(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 284 380 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
16.02.2011 Bulletin 2011/07

(21) Application number: **10172447.4**

(22) Date of filing: **11.08.2010**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK SM TR
Designated Extension States:
BA ME RS

(30) Priority: **12.08.2009 IT BO20090545**

(51) Int Cl.:
F02D 41/38 *(2006.01)* ***F02M 55/02*** *(2006.01)*
F02M 63/02 *(2006.01)*

(71) Applicant: **Magneti Marelli S.p.A.**
Corbetta (MI) (IT)

(72) Inventors:
- **Serra, Gabriele**
  40068 S. Lazzaro di Savena (IT)
- **De Cesare, Matteo**
  71017 Torremaggiore (IT)
- **Parotto, Marco**
  40138 Bologna (IT)

(74) Representative: **Jorio, Paolo et al**
STUDIO TORTA S.r.l.
Via Viotti, 9
10121 Torino (IT)

(54) **Method for controlling the common rail pressure of a direct injection engine**

(57) A method for controlling a direct injection system (1) of common-rail type of an internal combustion engine (2); the direct injection system (1) has: a fuel tank (10), a low pressure pump (8) which draws from the tank (10), and a high pressure pump (6) which receives the fuel from the low pressure pump (8) and feeds the pressurized fuel to a common rail (5) connected to a number of injectors (4); the control method includes the steps of: determining a desired pressure ($P_{railref}$) of the fuel inside the common rail (5); and regulating the delivery of the low pressure pump (8) towards the high pressure pump (6) to pursue the desired pressure ($P_{railref}$) of the fuel inside the common rail (5) and so as to obtain a corresponding regulation of the delivery of the high pressure pump (6) towards the common rail (5). The method involves determining closed loop contribution, open loop contribution (feedforward) and the use of nested control loops.

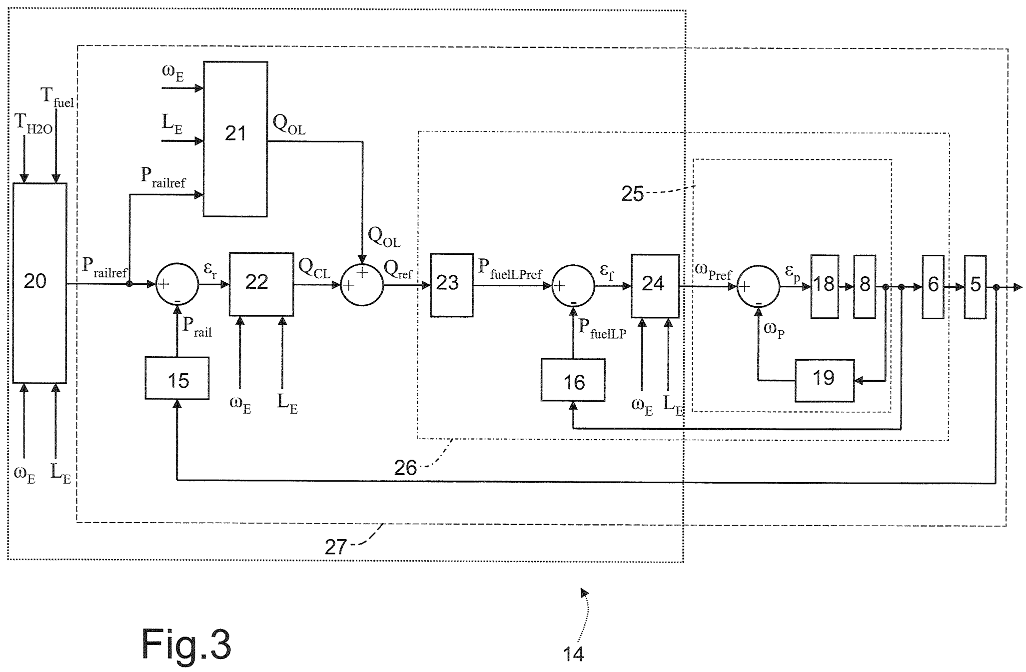

Fig.3

Printed by Jouve, 75001 PARIS (FR)

Description

TECHNICAL FIELD

[0001] The present invention relates to a method for controlling a direct injection system of the common-rail type.

PRIOR ART

[0002] In a direct injection system of the common-rail type, a high pressure pump receives a flow of fuel from a tank by means of a low pressure pump and feeds the fuel to a common rail, hydraulically connected to a plurality of injectors. The pressure of the fuel inside the common rail is to be constantly controlled according to the engine point either by varying the instantaneous delivery of the high pressure pump or by constantly feeding an excess of fuel to the common rail and discharging the excess fuel from the common rail itself by means of a regulating valve. The solution of regulating the instantaneous delivery of the high pressure pump is generally preferred, because it has a much better energy efficiency and does not result in fuel overheating.

[0003] In order to regulate the instantaneous delivery of the high pressure pump, a solution has been suggested, of the type disclosed in patent application EP0481964A1 or in patent US6116870A1, which describe the use of a variable delivery high pressure pump capable of feeding to the common rail only the amount of fuel needed to maintain the fuel pressure inside the common rail equal to the desired value; in particular, the high pressure pump is provided with an electromagnetic actuator capable of varying the delivery of the high pressure pump instant-by-instant, by varying the closing instant of an intake valve of the high pressure pump itself.

[0004] Alternatively, in order to regulate the instantaneous delivery of the high pressure pump, the insertion of a delivery regulating device upstream of the pumping chamber has been suggested, comprising a continuously variable-section bottleneck, which bottleneck is controlled according to the pressure required inside the common rail.

[0005] However, both the above-described solutions for regulating the instantaneous delivery of the high pressure pump are mechanically complex and therefore costly. Furthermore, the delivery regulating device comprising a variable section bottleneck has a small passage section in case of small deliveries, and such a small passage section determines a high local pressure loss (local load loss), which may compromise the correct operation of an intake valve which regulates the fuel intake into a pumping chamber of the high pressure pump.

[0006] For this reason, a solution of the type disclosed in patent application EP1612402A1 has been suggested, which relates to a high pressure pump comprising a number of pumping elements operated in reciprocating motion by means of corresponding intake and delivery strokes, and in which each pumping element is provided with a corresponding intake valve in communication with an intake duct fed by a low pressure pump. On the intake duct, an on-off valve is arranged which is controlled in a chopped manner for regulating the instantaneous delivery of fuel fed to the high pressure pump; in other words, the on-off valve is a valve of the open/closed type, which is controlled by modifying the ratio between the opening time and the closing time, so as to regulate the instantaneous delivery of fuel fed to the high pressure pump. Thereby, the on-off valve always has an effective, wide passage section, which does not determine an appreciable local pressure loss (local load loss).

[0007] However, the on-off valve is costly, because it should have very fast response times (i.e. opening/closing times), it should be free from "rebound" phenomena when opening and closing, and should ensure perfect sealing without leakages when in the closing position.

DESCRIPTION OF THE INVENTION

[0008] It is the object of the present invention to provide a method for controlling a direct injection system of the common-rail type, which control method is free from the above-described drawbacks, and in particular is easy and cost-effective to be implemented.

[0009] According to the present invention, a method for controlling a direct injection system of a common-rail type is provided as claimed in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The present invention will now be described with reference to the accompanying drawings, which illustrate a non-limitative embodiment thereof, in which:

- figure 1 is a diagrammatic view of an injection system of the common-rail type which implements the control method of the present invention;
- figure 2 is a diagrammatic view of an electrically actuated, low pressure pump of the injection system in figure 1;
- figure 3 is a block diagram of a control logic of the low pressure pump in figure 2; and
- figure 4 is a block diagram of a variant of the control logic in figure 3.

PREFERRED EMBODIMENTS OF THE INVENTION

[0011] In figure 1, numeral 1 indicates as a whole a common-rail type system for direct fuel injection into an internal combustion engine 2 provided with four cylinders 3. The injection system 1 comprises four injectors 4, each of which has a hydraulic needle actuation system (i.e. the needle actuation is hydraulically servo-assisted) and is adapted to directly inject the fuel into a respective cylinder 3 of engine 2 and to receive the pressurized fuel from a common rail 5.

[0012] System 1 comprises a high pressure pump 6 which feds fuel to the common rail 5 by means of a delivery duct 7 and is directly actuated by a driving shaft of engine 2 by means of a mechanical transmission with an actuation frequency being directly proportional to the rotation speed of the driving shaft. The high pressure pump 6 is fed in turn by a low pressure pump 8 of volumetric type by means of a duct 9 of the high pressure pump 6. The low pressure pump 8 is arranged inside a fuel tank 10, into which a recirculation duct 11 for the excess fuel of the injection system 1 leads, which duct receives the excess fuel from the injectors 4, from a mechanical pressure safety valve 12 which is hydraulically coupled to the common rail 5, and from a lubrication duct of the high pressure pump 6 (into which the fuel used to lubricate the high pressure pump 6 is discharged). The pressure safety valve 12 is calibrated to automatically open when the fuel pressure P_{rail} in the common rail 5 exceeds a safety value which ensures the tightness and safety of the injection system 1.

[0013] Each injector 4 is adapted to inject a variable amount of fuel into the corresponding cylinder 3 under the control of an electronic control unit 14. As previously mentioned, injectors 4 have a hydraulic needle actuation and are thus connected to the recirculation duct 11, which has a pressure slightly higher than ambient pressure, and leads upstream of the low pressure pump 8 directly into the tank 10. For its actuation, i.e. for injecting fuel, each injector 4 absorbs a certain amount of pressurized fuel, which is discharged into the recirculation duct 11.

[0014] According to a preferred embodiment, between the recirculation duct 11 and the tank 10 there is a recirculation valve 13, which is a one-way valve (i.e. only allows a flow of fuel into the tank 10), is entirely passive (i.e. free from controllable actuators), and is calibrated to open when the pressure difference at its ends is higher than a predetermined intervention threshold value. By virtue of the presence of the recirculation valve 13, the pressure of the fuel inside the recirculation duct 11 remains, in use, approximately equal to a predetermined value (typically between 1.3 and 1.8 bars) depending on the intervention threshold value of the recirculation valve 13 itself; thereby, the control of the injectors 4 is simpler, as the fuel pressure inside the recirculation duct 11 is constant (stable) and known (i.e. the fuel pressure difference at the ends of the injectors 4 is constant and known).

[0015] The electronic control unit 14 is connected to a pressure sensor 15, which detects the actual fuel pressure P_{rail} inside the common rail 5 and, according to the actual fuel pressure P_{rail} inside the common rail 5, feedback controls the delivery of the low pressure pump 8; thereby, the actual fuel pressure P_{rail} inside the common rail 5 is maintained equal to a desired pressure $P_{railref}$ which generally varies over time according to the engine point (i.e. according to the operating conditions of the internal combustion engine 2). Furthermore, the electronic control unit 14 is connected to a pressure sensor 16, which detects the actual pressure P_{fuelLP} of the fuel inside the duct 9 (and thus between the delivery of the low pressure pump 8 and the intake of the high pressure pump 6) and immediately upstream of the high pressure pump 6.

[0016] In other words, the electronic control unit 14 determines the desired pressure $P_{railref}$ of the fuel inside the common rail 5 according to the engine point, and thus regulates the delivery of the low pressure pump 8 towards the high pressure pump 6 to pursue the desired fuel pressure $P_{railref}$ inside the common rail 5 and so as to obtain a corresponding regulation of the delivery of the high pressure pump 6 towards the common rail 5. By regulating (varying) the delivery of the low pressure pump 8 towards the high pressure pump 6 (and thus by regulating the delivery of the high pressure pump 6 towards the common rail 5), the electronic control unit 14 pursues the desired fuel pressure $P_{railref}$ inside the common rail 5.

[0017] As shown in figure 2, the low pressure pump 8 is actuated by an electric motor 17, which is controlled by an electronic device comprising an electronic power converter 18, which is powered from a battery (not shown) of the vehicle. According to a preferred embodiment, the electric motor 17 is provided with a speed sensor 19, which measures the actual rotation speed ω_P of the electric motor 17 and thus of the low pressure pump 8. It is worth noting that the low pressure pump 8 is of the volumetric type, and therefore the delivery of the low pressure pump 8 towards the high pressure pump 6 is directly proportional to the actual rotation speed ω_P of the electric motor 17, and thus of the low pressure pump 8.

[0018] According to a preferred embodiment, the electronic power converter 18 is arranged close to tank 10 (i.e. close to the electric motor 17 which is integrated and forms a unit with the low pressure pump 8), and thus is physically separate from the electronic control unit 14; therefore, the electronic control unit 14 is connected to the electronic power converter 18 by means of a data line (e.g. the vehicle BUS working according to CAN (Car Area Network) protocol). Such a design choice avoids the transmission along the vehicle (the electronic control unit 14 is accommodated in the engine compartment, thus in frontal position, while the fuel tank 10 is arranged on the rear axle) of electric current of relatively high intensity (e.g. up to 15-20 A transient) and with a rather rapid frequency variation (up to several tens of Hertz), which would radiate a considerable amount of electromagnetic interferences throughout the vehicle. As a constructional variant, the electronic power converter 18 is completely integrated with the electric motor 17 and the low pressure pump 8, i.e. forms an indivisible unit with the electric motor 17 and the low pressure pump 8.

[0019] The control logic of the injection system 1 implemented in the electronic control unit 14 is illustrated below with reference to figure 3.

[0020] The electronic control unit 14 comprises a calculation block 20, which determines the desired pressure $P_{railref}$ of the fuel inside the common rail 5 according to the engine point, and in particular according to a rotation speed ω_E of the internal combustion engine 2, to a load L_E of the internal combustion engine 2, to a temperature T_{H2O} of a coolant of the internal combustion engine 2, and to a temperature of the fuel T_{fuel} inside the tank 10 (or, alternatively, in other points of the low pressure fuel circuit or of the high pressure fuel circuit). The calculation block 20 may implement an experimentally determined model of engine 2 and/or an experimentally determined map.

[0021] A desired delivery Q_{ref} of the high pressure pump 6 towards the common rail 5 is determined downstream of the calculation block 20, according to the desired pressure $P_{railref}$ of the fuel inside the common rail 5; as described below, the desired delivery Q_{ref} of the high pressure pump 6 towards the common rail 5 is used to control the low pressure pump 8. In particular, a regulator 21 determines an open loop contribution Q_{OL} according to the desired pressure $P_{railref}$ of the fuel inside the common rail 5, to the rotation speed ω_E of the internal combustion engine 2, and to the load L_E of the internal combustion engine 2. Moreover, a closed loop contribution Q_{CL} is determined according to a pressure error ε_r calculated by making the difference between the desired pressure $P_{railref}$ of the fuel inside the common rail 5 and the actual pressure P_{rail} of the fuel inside the common rail 5 (measured by pressure sensor 15); in particular, the closed loop contribution Q_{CL} is determined by a regulator 22 (typically of PID type), which takes into account the rotation speed ω_E of the internal combustion engine 2 and the load L_E of the internal combustion engine 2.

[0022] Downstream of the regulators 21 and 22, the closed loop contribution Q_{CL} is algebraically added (i.e. the sign being taken into account) to the open loop contribution Q_{OL} to obtain the desired delivery Q_{ref} of the high pressure pump 6 towards the common rail 5. The function of the closed loop contribution Q_{CL} is to pursue the desired pressure $P_{railref}$ of the fuel inside the common rail 5 by means of a classic feedback control; instead, the function of the open loop contribution Q_{OL} is to anticipate the future variation of the desired pressure $P_{railref}$ of the fuel inside the common rail 5 so as to increase the control response promptness.

[0023] A calculation block 23 determines a desired pressure $P_{fuelLPref}$ of the fuel (immediately) upstream of the high pressure pump 6 according to the desired delivery Q_{ref} of the high pressure pump 6 towards the common rail 5; as described below, the desired pressure $P_{fuelLPref}$ of the fuel upstream of the high pressure pump 6 is used to control the low pressure pump 8. In particular, a pressure error is calculated ε_f by making the difference between the desired pressure $P_{fuelLPref}$ of the fuel upstream of the high pressure pump 6 and the actual pressure P_{fuelLP} of the fuel upstream of the high pressure pump 6 (measured by the pressure sensor 16); the pressure error ε_f is processed by a regulator 24 (typically of PID type), which also takes into account the rotation speed ω_E of the internal combustion engine 2 and the load L_E of the internal combustion engine 2, and determines a desired speed ω_{Pref} of the low pressure pump 8. In other words, the desired speed ω_{Pref} of the low pressure pump 8 is determined by the regulator 24 according to the desired pressure $P_{fuelLPref}$ of the fuel upstream of the high pressure pump 6 (or more precisely according to the pressure error ε_f, which depends on the desired pressure $P_{fuelLPref}$ of the fuel upstream of the high pressure pump 6), to a rotation speed ω_E of the internal combustion engine 2, and to a load L_E of the internal combustion engine 2.

[0024] The low pressure pump 8 is controlled according to the desired speed ω_{Pref} of the low pressure pump 8; in particular, a speed error ε_r is calculated by making the difference between the desired speed ω_{Pref} of the low pressure pump 8 and the actual speed ω_p of the low pressure pump 8 (measured by the speed sensor 19). Thereby, the low pressure pump 8 is feedback controlled using the actual speed ω_p of the low pressure pump 8 as a feedback variable.

[0025] Regulators 21, 22 and 24 and calculation block 23 may implement experimentally determined models and/or experimentally determined maps.

[0026] As shown in figure 3, it is apparent that there are three feedback control loops: an internal feedback control loop 25, which uses the actual speed ω_p of the low pressure pump 8 as a feedback variable, an intermediate feedback control loop 26, which uses the actual pressure P_{fuelLP} of the fuel upstream of the high pressure pump 6 as a feedback variable, and an external feedback control loop 27, which uses the actual pressure P_{rail} of the fuel inside the common rail 5 as a feedback variable. Moreover, inside the electronic power converter 18, a further feedback control loop which uses the intensity (or duty cycle) of an electric current supplied to the electric motor 17 as a feedback variable, is normally present. Typically, the electronic power converter 18 controls the electric power supplied to the electric motor 17, thus allowing the actual speed ω_p of the low pressure pump 8 to be regulated by means of a PWM (Pulse Width Modulation) type technique, which includes chopping the electric voltage applied to the electric motor 17 over time.

[0027] Experimental simulations and tests have shown that the control logic illustrated in the diagram in figure 3 has a particularly high dynamic performance, i.e. the ability of rapidly and accurately pursuing the desired pressure $P_{railref}$ of the fuel inside the common rail 5, even in the presence of sudden variations; hence, in all operating conditions, the pressure error ε_r (i.e. the difference between the desired pressure $P_{railref}$ of the fuel inside the common rail 5 and the actual pressure P_{rail} of the fuel inside the common rail 5) is kepts at low, fully acceptable values.

[0028] According to the variant shown in figure 4, the intermediate feedback control loop 26, which uses the actual pressure P_{fuelLP} of the fuel upstream of the high pressure pump 6 as a feedback variable, is eliminated; in this embodiment, regulator 24 determines the desired speed ω_{Pref} of the low pressure pump 8 in open loop, directly according to the desired delivery Q_{ref} of the high pressure pump 6 towards the common rail 5. In particular, regulator 24 determines the desired speed ω_{Pref} of the low pressure pump 8 according to the desired delivery Q_{ref} of the high pressure pump 6 towards the common rail 5, to the rotation speed ω_E of the internal combustion engine 2, and to the load L_E of the internal combustion engine 2.

[0029] The control logic shown in the diagram in figure 4 is simpler than the control logic shown in the diagram in figure 3, and does not require measuring the actual fuel pressure P_{fuelLP} upstream of the high pressure pump 6; however, the control logic shown in the diagram in figure 4 has a lower dynamic performance (i.e. it is slower in reacting to variations) than the control logic shown in the diagram in figure 3.

[0030] The above-described mode of controlling the injection system 1 has many advantages.

[0031] Firstly, the above-described mode of controlling the injection system 1 is simpler and more cost-effective to be implemented than a known control mode in which an on-off valve arranged upstream of the high pressure pump 6 is inlcuded; indeed, the industrial cost of an on-off valve and of the corresponding control logic is higher than the industrial cost of the control electronics of the electric motor 17 of the low pressure pump 8 required by the above-described control mode.

[0032] The above-described mode of controlling the injection system 1 allows to rapidly and accurately pursue the desired pressure $P_{railref}$ of the fuel inside the common rail 5 even in the presence of sudden variations; hence, the above-described control mode substantially has the same dynamic performance as a known control mode including the presence of an on-off valve arranged upstream of the high pressure pump 6.

[0033] The above-described mode of controlling the injection system 1 allows to increase the overall energy efficiency, because in the above-described control mode, the low pressure pump 8 is controlled to pump each time only the amount of fuel needed to maintain the actual pressure P_{rail} of the fuel inside the common rail 5 equal to the desired pressure $P_{railref}$, and thus when the engine 2 is not at maximum load (i.e. over nearly all the operating time of engine 2), the fuel delivery of the low pressure pump 8 is lower (even much lower) than its nominal fuel delivery (corresponding to the full control voltage, e.g. 14 Volts). Instead, in the case of a known control mode in which an on-off valve arranged upstream of the high pressure pump 6 is included, the low pressure pump 8 is controlled to pump the nominal fuel delivery at each instant (and thus also when the engine 2 is idling); in this case, the excess fuel pumped by the low pressure pump 8 (i.e. the fuel which is not pumped by the high pressure pump 6 towards the common rail 5) is discharged into the tank 10.

[0034] As previously mentioned, in the case of a known control mode in which an on-off valve arranged upstream of the high pressure pump 6 is included, the low pressure pump 8 is controlled to pump the nominal fuel delivery at each instant; therefore, the low pressure pump 8 and the corresponding electric motor 17 should be dimensioned to continuously work at nominal fuel delivery (determined so as to be always in excess as compared to the maximum possible consumption of the high pressure pump 6). Instead, in the above-described control mode, the low pressure pump 8 is controlled to pump each time only the amount of fuel needed to maintain the actual pressure P_{rail} of the fuel inside the common rail 5 equal to the desired pressure $P_{railref}$; therefore, the low pressure pump 8 and the corresponding electric motor 17 may be dimensioned to continuously work at a fuel delivery which is much lower than nominal delivery (as previously defined), with an apparent cost saving and a reduction of weight and dimensions.

[0035] Finally, in the case of a known control mode in which an on-off valve arranged upstream of the high pressure pump 6 is inlcuded, a pressure regulating valve should be integrated in the intake system of the high pressure pump 6 itself; the integration of the pressure regulating valve in the intake system of the high pressure pump 6 is complex and thus costly due to the little available space inside the high pressure pump 6. Instead, in the above-described control mode, the high pressure pump 6 does not require the presence of any pressure regulating valve in the intake system. With this regard, it is worth noting that the recirculation valve 13 which regulates the re-introduction of fuel into the tank 10 and is provided in the above-described control mode, is a completely passive valve, is calibrated to work at low pressures (e.g. in the range from 1 to 2 bars), and is arranged in a large environment without dimensional constraints; therefore, the recirculation valve 13 is simple and cost-effective to be implemented and assembled. In other words, the installation of the recirculation valve 13 is simpler and more cost-effective than the installation of a pressure regulating valve in the intake system of the high pressure pump 6, as required in a known control mode in which an on-off valve arranged upstream of the high-pressure pump 6 is included.

Claims

1. Method for controlling a direct injection system (1) of common-rail type of an internal combustion engine (2); the direct injection system (1) comprises: a fuel tank (10), a low pressure pump (8) drawing the fuel from the tank (10) and a high pressure pump (6) receiving the fuel from the low pressure pump (8) and feeding the pressurized fuel into a common rail (5) connected to a number of injectors (4); the control method comprises the steps of:

    determining a desired pressure ($P_{railref}$) of the fuel inside the common rail (5); and

regulating the delivery of the high pressure pump (6) towards the common rail (5) to pursue the desired pressure ($P_{railref}$) of the fuel inside the common rail (5);
the control method is **characterized in that** it comprises the further step of regulating the delivery of the low pressure pump (8) towards the high pressure pump (6) to pursue the desired pressure ($P_{railref}$) of the fuel inside the common rail (5), so that a corresponding regulation of the delivery of the high pressure pump (6) towards the common rail (5) can be obtained.

2. Control method according to claim 1 and comprising the further steps of:

determining a desired delivery (Q_{ref}) of the high pressure pump (6) towards the common rail (5) according to the desired pressure ($P_{railref}$) of the fuel inside the common rail (5); and
controlling the low pressure pump (8) according to the desired delivery (Q_{ref}) of the high pressure pump (6) towards the common rail (5).

3. Control method according to claim 2 and comprising the further steps of:

measuring the actual pressure (P_{rail}) of the fuel inside the common rail (5);
determining a closed loop contribution (Q_{CL}) according to a pressure error (ε_r) calculated by making the difference between the desired pressure ($P_{railref}$) of the fuel inside the common rail (5) and the actual pressure (P_{rail}) of the fuel inside the common rail (5);
determining an open loop contribution (Q_{OL}) according to the desired pressure ($P_{railref}$) of the fuel inside the common rail (5); and
determining the desired delivery (Q_{ref}) of the high pressure pump (6) towards the common rail (5) by adding algebraically the closed loop contribution (Q_{CL}) and the open loop contribution (Q_{OL}).

4. Control method according to claim 3 and comprising the further step of determining the open loop contribution (Q_{OL}) according to the desired pressure ($P_{railref}$) of the fuel inside the common rail (5), a rotation speed (ω_E) of the internal combustion engine (2) and a load (L_E) of the internal combustion engine (2).

5. Control method according to claim 3 or 4 and comprising the further step of determining the closed loop contribution (Q_{CL}) according to the pressure error (ε_r), a rotation speed (ω_E) of the internal combustion engine (2) and a load (L_E) of the internal combustion engine (2).

6. Control method according to one of the claims from 2 to 5 and comprising the further steps of:

determining a desired speed (ω_{Pref}) of the low pressure pump (8) according to the desired delivery (Q_{ref}) of the high pressure pump (6) towards the common rail (5); and
controlling the low pressure pump (8) according to the desired speed (ω_{Pref}) of the low pressure pump (8).

7. Control method according to claim 6 and comprising the further step of determining the desired speed (ω_{Pref}) of the low pressure pump (8) according to the desired delivery (Q_{ref}) of the high pressure pump (6) towards the common rail (5), a rotation speed (ω_E) of the internal combustion engine (2) and a load (L_E) of the internal combustion engine (2).

8. Control method according to claim 6 or 7 and comprising the further steps of:

measuring the actual speed (ω_p) of the low pressure pump (8); and
controlling the low pressure pump (8) according to a speed error (ε_r) calculated by making the difference between the desired speed (ω_{Pref}) of the low pressure pump (8) and the actual speed (ω_p) of the low pressure pump (8).

9. Control method according to one of the claims from 2 to 5 and comprising the further steps of:

determining a desired pressure ($P_{fuelLPref}$) of the fuel upstream of the high pressure pump (6) according to the desired delivery (Q_{ref}) of the high pressure pump (6) towards the common rail (5); and
controlling the low pressure pump (8) according to the desired pressure ($P_{fuelLPref}$) of the fuel upstream of the high pressure pump (6).

10. Control method according to claim 9 and comprising the further steps of:

measuring the actual pressure (P_{fuelLP}) of the fuel upstream of the high pressure pump (6); and
controlling the low pressure pump (8) according to a pressure error (ε_f) calculated by making the difference between the desired pressure ($P_{fuelLPref}$) of the fuel upstream of the high pressure pump (6) and the actual pressure (P_{fuelLP}) of the fuel upstream of the high pressure pump (6).

11. Method according to claim 9 and comprising the further steps of:

determining a desired speed (ω_{Pref}) of the low pressure pump (8) according to the desired pressure ($P_{fuelLPref}$) of the fuel upstream of the high pressure pump (6); and
controlling the low pressure pump (8) according to the desired speed (ω_{Pref}) of the low pressure pump (8).

12. Control method according to claim 11 and comprising the further step of determining the desired speed (ω_{Pref}) of the low pressure pump (8) according to the desired pressure ($P_{fuelLPref}$) of the fuel upstream of the high pressure pump (6), a rotation speed (ω_E) of the internal combustion engine (2) and a load (L_E) of the internal combustion engine (2).

13. Control method according to claim 11 and comprising the further steps of:

measuring the actual pressure (P_{fuelLP}) of the fuel upstream of the high pressure pump (6); and
determining the desired speed (ω_{Pref}) of the low pressure pump (8) according to a pressure error (ε_f) calculated by making the difference between the desired pressure ($P_{fuelLPref}$) of the fuel upstream of the high pressure pump (6) and the actual pressure (P_{fuelLP}) of the fuel upstream of the high pressure pump (6).

14. Control method according to claim 13 and comprising the further step of determining the desired speed (ω_{Pref}) of the low pressure pump (8) according to a pressure error (ε_f), a rotation speed (ω_E) of the internal combustion engine (2) and a load (L_E) of the internal combustion engine (2).

15. Control method according to one of the claims from 11 to 14 and comprising the further steps of:

measuring the actual speed (ω_p) of the low pressure pump (8); and
controlling the low pressure pump (8) in feedback according to a speed error (ε_r) calculated by making the difference between the desired speed (ω_{Pref}) of the low pressure pump (8) and the actual speed (ω_p) of the low pressure pump (8).

16. Control method according to one of the claims from 1 to 15, wherein the low pressure pump (8) is activated by an electric engine (17) fed by an electronic power converter (18); the low pressure pump (8) is controlled by regulating an electric current fed by the electronic power converter (18) to the electric engine (17).

17. Control method according to one of the claims from 1 to 16, wherein there is a recirculation duct (11) which leads to the fuel tank (10) and receives the excess of fuel from the injectors (4), from a mechanical pressure safety valve (12) which is hydraulically coupled to the common rail (5), and/or from a lubrication duct of the high pressure pump (6); there is one recirculation valve (13) which is arranged between the recirculation duct (11) and the tank (10), is a one-way valve and is set to open when the difference in pressure at its ends is higher than a predetermined intervention threshold value.

18. Direct injection system (1) of common-rail type of an internal combustion engine (2); the injection system (1) comprises:

a fuel tank (10);
a low pressure pump (8) drawing the fuel from the tank (10);
a high pressure pump (6) receiving the fuel from the low pressure pump (8) and feeding the pressurized fuel into a common rail (5) connected to a number of injectors (4); and
an electronic control unit (14) which determines a desired pressure ($P_{railref}$) of the fuel inside the common rail (5), and regulates the delivery of the high pressure pump (6) towards the common rail (5) to pursue the desired pressure ($P_{railref}$) of the fuel inside the common rail (5);
the injection system (1) is **characterized in that** the electronic control unit (14) regulates the delivery of the low pressure pump (8) towards the high pressure pump (6) to pursue the desired pressure ($P_{railref}$) of the fuel inside the common rail (5), and so that a corresponding regulation of the delivery of the high pressure pump (6) towards the common rail (5) can be obtained.

19. Injection system (1) according to claim 17, wherein the low pressure pump (8) is activated by an electric engine (17) controlled by an electronic device comprising an electronic power converter (18) which is arranged in proximity of the electric engine (17), is physically separated form the electronic control unit (14) and is connected to the electronic control unit (14) through a data line.

20. Injection system (1) according to claim 17 or 18 and comprising:

a recirculation duct (11) which leads to the fuel tank (10) and receives the excess of fuel from the injectors (4), from a mechanical pressure safety valve (12) which is hydraulically coupled to the common rail (5), and/or from a lubrication duct of the high pressure pump (6);
a recirculation valve (13) which is arranged between the recirculation duct (11) and the tank (10), is a one-way valve and is set to open when

the difference in pressure at its ends is higher than a predetermined intervention threshold value.

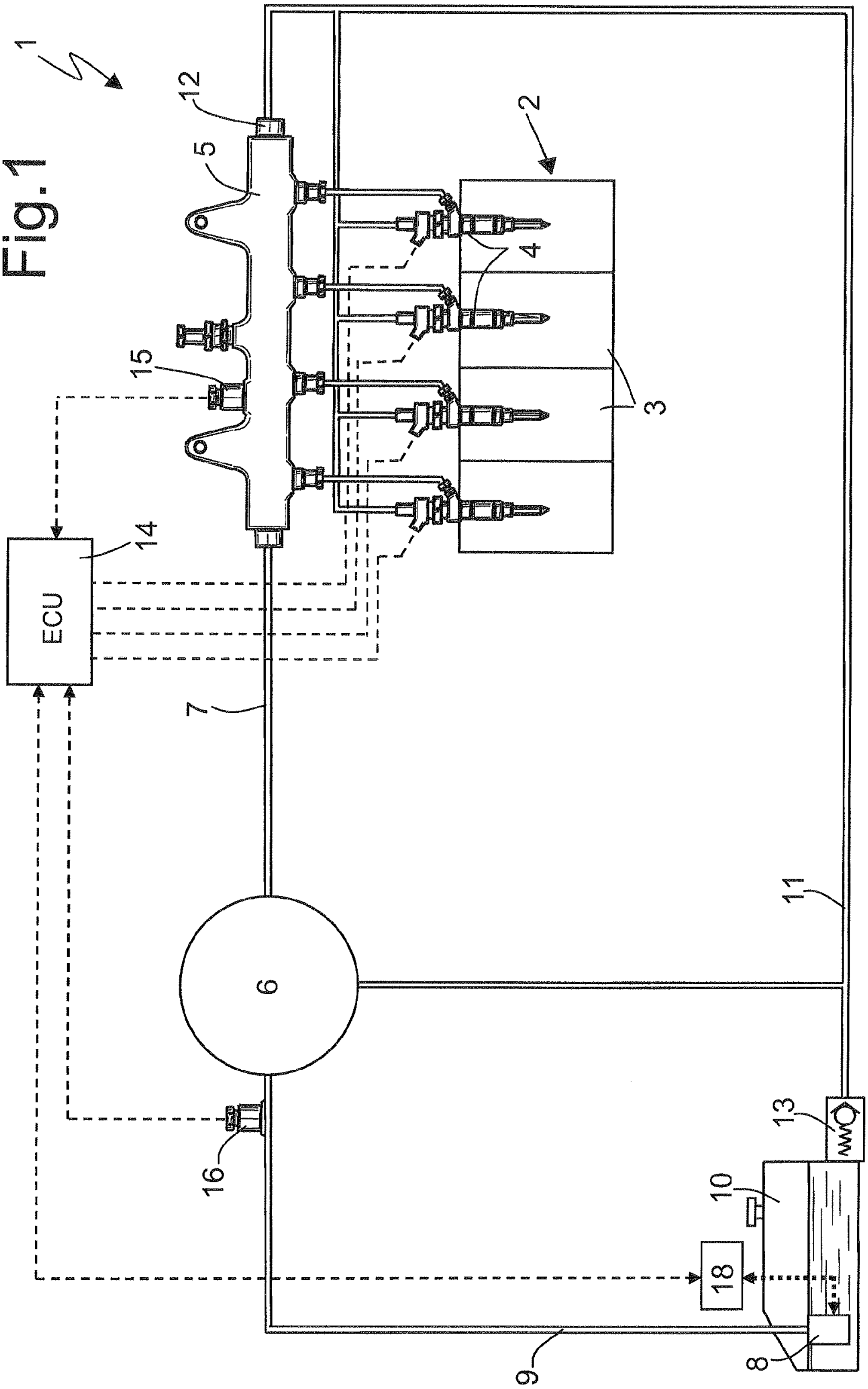

Fig.1

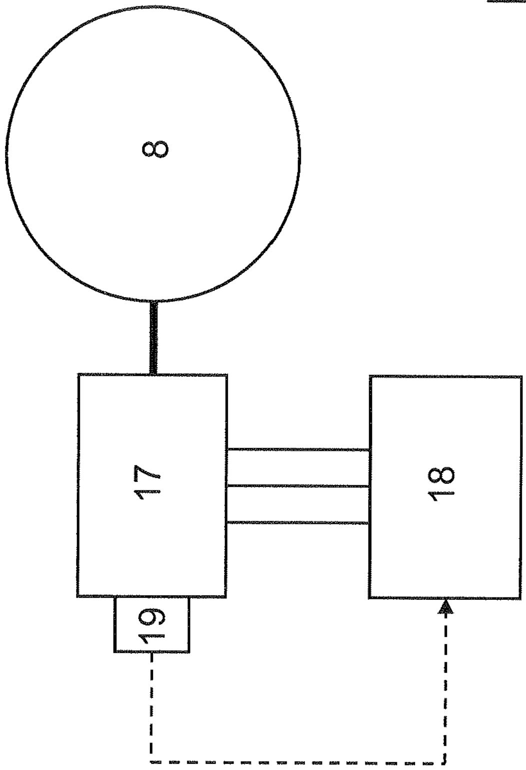

Fig.2

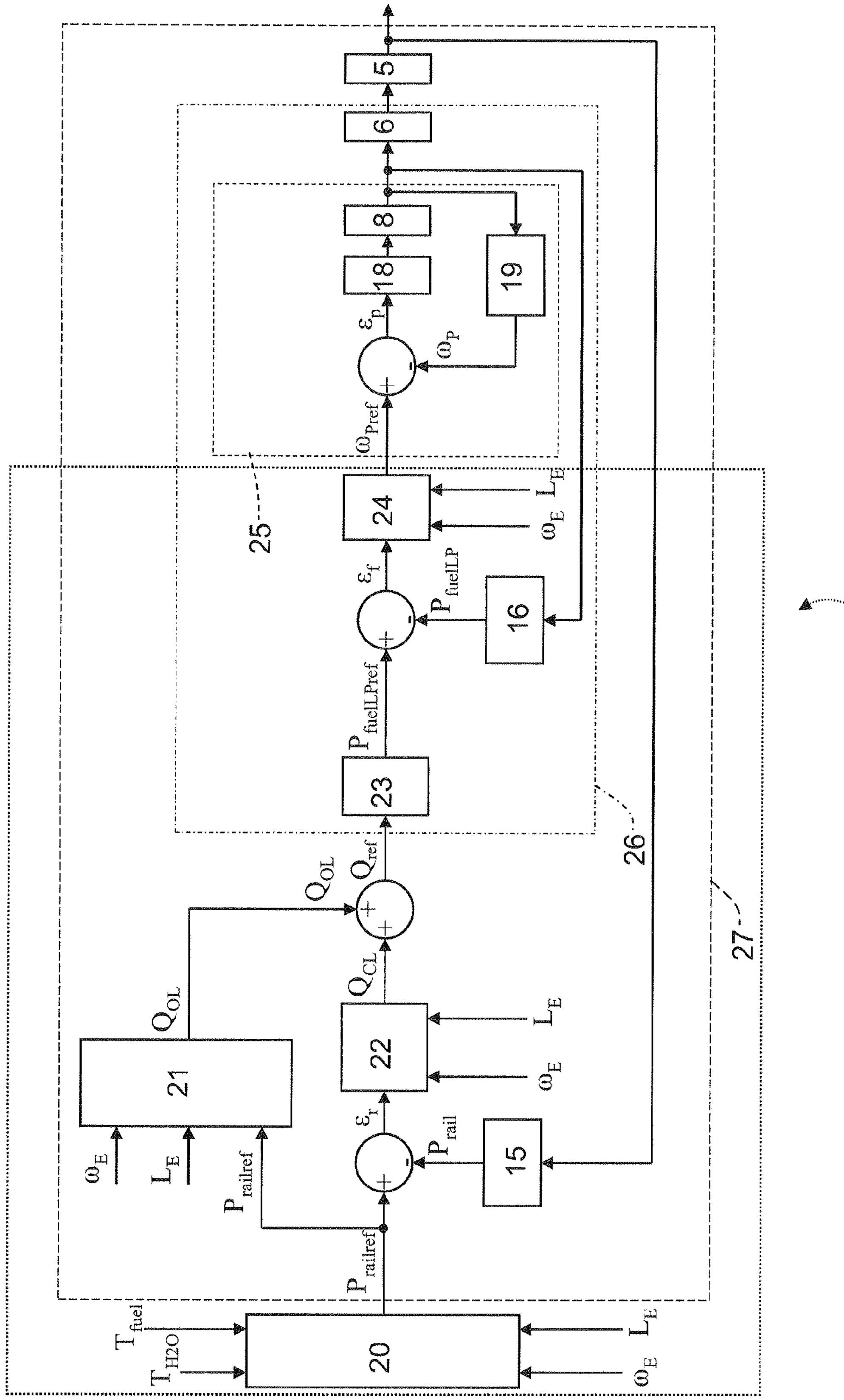
5
6
8
18
19
23
24
16
15
20
21
22
25
26
27
14
ε_p
ω_P
ω_Pref
ε_f
P_fuelLP
P_fuelLPref
L_E
ω_E
Q_OL
Q_ref
Q_CL
ε_r
P_rail
P_railref
T_fuel
T_H2O

Fig.3

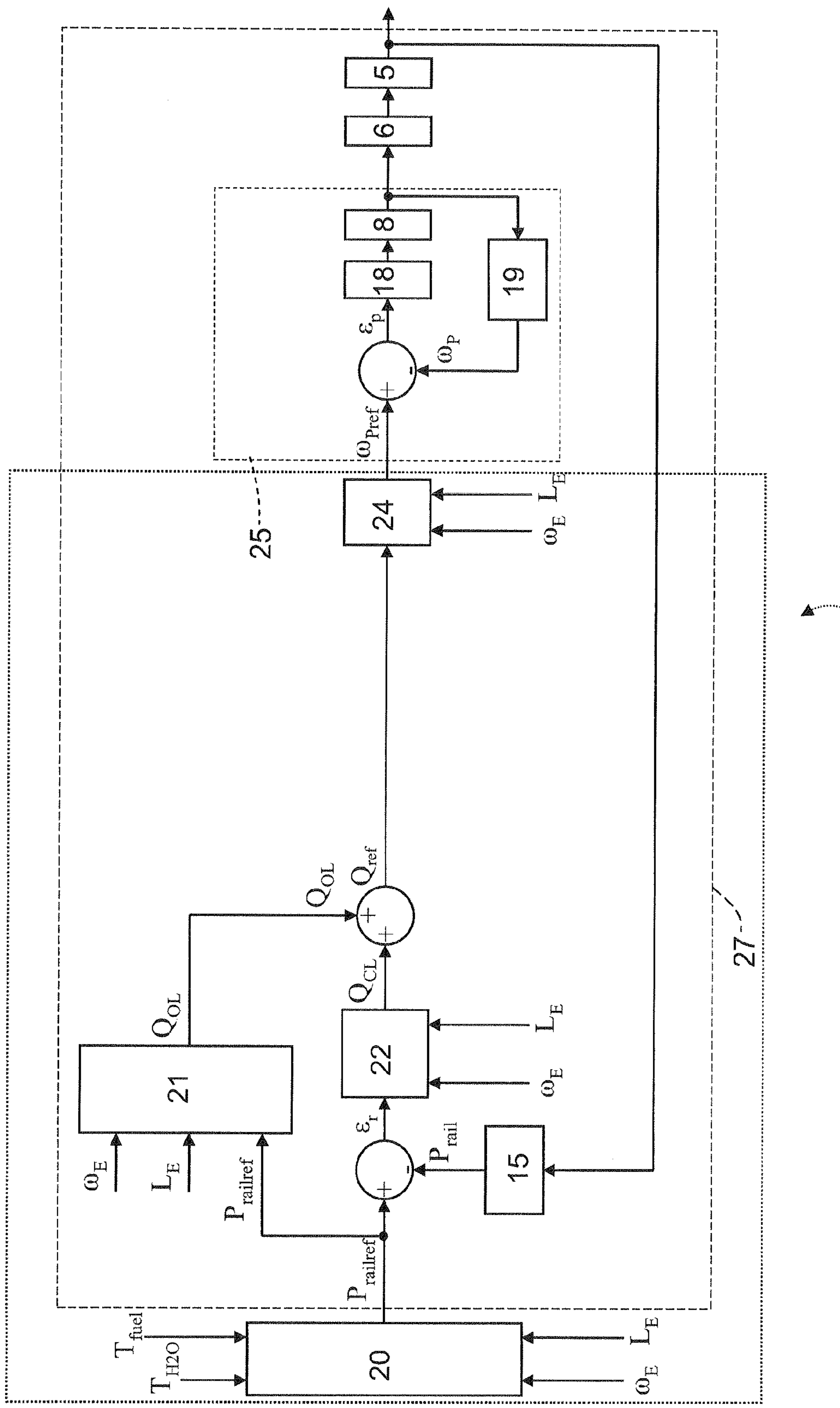
5
6
8
18
19
ε_P
ω_P
ω_Pref
25
24
L_E
ω_E
14
Q_OL
Q_ref
Q_CL
27
21
22
ε_r
P_rail
15
P_railref
T_fuel
T_H2O
20

Fig.4

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- EP 0481964 A1 **[0003]**
- US 6116870 A1 **[0003]**
- EP 1612402 A1 **[0006]**