the absence of the

pressure differential between the fuel chamber (8) and the return line (12).

25. A method of controlling fuel injection into an
5 internal combustion engine according to claim 23 or 24,
wherein the closing of the first valve (10,110) in the
return line (12) is performed via an electrical actuator
(116).

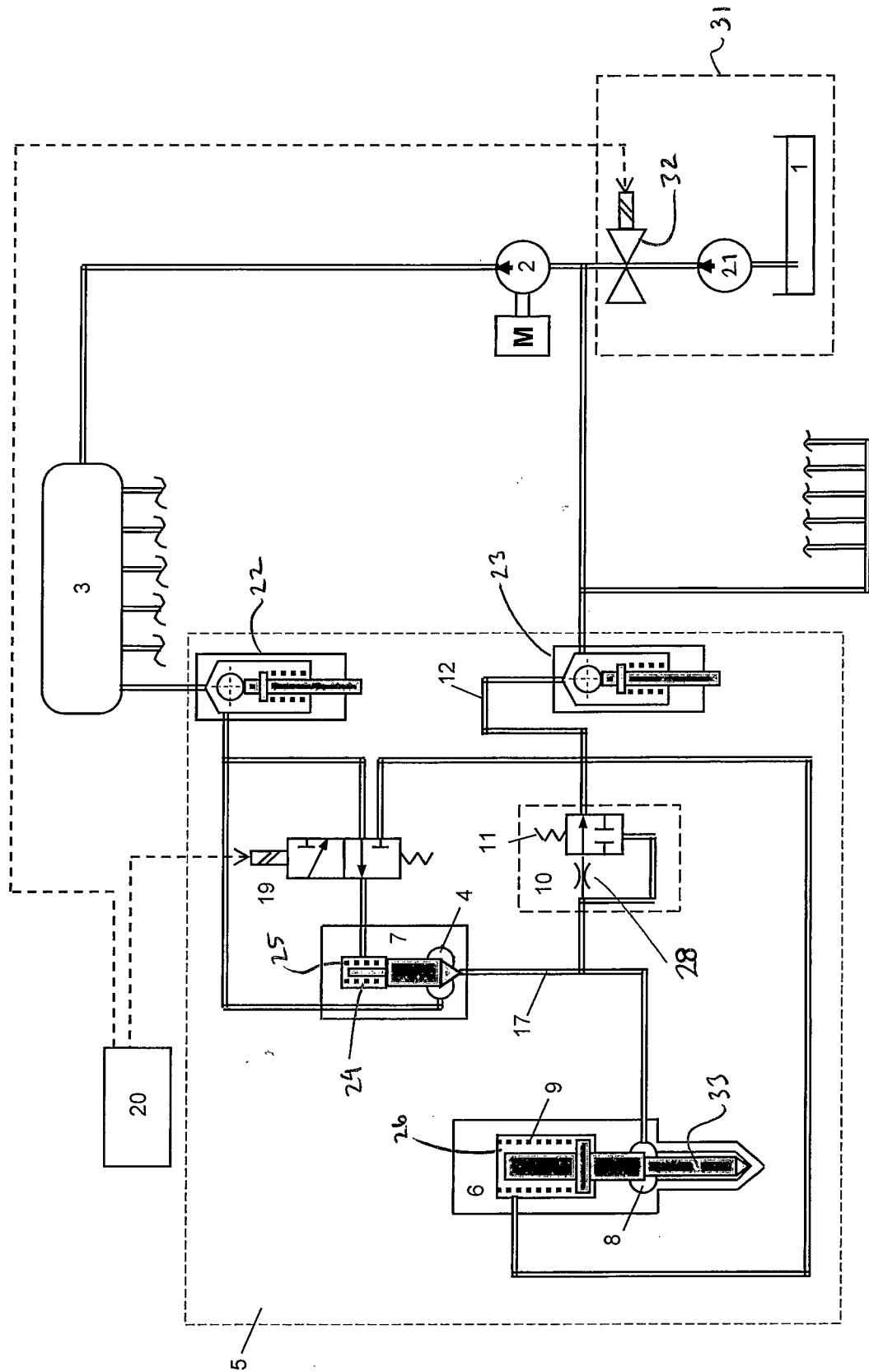


Fig.1

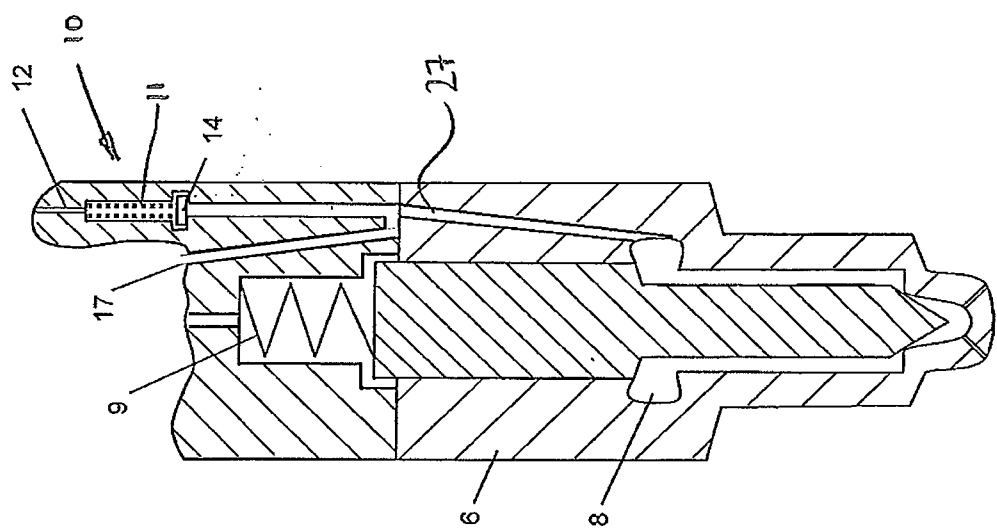


Fig. 2

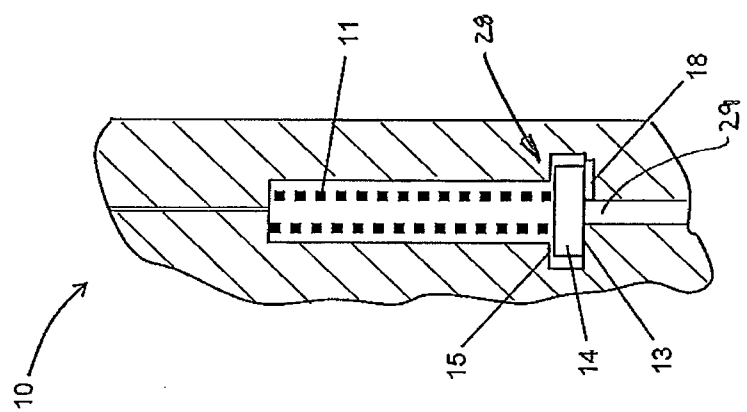


Fig. 3

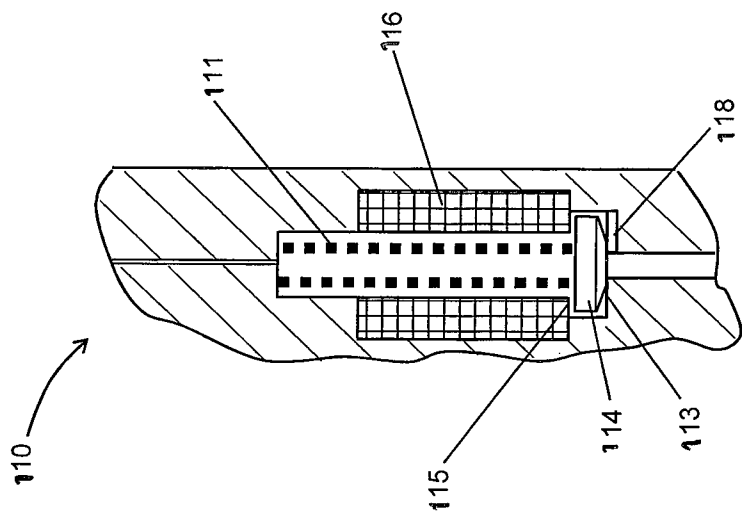


Fig.4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/002861

A. CLASSIFICATION OF SUBJECT MATTER

INV. F02M63/00 F02M55/00 F02M61/20
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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/114750 A1 (VOLVO LASTVAGNAR AB [SE]; YUDANOV SERGI [SE]) 11 October 2007 (2007-10-11) pages 6-7; figures -----	1,2,6,9, 12-23,25
X	WO 2007/046733 A1 (VOLVO LASTVAGNAR AB [SE]; YUDANOV SERGI [SE]) 26 April 2007 (2007-04-26) cited in the application page 9, paragraph 2. - page 11, paragraph 1.; figures -----	1,2,9, 12-23,25
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Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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"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

29 January 2014

Date of mailing of the international search report

10/02/2014

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INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2013/002861

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/081928 A1 (BURKE DAVID H [US] ET AL BURKE DAVID HOWARD [US] ET AL) 21 April 2005 (2005-04-21) paragraphs [0012] - [0015]; figures -----	3-5,7,8

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