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

(11) EP 2 706 216 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
12.03.2014 Bulletin 2014/11

(51) Int Cl.:
F02D 41/24 *(2006.01)*

(21) Application number: **12183485.7**

(22) Date of filing: **07.09.2012**

(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 RS SE SI SK SM TR
Designated Extension States:
BA ME

(71) Applicant: **Delphi Technologies Holding S.à.r.l.**
4940 Bascharage (LU)

(72) Inventors:
- **Sauret, Edouard**
  F-54440 Herserange (FR)
- **Garnier, Laurent**
  F-57180 Terville (FR)
- **Schickes, Pascal**
  8820 Holts (LU)

(74) Representative: **Neill, Andrew Peter et al**
Delphi Diesel Systems
Patent Department
Courteney Road
Gillingham, Kent ME8 0RU (GB)

(54) **Method of determining fuel injector characteristics**

(57) The invention concerns a method of operating an internal combustion engine with a fuel injection system comprising at least one fuel injector for performing injector events in a respective engine cylinder, the fuel injector being associated with an intermediate fuel tank of pressurized fuel. The method comprising the steps of:
a) performing at least one injector event by applying to said fuel injector a drive pulse having a predetermined pulse width;
b) measuring the resulting pressure in said intermediate fuel tank;
c) repeating steps a) and b) with drive pulses of increased pulse width until a predetermined pulse width is reached;
d) storing a test data set comprising data indicative of the rate of pressure loss for corresponding pulse widths;
e) determining an injector characteristic from said test data set by detecting expected variations of said data indicative of said rate of pressure loss.

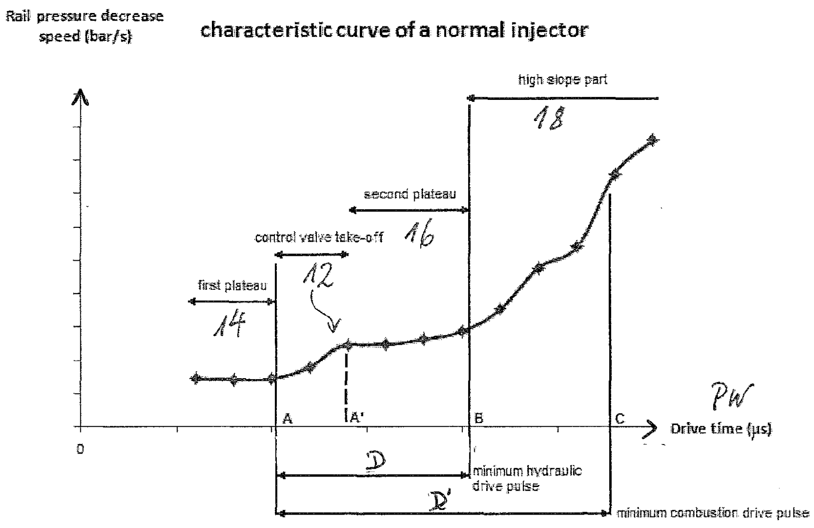

FIG. 2

EP 2 706 216 A1

Description

Field of Invention

[0001] The present invention relates to fuel injection in internal combustion engines. More specifically, the present invention relates to the determination of specific characteristics of a fuel injector in particular for the purpose of injector diagnosis and detecting injection system faults.

Background of the Invention

[0002] The contemporary design of internal combustion engines must cope with the increasingly stringent regulations on pollutant emissions. Accordingly, automotive engineers strive for designing engines with low fuel consumption and low emission of pollutants, which implies including electronic devices capable of monitoring the combustion performance and emissions in the exhaust gases.

[0003] In this connection, a proper operation of a fuel-injected engine requires that the fuel injectors and their controller allow for a timely, precise and reliable fuel injection. However, the manufacturing process of fuel injectors and their ageing lead to part-to-part variations. Accordingly, in order to take into account the specificities of a solenoid actuated fuel injector, it has been proposed to associate to a given fuel injector a number of performance parameters thereof, generally referred to as "injector codes". These injector codes are, e.g., encoded in a bar code applied to the injector, so that the injector codes can be retrieved by a bar code scanner at the time of installation in the engine and transferred to the engine control unit (ECU). Such method for fuel injector parameters installation is for example described in US 7,136,743.

[0004] Another method of fuel injector installation has been disclosed in W02011/073147, which uses a segmented master performance curve. Each fuel injector to be installed in the engine is provided with specific injector codes in a machine-readable format, and these injector codes are transferred to the engine ECU. Fitting information, preferably coefficients for a characteristic equation attributed to each respective segment of the master flow curve, are contained in these injector codes.

[0005] The above method is beneficial in that it allows appropriately describing the flow performance per injector and provides finer injector control, in particular in the ballistic operating range. However, the ballistic range is a critical operating region and it has appeared that the above method may, under certain conditions, not discriminate cases where the injector does not open. To remedy to this situation, it is now known to detect the so-called Minimum Drive Pulse (MDP), i.e. the shortest duration of drive signal that can be applied to an injector to initiate injection.

[0006] The MDP is an injector characteristic, which can be considered specific to an injector and the knowledge of which allows for an improved injection control. Furthermore, the MDP is an injector characteristic that may vary over the lifetime of a fuel injector. Several method of determining an injector MDP have been proposed, e.g. by monitoring crank shaft speed and detecting the moment at which sufficient fuel is injected such that a torque producing combustion event is produced..

[0007] The above measures allow a reliable injection control. But there are other sources of injection malfunction, such as e.g. injector lacquering or wrong injector corrections. It may be noticed that such errors should be detected as early as possible to meet the OBD (On-Board Diagnostic) requirements.

[0008] Hence, there is a need to be able to detect injector-specific characteristics in order to diagnose injector malfunctions.

Summary of the Invention

[0009] The present invention relies on the finding that fuel injectors may have a peculiar pre-injection behaviour that is specific to the injector. Accordingly, the present invention proposes a method of operating an internal combustion engine, wherein an injector characteristic is determined from a test data set obtained during a test sequence, in which drive pulses are applied to the fuel injector and the resulting pressure loss is measured. This test sequence is carried out for low drive pulses, mostly at non-injecting drive pulses.

[0010] It shall be appreciated that the present inventors have observed that it is possible to determine an injector characteristic by detecting, from the test data set, expected variations of data indicative of the rate of pressure loss. This rate of pressure loss reflects the speed at which the pressure changes at the corresponding pulse width; the rate of pressure loss thus has the dimension of a pressure per unit of time (e.g. bar/s or Pa/s).

[0011] As it will be understood by those skilled in the art, the test data set comprises data that represent a certain curve, and the present method processes these data in order to recognise predetermined profiles/evolutions of the data. In other words, the test data set is processed to detect one or more predetermined variation pattern(s) of the rate of pressure loss, and identify the pulse widths at which it/they occur(s). The term "pulse width", or PW, herein conventionally designates the time period during which a drive pulse is applied to an injector to influence a desired injection time.

[0012] One advantage of the present invention is that it is unobtrusive and undetectable in the driveline since the test sequence can be performed when the vehicle is in a "foot off" condition. As used herein, the term "foot off" designates a condition where no torque is requested from the driver nor from the ECU, especially with the driver's foot off the accelerator pedal or during coasting conditions (e.g. downhill or deceleration). Additionally, the test drive pulses sent to the injector under test can be scheduled for periods of engine operation when possible injection of fuel into the associated engine cylinder would not result in work output, e.g. during an exhaust stroke.

[0013] As it will be understood by those skilled in the art, the present method is based on the recognition of some variation patterns in the collected test data set. It should be noticed that the collected test data set contains data indicative of the rate of pressure loss as a function of the length of the corresponding drive pulses, i.e. in function of pulse width. The implementation scheme of the present method will thus analyse the test data set to identify expected variations in the rate/speed of pressure loss (not simply of pressure loss) in order to assign them to a known characteristic feature of the fuel injector.

[0014] Two main injector characteristics are of concern in the present method:

1) Minimum Delivery Pulse

[0015] The idea is here to detect what could be qualified as a "hydraulic" MDP, by contrast to method detecting the MDP by methods involving combustion. The present inventors have observed that when considering the curve described by the test data set, the MDP corresponds to the foot portion of a steadily ascending curve portion, with relatively steep slope.

2) Control valve take-off

[0016] Fuel injectors conventionally used in common rail systems comprise a fuel return path and a servo valve to operate a hydraulic actuation of the nozzle needle, the servo valve being e.g. actuated via a solenoid actuator. The present inventors have observed that, as from a certain minute pulse width (below the MDP), this control valve takes off from its seat. At this moment there is a sudden increase in the return fuel flow, which can be observed as a corner point, i.e. a discontinuity or a steep variation of the derivative of the rate of pressure loss as a function of pulse width, such as a step. Detecting the corner point from the data set (rate of pressure loss vs. pulse width) allows determining this injector-specific take-off and the corresponding pulse width. It shall be understood that the term "corner point", as used herein, is not necessarily limited to a "sharp" corner point (corresponding to a discontinuity of the derivative) but shall be construed to encompass a "smooth" corner point (corresponding to a comparatively steep variation of the derivative.)

[0017] As it will be explained in more detail herein below, the determination of the MDP and take-off point are of interest for injector diagnostic. In particular, it has been found that a modification of injector codes can be observed as a shift in the take-off position. Furthermore, injector lacquering results in a longer opening delay, which can be observed through a shift in MDP. However, it should be appreciated that the present method allows detecting the MDP without combustion, and hence can be detected when the engine is cold. In this connection, the present inventors have observed that the increase in opening delay due to lacquering is even greater at cold engine. This effect can be measured as a substantial increase in the time interval between the control valve take-off and the MDP.

[0018] It may be noticed that the present method has been particularly developed for common rail fuel injection systems, where the fuel injectors include a fuel return path and a servo/control valve, the injector comprising an actuator device acting on the hydraulic control valve, the latter triggering the nozzle needle.

[0019] Preferably, the method may be performed when the fuel system is in a closed pressurised state. Such a closed pressurised state may be achieved either by closing all the injectors within the fuel system and ceasing pumping of fuel to the intermediate tank (common rail) or by scheduling the test to run during a portion of the engine cycle when the injectors are closed and the pump is not actively charging the intermediate fuel tank. In this latter example, the pump may conveniently be set to compensate for natural fuel leakage. In the closed pressurized state, any other valve on the intermediate tank should also be closed.

[0020] The determination of the two injector characteristics may be carried out in various manners; preferred possibilities are the following.

[0021] Considering a fuel injector in a rest position, the control valve take-off is the first phenomenon occurring as the pulse width is increased, and can be detected as a corner point in the rate of pressure loss situated in-between two plateau regions. Alternatively, the control valve take-off can be detected by comparing the rate of pressure loss to a first threshold occurring after a first plateau in the test data set.

[0022] The pulse width corresponding to the corner point may be set as a first injector characteristic indicative of the control valve triggering.

[0023] It may be noticed that the pulse width used as first injector characteristic does not need to match to the exact corner point, but can be approximated as:

- the start or foot portion of the positive slope (rising edge) following the first plateau,
- an inflection point on the positive slope preceding the corner point,
- the end of the positive slope,
- or any other position relative thereto, including the PW corresponding to the corner point itself.

[0024] The MDP can, in turn, be determined at step e) by detecting from the test data set an increase of the rate of pressure loss above a predetermined threshold, and this over a predetermined pulse width interval (during a certain length of PW). Preferably, the second injector characteristic is the MDP and the pulse width corresponding to the beginning of this increase in the test data set is set as MDP, respectively the second injector characteristic.

[0025] In practice, the detection of injector malfunction can be carried out by comparing the first injector characteristic, respectively second injector characteristic, against a reference value for the injector and the presence of malfunction is determined if the first injector characteristic value determined in step e) exceeds said previously stored value, or deviates therefrom by a predetermined amount.

[0026] For lacquering detection, a parameter indicative of the time interval separating the first from the second injector characteristic may be calculated and compared to a reference value, and the presence of an injector fault is determined if the calculated parameter exceeds said reference value.

[0027] These and other embodiments of the present method are recited in the appended dependent claims 2 to 13.

[0028] According to another aspect of the invention, a system for a fuel injection system for an internal combustion system is claimed in claim 14.

[0029] The invention further extends to a carrier medium for carrying a computer readable code for controlling an electronic control unit to carry out the above method.

Brief Description of the drawings

[0030] In order that the invention may be more readily understood, reference will now be made, by way of example, to the accompanying drawings in which:

Figure 1: shows a representation of a typical fuel system within an internal combustion engine;

Figure 2: shows a characteristic curve of a fuel injector in the pre-injection, low pulse width range;

Figure 3: is a plot showing an example of pressure decay versus time during test sequence according to the present method;

Figure 4: is a graph illustrating the shift of the control valve take-off point;

Figure 5: is a graph illustrating the effect of lacquering on the MDP;

Figure 6: is a flowchart describing a test sequence used in the present method.

Detailed Description of the Invention

[0031] Figure 1 shows a representation of a fuel system 1 within an internal combustion engine comprising a fuel tank 2, a controllable high pressure fuel pump 3, a common rail (intermediate fuel reservoir) 4, a rail pressure sensor 5, a pressure limiter 6, a plurality of injectors 7 and an electronic control unit (ECU) 8.

[0032] In use, the ECU 8 controls pumping of fuel from the tank 2 to the rail 4 by the pump 3. The ECU 8 also controls the operation of the injectors 7 and receives sensor data on the pressure within the rail 4 from the pressure sensor 5.

[0033] Under normal operating conditions, fuel injection is achieved by applying to the injector 7 a drive pulse in order to influence an opening duration of the injector nozzle needle and hence inject a certain amount of fuel. For this purpose, the drive pulse has a certain pulse width, which is mainly calculated based on the requested fuel amount, although generally taking into account many operating parameters and sensors and possibly subject to correction.

[0034] In the control of fuel injectors, it is now customary to take into account the flow specificities of fuel injectors, by way of transferring injector codes to the ECU (or other injector control unit) that help describing the general flow performance of the injectors. These injector codes are then used in a master performance function comprising a fuel demand versus PW relationship.

[0035] In this connection, another parameter that has more recently been taken into account is the minimum delivery pulse MDP, i.e. the shortest duration of drive signal (shortest pulse width) that can be applied to an injector to initiate injection.

[0036] Recent fuel injection schemes based on master performance functions and MDP allow for an improved precision in the fuel delivery. Nevertheless, emission regulations are always more stringent, in particular regarding diagnostic capabilities.

[0037] The present invention provides a method allowing the characterization of a fuel injector in the low pulsewidth region, where no or almost no fuel injection occurs.

[0038] The present method has been devised for application with fuel injectors having a fuel return path and servo or control valve that hydraulically triggers the actuation of the nozzle needle, the control valve being associated with an actuator device, preferably of the electromagnetic type.

[0039] As it is known, such a fuel injector has three main components: a nozzle portion with more injection orifice(s) that can be selectively opened or closed by means of a nozzle needle, a hydraulic servo system with control valve, and an actuator. The fuel is routed from a high-pressure inlet port via an inlet passage to the nozzle portion and via an inlet restrictor to a control chamber. The control chamber is connected by the outlet restrictor, which can be opened by a solenoid valve, to the fuel return. In the closed position of the fuel injector, the spring of the control valve presses the valve member into the seat of the outlet restrictor. A pressure corresponding to that of the fuel rail is present in the control chamber and in the nozzle; the nozzle needle is biased in closed position, i.a. by a spring. Fuel injection may be achieved by applying a drive signal (above MDP) to the solenoid of the electromagnetic actuator. This will cause the armature to move and lift the control valve member off its seat.

Fuel flows back to the return line. Pressure in the control chamber then falls below that in the nozzle chamber, forces on the nozzle needle are changed and the latter begins to open and fuel injection commences. Such fuel injectors, their design and operation, are well known in the art and need not be further explained herein.

[0040] It shall be appreciated that the present inventors have found that it is possible to characterize the pre-opening behavior of such fuel injector, up to about the MDP.

[0041] In particular, the present inventors have observed that one or two injector characteristic(s) of a fuel injector can be determined from a particular test procedure carried out in a non intrusive manner and with no, or almost no fuel consumption. The test procedure allows building a test data set comprising data indicative of a rate (speed) of pressure loss in the fuel rail for injections carried out at corresponding pulse widths. Such data set is illustrated in Fig. 2, where each point corresponds to rate of pressure loss in the fuel rail (rail pressure decrease speed) when the injector is actuated by the corresponding drive pulse with a duration PW.

[0042] From this data set, the present method allows determining two injector-specific characteristics:

1. a first characteristic, which is believed to reflect the setting into movement of the injector's servo/control valve that hydraulically triggers the nozzle needle. This characteristic is herein referred to as control valve take-off point.
2. a minimum drive pulse, which may be referred to as "hydraulic" MDP by contrast to a "combustion" MDP that would occur at a greater PW, as illustrated in Fig.2.

[0043] As can be observed in Fig.2, the first characteristic-control valve take-off point- is indicated by reference number 12 and appears in the curve as a corner point between two plateau sections 14 and 16.

[0044] The second characteristic, reflecting the hydraulic MDP, corresponds to the base or foot of the relatively high slope section 18 of the curve, after the second plateau 16.

[0045] In Fig.2, point A (or A') is the first injector characteristic, i.e. the PW of the control valve take-off point. Point B is the second characteristic, i.e. the PW determined as the foot of the high slope section 18 after the second plateau 16, and representing the injector MDP.

[0046] The detection of these two injector characteristics will be explained in more detail below. Before that, the gathering of the test data set required for determining the take-off point and the MDP will now be explained with reference to Figs 3 and 6.

[0047] In order to build the test data set as e.g. shown in Fig.2, it necessary to measure the pressure loss in the fuel rail over a range of pulse widths. Fig.3 illustrates a possible embodiment of this test sequence, which is preferably carried out during a foot off phase.

[0048] In Fig. 3 there are 4 groups of pulses G_1 to G_4. Group G_1 comprises 8 injection pulses at substantially same pulse width PW_1. The starting drive pulse in Group G_1 has a pulse width PW_1 known to be low, below the first characteristic of interest.

[0049] As can be seen, applying these same drive pulses PW_1 causes a significant drop in the fuel rail pressure (which is closed during the measurement). Between the applications of the groups of pulses, a decrease of the fuel rail pressure due to leakage can be observed. However, the pressure loss due to leakage is significantly smaller than the pressure decrease occurring during the application of the drive pulses.

[0050] For a unitary drive pulse having a duration PW_i within group G_i, the rate of pressure loss can thus be calculated as: $\frac{\Delta P}{n * PWi}$, where ΔP is the difference of rail pressure before the first pulse and after the last one of group Gi, and n is the number of pulses applied in the group. The given formula is insofar an approximation as it does not take into account the pressure loss resulting from leakage. If the leakage cannot be neglected, one has to calculate the rate of pressure loss as $\frac{\Delta P - \delta P_L}{n * PWi}$, where δP_L represents the pressure loss due to underlying leakage over the duration of the group of pulses G_i.

[0051] If, as is the case in Fig. 3, rail pressure decreases over the duration of the test (i.e. if rail pressure is not the same at the beginning of each group G_i of pulses), the rate of pressure loss is not obtained for a precise rail pressure. If the dependency from the initial rail pressure is known, this effect can be corrected in the data collected. Alternatively, a compensation factor can be applied to the pulse widths PW_i. Preferably, however, between each group G_i of drive pulses, the rail is pressurized again, so that the rail pressure at the beginning of each group G_i of pulses is the same.

[0052] The data acquisition process is schematically represented in Fig.6, in an open loop approach. In a first step 100, the unitary drive time (i.e. the starting pulse width) is defined as the last take-off drive pulse minus an Offset. This is done to ensure that the PW sweeping process is initiated at a sufficiently low PW, below that of the take-off point of interest. The last take-off drive pulse may e.g. be known from previous measurements, or from the injector installation where this take-off point may be installed in the ECU with the injector codes. Alternatively, the starting PW can be calculated as an offset with respect to a MDP value determined by any appropriate method.

[0053] According to step 110, the system waits for a foot-off phase. As soon as a foot off phase is identified, the rail pressure is controlled to reach a predetermined start pressure, and the rail is closed (steps 120 and 130). Such rail closing may be achieved by either by closing all the injectors within the fuel system and ceasing pumping of fuel to the source. Alternatively the test may be run during a portion of the engine cycle when the injectors are closed and the pump is not actively charging the fuel source. In this latter example, the pump may conveniently be set to compensate for natural fuel leakage.

[0054] A same drive pulse (i.e. constant PW) is thus applied n times to the injector, as indicated by steps 140 and 150. Thereafter, the end pressure in the fuel rail is measured and the rail pressure decrease speed corresponding to the drive pulses is calculated at step 160. The corresponding point is then stored in a test data table.

[0055] The unitary drive time (PW_i) of the test drive pulse is then increased (step 170) by a predetermined amount ($PW_{i+1}=PW_i+\delta$) and steps 110 to 160 are repeated during the same or a next foot-off phase. It should be noted that the rail pressure at the beginning of the different groups of pulses is held constant during the whole process, since steps 120 and 130 are included in the outer loop. This means that, unlike shown in Fig. 3, the rail pressure is increased after each group of pulses to a predefined pressure P_{init}.

[0056] This process is repeated until an upper end PW is reached, which means that the test data table (rate of pressure loss vs. PW) is populated over the PW range of interest.

[0057] The control valve take-off point and/or the injector MDP can then be determined from the gathered test data. The whole test procedure may be carried out for different predefined pressures P_{init}.

[0058] As it has been mentioned above, both injector characteristics are preferably determined by derivation with respect to PW from the acquired data set indicative of the rate of pressure loss and corresponding PW.

[0059] Referring again to Fig.2, the take off point can be identified by detecting a positive slope between the two plateau regions 14 and 16. Alternatively, the position of the take off point A can be determined by comparing the rate of pressure loss to a first threshold, located after a first plateau 14. As yet another alternative, the position of the take off point can be determined as the point of inflection on the slope following the first plateau 14. In practice, depending on the desired strategy and amount of data available, the PW used as first characteristic may correspond either to the maximum of the take-off region 2 (point A in Fig.2) or to the beginning take-off region 2 (point A' in Fig.2).

[0060] The second characteristic point is the MDP. It corresponds to the base of the high slope part of the data set, after the second plateau (i.e. at higher PW values). The high slope part 18 can be detected based on its higher slope (higher derivative of the rate of pressure loss over PW) over an extended range of PW, preferably in conjunction with the fact that it is located after the second plateau 16 (i.e. larger PW).

[0061] In the present method the variable of interest is the rate of pressure decrease in the fuel rail, and in particular the variations of this rate of pressure decrease in the test data set. For ease of implementation, the rate of pressure decrease is compared to thresholds, but other any appropriate mathematical method can be used to recognize, from the test data set, the corner point 12 corresponding to the take-off point or base of the high slope section 18 corresponding to the MDP.

[0062] As already mentioned, the present method is normally carried out during a foot off phase, in a non-intrusive manner, so that it does not compromise driveability or comfort. Furthermore, the valve characterization does not require combustion, whereby the method can be performed when the engine is hot or cold.

[0063] The so-determined first injector characteristic (take-off point) can advantageously be used for injector diagnostic, since a shift of the take-off point can be attributed to an injector code problem. This problem may arise when a fuel injector is replaced, but the new injectors codes are not transferred to the ECU, or wrong codes are transferred. At the next engine cycle, the injector will thus be operated with wrong codes. The effect of the wrong injector codes is illustrated in Fig.4. Line 40 indicates the injector characteristic measured for the original injector with original codes. Lines 42 and 44 represent two situations where the injector codes are changed for the same injector. As can be seen, when an injector is operating with wrong codes, there is a noticeable shift of the take-off point.

[0064] In order to detect such case where injector codes are not updated when installing a new injector, the present method proposes determining for each engine cycle (i.e. each time the engine is started) the take-off point and determining whether a shift of take-off point has occurred, e.g. by comparing to a reference take-off point (determined in the previous engine cycle or transferred to the ECU at injector installation).

[0065] For improved reliability of the diagnostic, the ECU comprises a set of reference take-off points at different pressures, in accordance with the prescribed pressures of injector codes. Hence, where different sets of injector codes are defined for different rail pressures with corresponding reference take-off points, the take-off point may be determined at each prescribed pressure. A malfunction is signaled only if a significant shift from one or more of the reference take off points is observed. Depending on the circumstances (e.g. when a shift is detected for one rail pressure only), the diagnostic test may be repeated before a malfunction is signaled (or discarded following the repeated test.)

[0066] Fig.5 illustrates the effect of lacquering (pollution due to poor fuel quality) on the pre-injection characteristic of the injector. Lacquering does not appear to affect the take-off point, which remains substantially constant. In the figure, D1, D2 and D3 indicate respectively the distance between the take-off point and the MDP, for a normal injector (line 50), a hot injector with lacquering (line 52) and a cold injector with lacquering (line 54). It can be seen that lacquering causes a shift towards increasing PWs, but this shift is more severe when the pre-injection characteristic is measured with cold engine/injector.

[0067] From Fig.5, it will thus be understood that injector lacquering can be determined with better sensitivity shortly after (up to a few minutes) an engine start-up (when the engine is still cold). Lacquering drastically increases the opening delay of the injectors. In order to detect such situation, a time threshold can be conveniently used. The time interval D between the take-off point and the MDP is thus measured shortly after start-up and if it exceeds the time threshold, it is concluded to injector lacquering.

[0068] As it will be understood, the start and stop values of the test sequence are set to encompass the two characteristics of interest. The start and stop values can be preset or adjusted based on more specific data, e.g. from data transferred to the ECU at injector installation (e.g. pre-defined MDP value and/or take-off point). Furthermore, the sweeping rate of the pulse width during the test of Fig.6, i.e. the amplitude of the PW increment, may be finer or coarser, depending on the desired accurarcy.

[0069] Besides, the test sequence of Fig.6 could be limited to the determination of only one of the two injector characteristics. In case only the control valve take-off point is of interest, it is not required to sweep the PW all over to the MDP. It suffices to gather data encompassing the two plateaus, with the corner point in between. Conversely, to determine the MDP as in the present method, it is sufficient to sweep PW over values encompassing the end of the second plateau and the subsequent steep curve section.

[0070] The present method is preferably carried out for each engine cycle (each start-up) and for the entire set of fuel injectors.

Claims

1. A method of operating an internal combustion engine with a fuel injection system comprising at least one fuel injector for performing injector events in a respective engine cylinder, said fuel injector being associated with an intermediate fuel tank of pressurized fuel, said method comprising the steps of:

a) performing at least one injector event by applying to said fuel injector a drive pulse having a predetermined pulse width;
b) measuring the resulting pressure in said intermediate fuel tank;
c) repeating steps a) and b) with drive pulses of different pulse widths;
d) storing a test data set comprising data indicative of the rate of pressure loss for corresponding pulse widths;
e) determining an injector characteristic from said test data set by detecting expected variations of said data indicative of said rate of pressure loss.

2. The method according to claim 1, wherein step e) comprises detecting from said test data set a corner point, e.g. a discontinuity or a steep variation of the derivative of the rate of pressure loss as a function of pulse width, in said rate of pressure loss in-between two plateau regions.

3. The method according to claim 1, wherein step e) comprises detecting from said test data set a corner point by comparing said rate of pressure loss to a first threshold, following a first plateau.

4. The method according to claim 2 or 3, wherein the pulse width corresponding to said corner point is set as a first injector characteristic indicative of the control valve triggering.

5. The method according to claim 4, wherein the pulse width of said corner point is the pulse width corresponding to one of: the foot of a rising edge following a first plateau, an inflection point on the rising edge or the end portion of the rising edge, or any other position relative thereto.

6. The method according to any one of the preceding claims, wherein step e) comprises detecting from said test data set the foot of an increase of said rate of pressure loss above a predetermined threshold and over a predetermined pulse width interval.

7. The method according to claim 6, comprising setting as second injector characteristic the pulse width corresponding to the beginning of said increase in the test data set, said second injector characteristic corresponding to the minimum delivery pulse.

8. The method according to any one of the preceding claims, wherein the method is performed when the fuel system is in a closed pressurised state.

9. The method according to claim 8, wherein the closed pressurised state is achieved by closing all injectors within the fuel system and ceasing pumping of fuel to the intermediate fuel tank.

10. The method according to any one of the preceding claims, wherein said first injector characteristic and/or second injector characteristic is/are further used in engine control, in particular by comparison to a threshold for injector diagnostic purposes.

11. The method according to any one of the preceding claims, wherein the first injector characteristic, respectively second injector characteristic, is compared against a reference value for the injector and the presence of malfunction is determined if the first injector characteristic value determined in step (e) exceeds said previously stored value, or deviates therefrom by a predetermined amount.

12. The method as claimed in claim 8, wherein a parameter indicative of the time interval separating the first from the second injector characteristic is calculated and compared to a reference value, and the presence of an injector fault is determined if the calculated parameter exceeds said reference value.

13. A method as claimed in any one of the preceding claims, wherein the engine comprises a plurality of injectors and each injector is tested in turn to determine the first and/or second characteristic of each injector.

14. A method as claimed in any one of the preceding claims, wherein steps a) to c) are carried out by starting at a predetermined lower pulse width and the pulse width is progressively increased by a predetermined increment, until reaching an upper pulse width.

15. A fuel injection system for an internal combustion system comprising at least one fuel injector for performing injector events in a respective engine cylinder, said fuel injector being associated with an intermediate fuel tank of pressurized fuel, and a control unit configured to:

a) perform at least one injector event by applying to said fuel injector a drive pulse having a predetermined pulse width;
b) measure the resulting pressure in said intermediate fuel tank;
c) repeat steps a) and b) with drive pulses of different pulse widths;
d) store a test data set comprising data indicative of the rate of pressure loss for corresponding pulse widths;
e) determine an injector characteristic from said test data set by detecting expected variations of said data indicative of said rate of pressure loss.

16. The fuel injection system according to claim 15, wherein said injector characteristic is a corner point, e.g. a discontinuity or a steep variation of the derivative of the rate of pressure loss as a function of pulse width, in said rate of pressure loss in-between two plateau regions; or the foot of an increase of said rate of pressure loss above a predetermined threshold and over a predetermined pulse width interval.

17. A carrier medium carrying a computer readable code comprising instructions causing an electronic control unit, when said code is executed by said electronic control unit, to carry out the method of any one of claims 1 to 14.

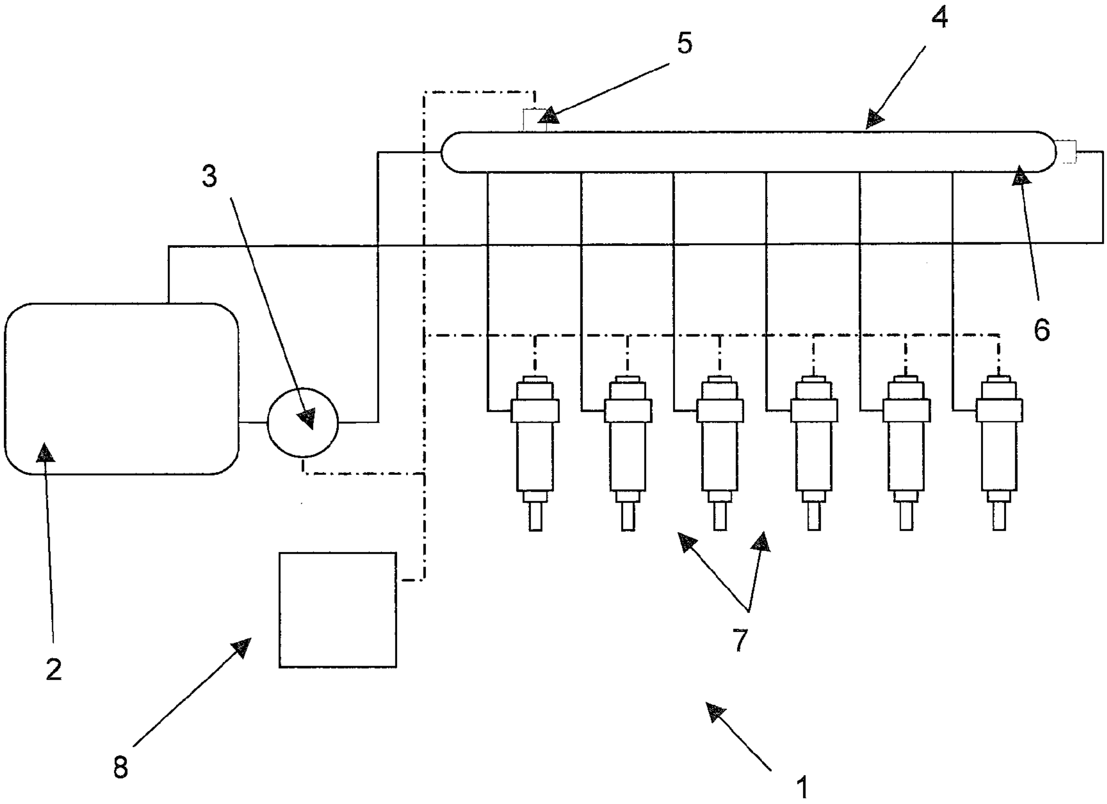

FIG. 1

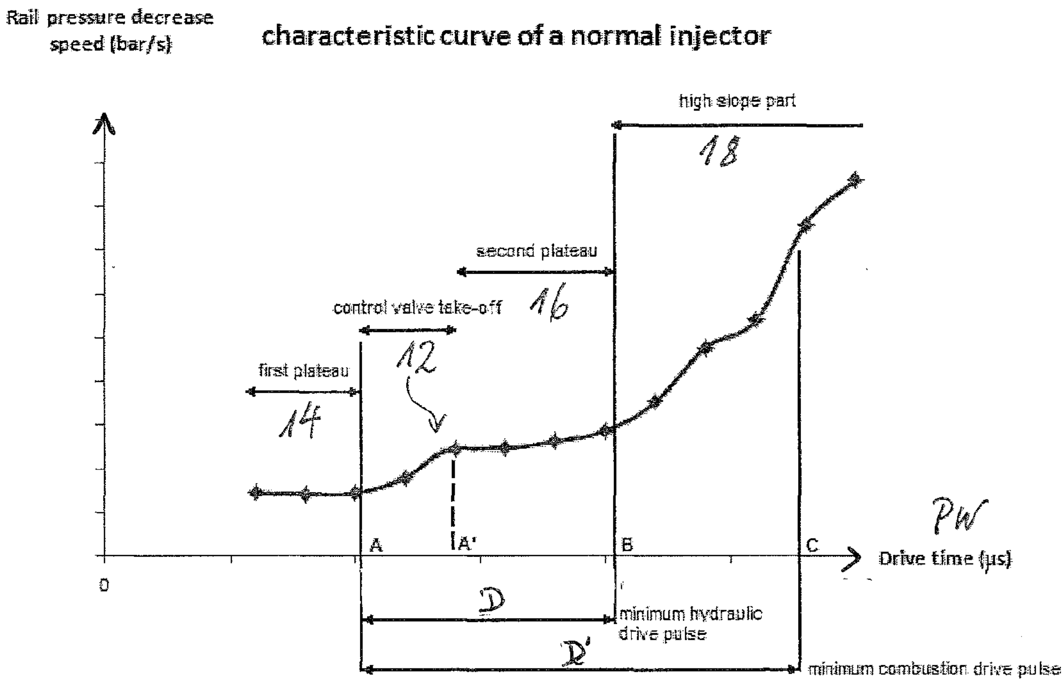
Rail pressure decrease speed (bar/s)
characteristic curve of a normal injector
high slope part
18
second plateau
16
control valve take-off
12
first plateau
14
A
A'
B
C
0
PW
Drive time (µs)
D
minimum hydraulic drive pulse
D'
minimum combustion drive pulse

FIG. 2

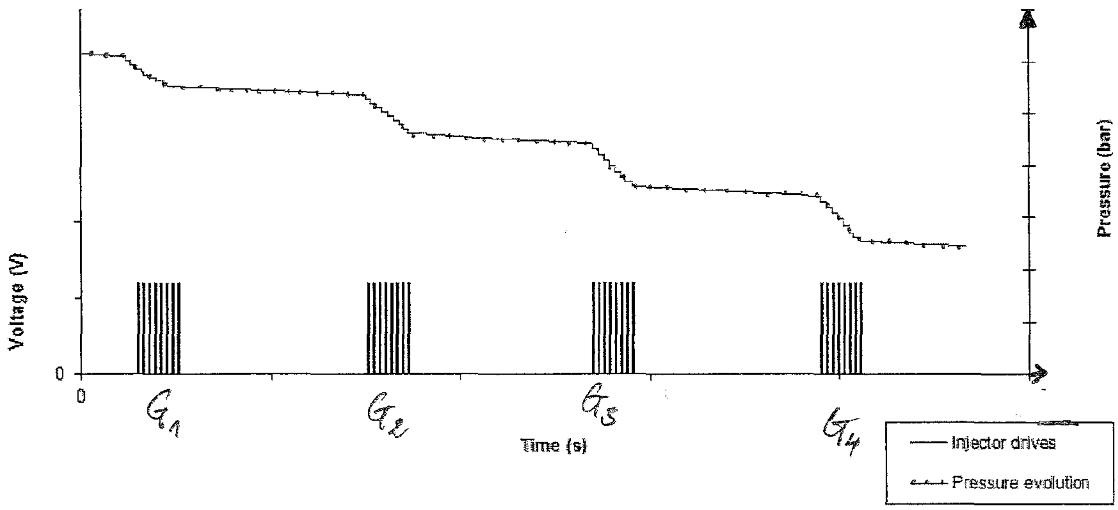
Voltage (V)
Pressure (bar)
0
0
G1
G2
G3
G4
Time (s)
Injector drives
Pressure evolution

FIG. 3

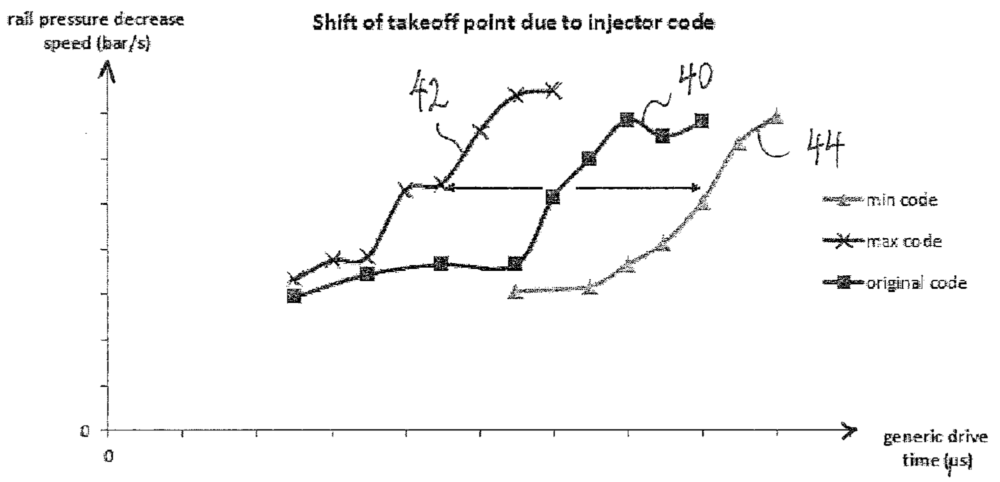
rail pressure decrease speed (bar/s)
Shift of takeoff point due to injector code
42
40
44
min code
max code
original code
0
0
generic drive time (μs)

FIG. 4

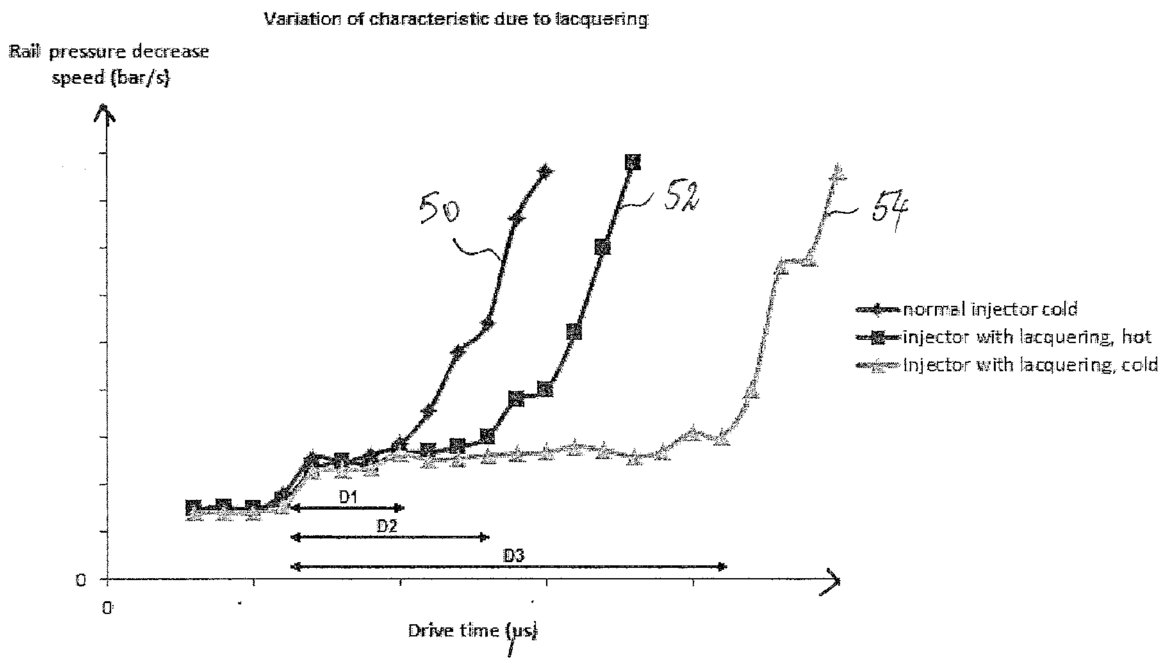
Variation of characteristic due to lacquering
Rail pressure decrease speed (bar/s)
50
52
54
normal injector cold
injector with lacquering, hot
Injector with lacquering, cold
D1
D2
D3
0
0
Drive time (μs)

FIG. 5

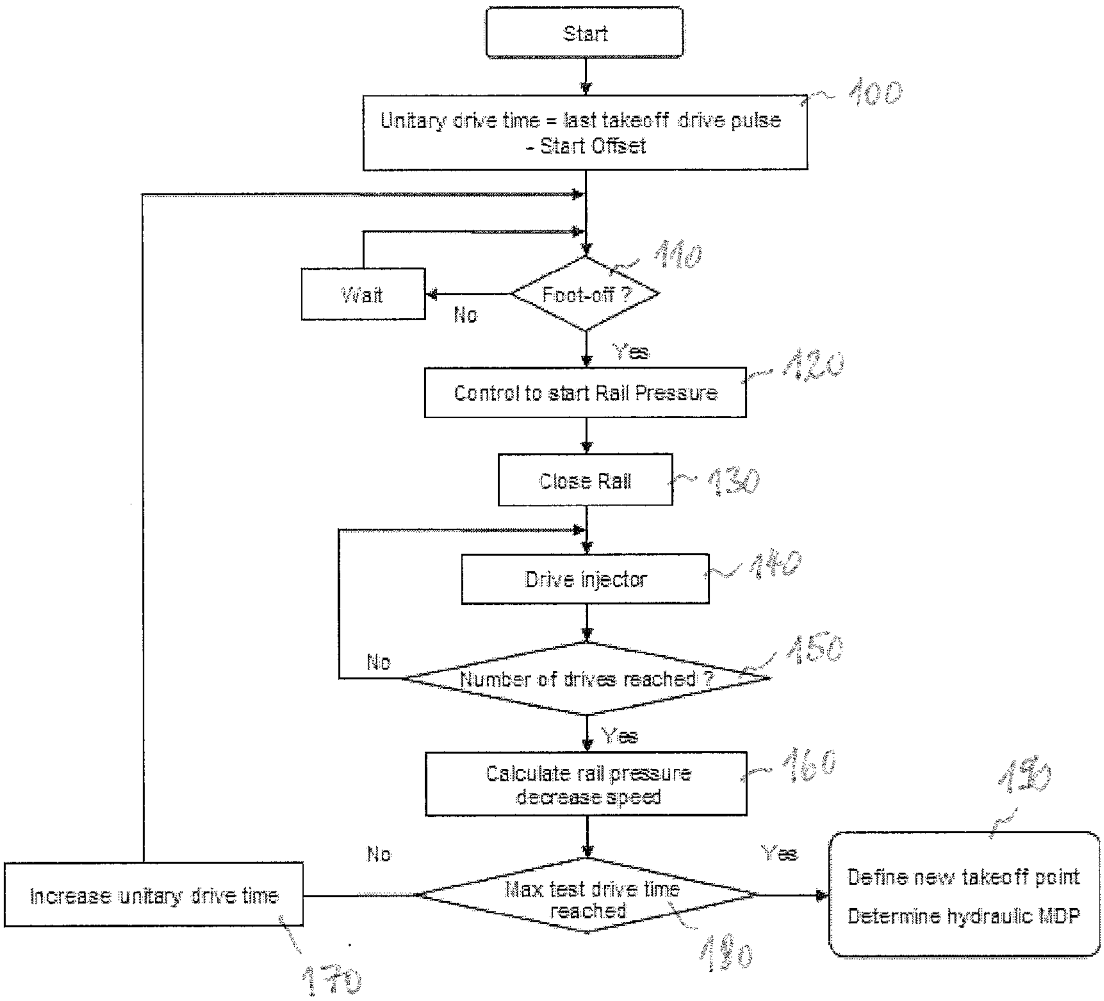
Start
100
Unitary drive time = last takeoff drive pulse - Start Offset
110
Wait
Foot-off ?
No
Yes
120
Control to start Rail Pressure
130
Close Rail
140
Drive injector
150
No
Number of drives reached ?
Yes
160
Calculate rail pressure decrease speed
190
No
Yes
Increase unitary drive time
Max test drive time reached
Define new takeoff point
Determine hydraulic MDP
170
180

FIG.6

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 12 18 3485

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 2 453 124 A1 (DELPHI TECH HOLDING SARL [LU]) 16 May 2012 (2012-05-16) * abstract * * paragraph [0002] * * paragraph [0006] - paragraph [0018] * * paragraph [0020] - paragraph [0041] * * paragraph [0044] * * paragraph [0050] - paragraph [0055] * * figures 2,6 * -----	1-17	INV. F02D41/24
X	EP 2 453 123 A1 (MAGNETI MARELLI SPA [IT]) 16 May 2012 (2012-05-16) * abstract * * paragraph [0005] - paragraph [0008] * * paragraph [0020] - paragraph [0022] * * paragraphs [0026], [0027] * * paragraph [0035] - paragraph [0039] * * figures 3,5,6 * -----	1,8,10, 11, 13-15,17	
X	EP 2 031 225 A2 (DENSO CORP [JP]) 4 March 2009 (2009-03-04) * abstract * * paragraph [0045] - paragraph [0064] * * figures 5-7 * -----	1,15,17	TECHNICAL FIELDS SEARCHED (IPC) F02D
X	EP 1 854 987 A2 (SCANIA CV ABP [SE]) 14 November 2007 (2007-11-14) * abstract * * paragraph [0006] - paragraph [0008] * * paragraph [0011] * * paragraph [0026] - paragraph [0036] * -----	1,15,17	
A,D	EP 2 336 534 A1 (DELPHI TECH INC [US]) 22 June 2011 (2011-06-22) * the whole document * -----	1-17	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	20 February 2013	Wettemann, Mark

CATEGORY OF CITED DOCUMENTS

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

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

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 12 18 3485

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

20-02-2013

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2453124 A1	16-05-2012	EP 2453124 A1	16-05-2012
		WO 2012066044 A1	24-05-2012
EP 2453123 A1	16-05-2012	EP 2453123 A1	16-05-2012
		US 2012123703 A1	17-05-2012
EP 2031225 A2	04-03-2009	CN 101377167 A	04-03-2009
		EP 2031225 A2	04-03-2009
		JP 4462307 B2	12-05-2010
		JP 2009057926 A	19-03-2009
		US 2009056676 A1	05-03-2009
EP 1854987 A2	14-11-2007	EP 1854987 A2	14-11-2007
		SE 0601055 A	12-11-2007
		US 2007261483 A1	15-11-2007
EP 2336534 A1	22-06-2011	EP 2336534 A1	22-06-2011
		WO 2011073147 A1	23-06-2011

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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

- US 7136743 B **[0003]**
- WO 2011073147 A **[0004]**