(12) UK Patent Application (19) GB (11) 2500207 (13) A

(43) Date of A Publication 18.09.2013

(21) Application No: 1204368.3

(22) Date of Filing: 12.03.2012

(71) Applicant(s):
GM Global Technology Operations LLC
PO Box 300, 300 Renaissance Center, Detroit, 48265-3000, United States of America

(72) Inventor(s):
Massimiliano Melis
Antonio Arpaia
Daniele Carboni

(74) Agent and/or Address for Service:
Adam Opel GmbH
Intellectual Property Patents, IPC:AO-02, Rüsselsheim 65423, Germany

(51) INT CL:
F02D 41/40 (2006.01) ***F02D 41/38*** (2006.01)

(56) Documents Cited:
GB 2284908 A
JP 090060542 A
JP 2010180825 A
US 20110137541 A1
US 20060037586 A1

(58) Field of Search:
INT CL **F02D**
Other: **EPODOC, WPI**

(54) Title of the Invention: **Method of operating a fuel injection system of an internal combustion engine**
Abstract Title: **Fuel injection method comprising correction factors for fuel rail pressure and fuel temperature**

(57) Disclosed is a method of operating a fuel injection system of an internal combustion engine by controlling the injection timing. The injection system comprises a fuel injector, hydraulically connected to a fuel rail. The method comprises determining a nominal energizing time indicative of a nominal fuel quantity to be injected into the cylinder, determining a first energizing time correction as a function of the nominal energizing time and a fuel rail pressure and determining a second energizing time correction as a function of the first energizing time correction, the fuel rail pressure, and a fuel temperature. A target energizing time is calculated by adding the nominal energizing time and the first and second correction times. The fuel injector is then energized for the target energizing time to inject the nominal fuel quantity.

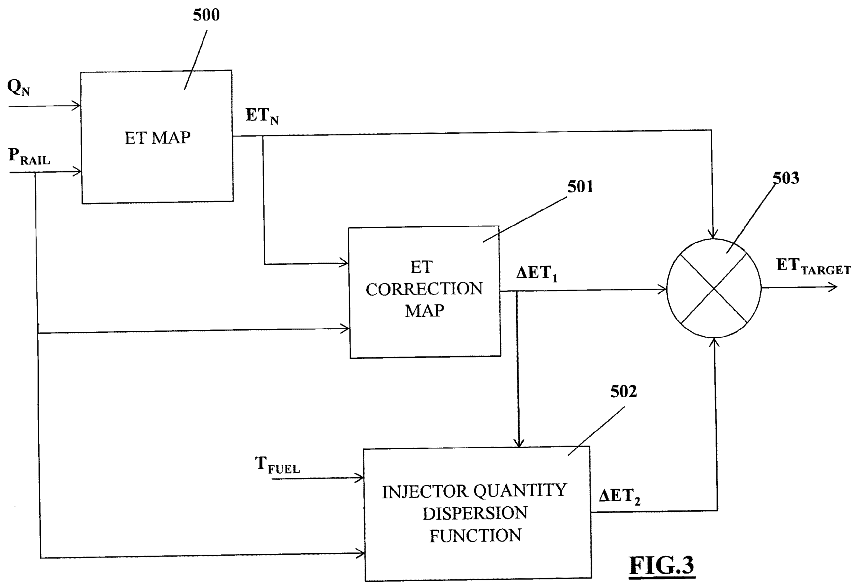

FIG.3

GB 2500207 A

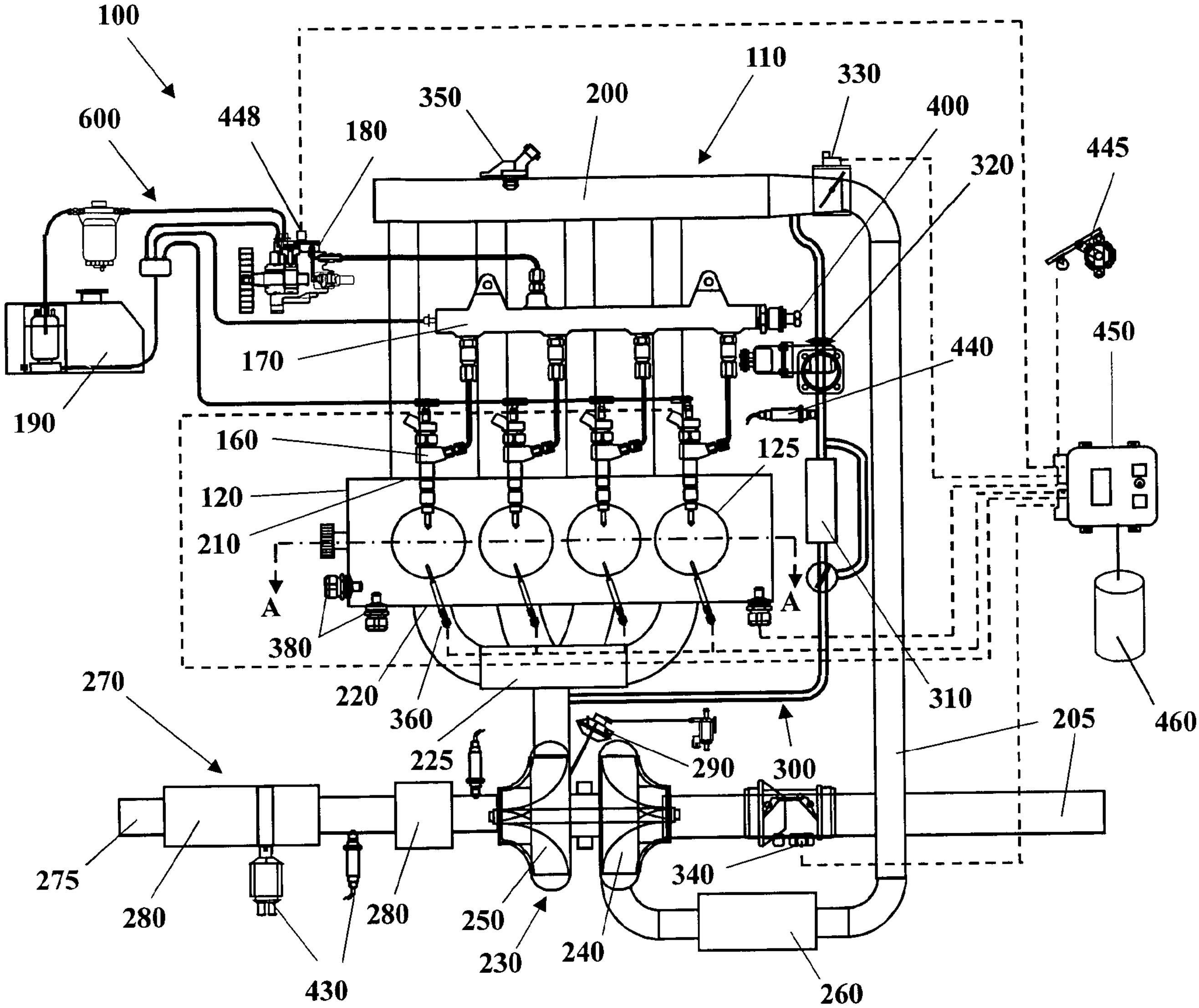
100
600
448
180
350
200
110
330
400
320
445
190
170
440
450
160
125
120
210
A
A
380
220
360
225
310
460
270
290
300
205
275
280
280
250
230
240
340
430
260

FIG.1

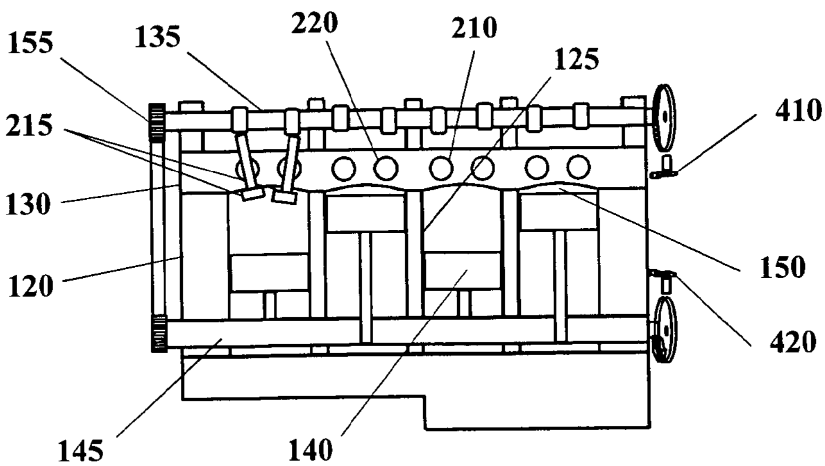
155
135
220
210
125
215
410
130
150
120
420
145
140

FIG.2

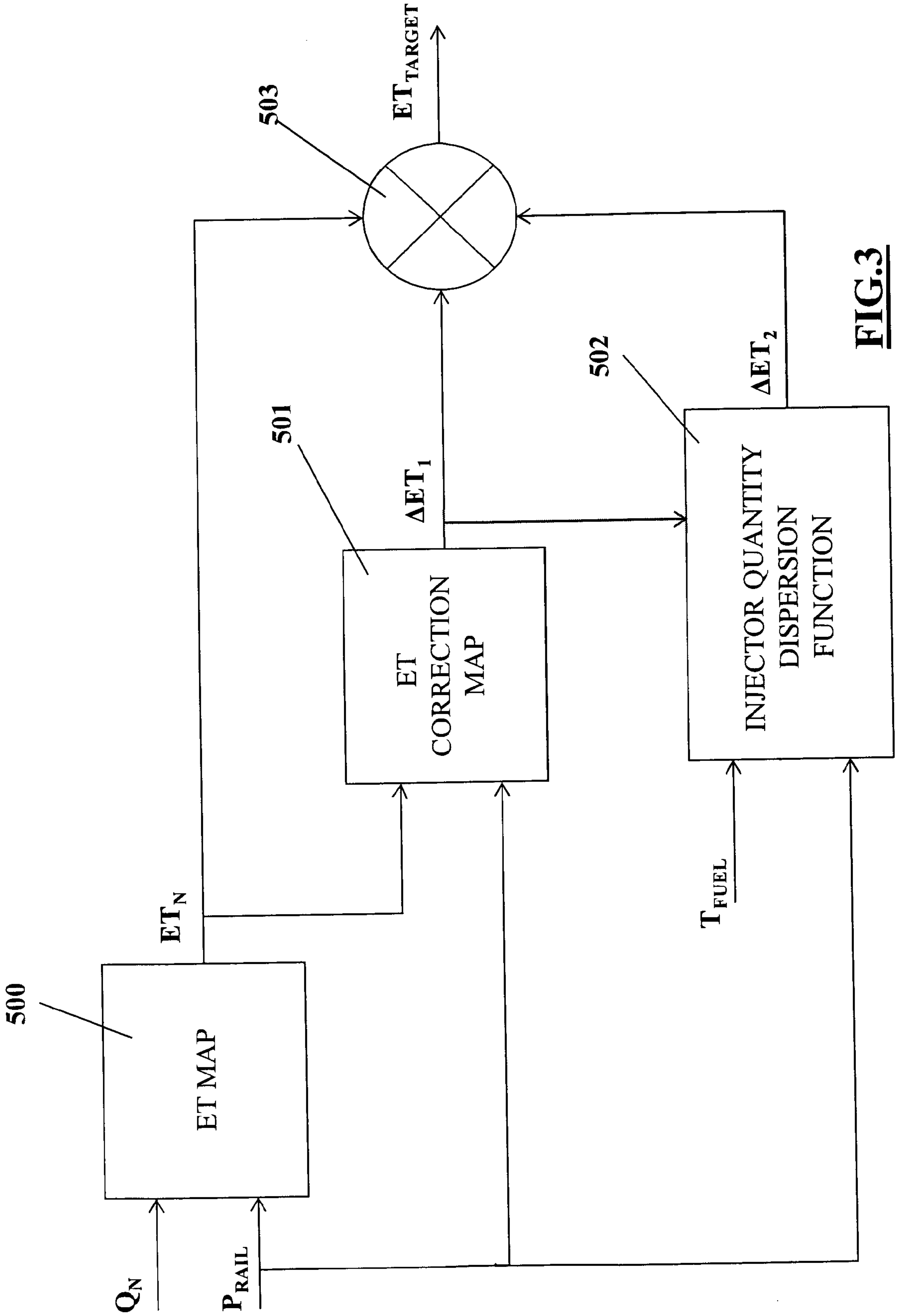
500
ET MAP
501
ET CORRECTION MAP
502
INJECTOR QUANTITY DISPERSION FUNCTION
503
Q_N
P_{RAIL}
ET_N
ΔET_1
ΔET_2
T_{FUEL}
ET_{TARGET}

FIG.3

METHOD OF OPERATING A FUEL INJECTION SYSTEM OF AN INTERNAL COMBUSTION ENGINE

TECHNICAL FIELD

The present disclosure relates to a method of operating a fuel injection system for an internal combustion engine.

BACKGROUND

It is known that modern Diesel engines are provided with a fuel injection system for directly injecting fuel into the cylinders of the engine.

The fuel injection system generally comprises a fuel common rail and a plurality of electrically controlled fuel injectors, which are individually located in a respective cylinder of the engine and which are hydraulically connected to the fuel common rail through dedicated feeding conduits. In detail, each fuel injector comprises an injection needle allowing the injection of fuel, from the fuel common rail, into the cylinder. The injection needle works as a valve member opening and closing a valve seat.

With present injector technology, the actually injected fuel quantity, in each cylinder and for each injection, can be different from the desired or nominal fuel quantity.

This undesirable condition may be caused by several reasons and basically by dispersion on injection characteristics due to the production spread or drift of injection characteristic due to aging of the injection system.

Present injector production processes are actually not precise enough to produce injectors with tight tolerances. Moreover those tolerances tend to get worse with aging during injector lifetime.

As a result of all these factors, taking as an example the case of a solenoid injector, for a given energizing time at a given rail pressure, the actually injected fuel quantity can be different injector-by-injector.

In order to solve this problem, in the prior art injection system, the engine control unit, which controls the operation of the injectors, comprises an energizing time correction map containing correction energizing time values as a function of different fuel quantity values to be injected and of fuel rail pressure values. The correction map is experimentally determined at a reference fuel temperature, typically at 40° C.

A drawbacks of the above disclosed injection systems is due to the fact that the actually injected fuel quantity depends on the fuel temperature. As a consequence the prior art injection systems works properly only at the reference fuel temperature.

This fact forces the engine manufacturers to time spending process of calibration of the engine fuel injection system.

An object of an embodiment of the invention is to provide a method of operating a fuel injection system for an internal combustion engine which allows the precise delivery of fuel for different fuel temperature.

Another object of an embodiment of the invention is to provide a fuel injection system for an internal combustion engine that can be controlled for supplying the actual fuel requested for operating the engine for each operating point.

SUMMARY

These and/or other objects are attained by the characteristics of the embodiments of the invention as reported in independent claims. The dependent claims recite preferred and/or especially advantageous features of the embodiments of the invention.

In detail, an embodiment of the invention provides a method of operating a fuel injection system of an internal combustion engine, wherein the injection system comprises a fuel injector, hydraulically connected to a fuel rail, the method comprising the following steps:

- determining a nominal energizing time indicative of a nominal fuel quantity to be injected into the cylinder,
- determining a first energizing time correction as a function of the nominal energizing time and a fuel rail pressure,
- determining a second energizing time correction as a function of the first energizing time correction, the fuel rail pressure, and a fuel temperature,
- calculating a target energizing time by adding the nominal energizing time and the first and second correction,
- activating the fuel injector for the target energizing time to inject the nominal fuel.

An advantage of this embodiment is to provide a reliable and accurate method of injecting the nominal fuel quantity into the cylinder of the engine.

An accurate injection of the nominal fuel quantity reduces cost relative to the engine injection system calibration.

According to an aspect of the invention, the second correction energizing time is determined by means of a function representing an injector fuel quantity dispersion.

An advantage of this aspect of the invention is that the use of statistical dispersion function, empirically determined, allows a faster acquisition of the data during the development tests over a reasonable number of sample injectors.

According to another aspect of the invention, the injector fuel quantity dispersion function is expressed by the following equation:

$$\Delta ET\,(T) = a \cdot T + b \cdot T + c \cdot {P_{RAIL}}^2$$

wherein a, b, c are indexes, T indicates the fuel temperature and P_{RAIL} is a fuel rail pressure .

This equation of the fuel quantity dispersion function allows an accurate determination of the second correction energizing time as a function of the first correction energizing time, the rail pressure, and a fuel temperature.

A further aspect of the invention relates to a fuel injection system for an internal combustion engine, comprising a fuel injector, for injecting the fuel into a cylinder of the engine, said fuel injector being hydraulically connected to a fuel rail, an electronic control unit connected to the injector and to a fuel temperature sensor wherein the electronic control unit is configured to operate according to the above disclosure.

An advantage of this embodiment of the invention is that the injector is activated to inject the nominal fuel quantity for a target energizing time which keeps into account also the actual operating fuel temperature. This allows an accurate injection of the nominal fuel quantity.

A further aspect of the invention relates to an internal combustion engine comprising an engine block, defining a cylinder, and a fuel injection system according to the above disclosure arranged to inject fuel into the cylinder.

Another aspect of the invention relates to an apparatus for operating an internal combustion engine according to the above disclosure, the apparatus comprising:

- means for determining a nominal energizing time indicative of a nominal fuel quantity to be injected into the cylinder,
- means for determining a first energizing time correction as a function of the nominal energizing time and a fuel rail pressure ,
- means for determining a second energizing time correction as a function of the first energizing time correction, the fuel rail pressure, and a fuel temperature,
- means for calculating a target energizing time by adding the nominal energizing time and the first and second correction,
- means for activating the fuel injector for the target energizing time to inject the

nominal fuel quantity.

A further aspect of the invention relates to an automotive system comprising an internal combustion engine according to the above disclosure and an Electronic Control Unit, wherein the Electronic Control Unit is configured to:

- determining a nominal energizing time indicative of a nominal fuel quantity to be injected into the cylinder,
- determining a first energizing time correction as a function of the nominal energizing time and a fuel rail pressure,
- determining a second energizing time correction as a function of the first energizing time correction, the fuel rail pressure , and a fuel temperature,
- calculating a target energizing time by adding the nominal energizing time and the first and second correction,
- activating the fuel injector for the target energizing time to inject the nominal fuel quantity.

The advantages of the engine, of the apparatus and of the automotive system embodiments of the invention are substantially the same of those of the method of operation of the internal combustion engine provided with a fuel injection system according to the various embodiments of the invention.

The methods according to the invention can be carried out with the help of a computer program comprising a program-code for carrying out all the steps of the method described above, and in the form of a computer program product on which the computer program is stored. The method can be also embodied as an electromagnetic signal, said signal being modulated to carry a sequence of data bits which represent a computer program to carry out all steps of the method.

BRIEF DESCRIPTION OF THE DRAWINGS

The various embodiments will now be described, by way of example, with reference to the accompanying drawings, wherein like numerals denote like elements, and in which:

Figure 1 shows an automotive system;

Figure 2 is a cross-section of an internal combustion engine belonging to the automotive system of figure 1;

Figure 3 is a schematic representation of a control logic that can be employed to control the fuel injection system according to an embodiment of the invention;

DETAILED DESCRIPTION

Some embodiments may include an automotive system 100, as shown in Figures 1 and 2, that includes an internal combustion engine (ICE) 110 having an engine block 120 defining at least one cylinder 125 having a piston 140 coupled to rotate a crankshaft 145. A cylinder head 130 cooperates with the piston 140 to define a combustion chamber 150. A fuel and air mixture (not shown) is disposed in the combustion chamber 150 and ignited, resulting in hot expanding exhaust gasses causing reciprocal movement of the piston 140. The fuel is provided by at least one fuel injector 160 and the air through at least one intake port 210.

In greater detail the fuel is provided by a fuel injection system 600 comprising the fuel injector 160 hydraulically connected to a fuel rail 170 in fluid communication with a high pressure fuel pump 180 that increases the pressure of the fuel received from a fuel source 190.

Each of the cylinders 125 has at least two valves 215, actuated by a camshaft 135 rotating in time with the crankshaft 145. The valves 215 selectively allow air into the combustion chamber 150 from the port 210 and alternately allow exhaust gases to exit through at least one exhaust port 220. In some examples, a cam phaser 155 may selectively vary the timing between the camshaft 135 and the crankshaft 145.

The air may be distributed to the air intake port(s) 210 through an intake manifold 200. An air intake pipe 205 may provide air from the ambient environment to the intake manifold 200. In other embodiments, a throttle body 330 may be provided to regulate the flow of air into the manifold 200. In still other embodiments, a forced air system such as a turbocharger 230, having a compressor 240 rotationally coupled to a turbine 250, may be provided. Rotation of the compressor 240 increases the pressure and temperature of the air in the intake pipe 205 and manifold 200. An intercooler 260 disposed in the intake pipe 205 may reduce the temperature of the air. The turbine 250 rotates by receiving exhaust gases from an exhaust manifold 225 that directs exhaust gases from the exhaust ports 220 and through a series of vanes prior to expansion through the turbine 250. This example shows a variable geometry turbine (VGT) with a VGT actuator 290 arranged to move the vanes to alter the flow of the exhaust gases through the turbine 250. In other embodiments, the turbocharger 230 may be fixed geometry and/or include a waste gate.

The exhaust gases exit the turbine 250 and are directed into an exhaust system 270. The exhaust system 270 may include an exhaust pipe 275 having one or more exhaust aftertreatment devices 280. The aftertreatment devices may be any device configured to change the composition of the exhaust gases. Some examples of aftertreatment devices 280 include, but are not limited to, catalytic converters (two and three way), oxidation catalysts, lean NOx traps, hydrocarbon adsorbers, selective catalytic reduction (SCR) systems, and particulate filters. Other embodiments may include an exhaust gas recirculation (EGR) system 300 coupled between the exhaust manifold 225 and the intake manifold 200. The EGR system 300 may include an EGR cooler 310 to reduce the temperature of the exhaust gases in the EGR system 300. An EGR valve 320 regulates a flow of exhaust gases in the EGR system 300.

The automotive system 100 may further include an electronic control unit (ECU) 450 in communication with one or more sensors and/or devices associated with the ICE 110. The ECU 450 may receive input signals from various sensors configured to generate the signals in proportion to various physical parameters associated with the ICE 110. The sensors include, but are not limited to, a mass airflow and temperature sensor 340, a manifold pressure and temperature sensor 350, a combustion pressure sensor 360, coolant and oil temperature and level sensors 380, a fuel rail pressure sensor 400, a camshaft position sensor 410, a crankshaft position sensor 420, exhaust pressure and temperature sensors 430, an EGR temperature sensor 440, an accelerator pedal position sensor 445, and a fuel temperature sensor 448 located in the high pressure fuel pump 180. Furthermore, the ECU 450 may generate output signals to various control devices that are arranged to control the operation of the ICE 110, including, but not limited to, the fuel injectors 160, the throttle body 330, the EGR Valve 320, the VGT actuator 290, and the cam phaser 155. Note, dashed lines are used to indicate communication between the ECU 450 and the various sensors and devices, but some are omitted for clarity.

Turning now to the ECU 450, this apparatus may include a digital central processing unit (CPU) in communication with a memory system 460 and an interface bus. The memory system 460 may include various storage types including optical storage, magnetic storage, solid state storage, and other non-volatile memory. The interface bus may be configured to send, receive, and modulate analog and/or digital signals to/from the various sensors and control devices. The CPU is configured to execute instructions stored as a program in the memory system 460, and send and receive signals to/from the interface bus. The program may embody the methods disclosed herein, allowing the CPU to carryout out the steps of such methods and control the ICE 110.

Figure 3 is a schematic representation of a control logic that can be employed to operate the fuel injection system 600 of the engine.

According to the present embodiment of the invention the ECU 450 determines, for each engine operating point, i.e. for each engine load EL and engine speed ES, a nominal fuel quantity Q_N to be injected into a cylinder 125 of the engine 110 and a nominal fuel rail pressure P_{RAIL}.

A map, stored in the memory system 460, correlates each nominal fuel quantity Q_N and nominal fuel rail pressure P_{RAIL} to a predetermined energizing time ET_N (block 500) of activation of the injectors 160, i.e. the time duration of activation of the injectors 160 for injecting the nominal fuel quantity Q_N into the cylinders 125. This map may be a calibration map, which is empirically determined during an experimental activity on a test bench and then stored in the memory system 460.

The ECU 450 then determines a first and a second energizing time correction . In detail, the first energizing time correction ΔET_1 is determined (block 501) by means of an energizing time correction map, stored in the memory system 460, as a function of the nominal energizing time ET_N and the nominal fuel rail pressure P_{RAIL}.

The second energizing time correction ΔET_2 is determined (block 502)as a function of the first energizing time correction ΔET_1 , the nominal fuel rail pressure P_{RAIL}, measured by the fuel rail sensor 400, and the fuel temperature T_{FUEL}, measured by the fuel temperature sensor 448.

In particular, the second energizing time correction is determined by means of an empirically determined function representing an injector fuel quantity dispersion, which, accordingly to the present embodiment of the invention, can be expressed by the following equation:

$$\Delta ET_2\,(T) = a \cdot T + b \cdot T + c \cdot {P_{RAIL}}^2$$

wherein a, b, c are statistically evaluated indexes, T indicates the fuel temperature T_{FUEL}, measured by the fuel temperature sensor 448, and P_{RAIL} is the nominal fuel rail pressure .

The first and second energizing time corrections are then added (adder 503), by the ECU, to the nominal energizing time determining a target energizing time ET_{TARGET}:

$$ET_{TARGET} = ET_N + \Delta ET_1 + \Delta ET_2$$

The ECU activates the fuel injector 160 for the target energizing time ET_{TARGET} to inject the nominal fuel quantity into a cylinder 125 of the engine 110 to inject the nominal fuel quantity into the cylinder 125.

While at least one exemplary embodiment has been presented in the foregoing summary and detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration in any way. Rather, the foregoing summary and detailed description will provide those skilled in the art with a convenient road map for implementing at least one exemplary embodiment, it being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope as set forth in the appended claims and their legal equivalents.

REFERENCES

100 automotive system
110 internal combustion engine
120 engine block
125 cylinder
130 cylinder head
135 camshaft
140 piston
145 crankshaft
150 combustion chamber
155 cam phaser
160 fuel injector
170 fuel rail
180 fuel pump
190 fuel source
200 intake manifold
205 air intake pipe
210 intake port
215 valves
220 exhaust port
225 exhaust manifold
230 turbocharger
240 compressor
250 turbine
260 intercooler
270 exhaust system
275 exhaust pipe
280 aftertreatment devices
290 VGT actuator
300 exhaust gas recirculation system
310 EGR cooler
320 EGR valve
330 throttle body
340 mass airflow and temperature sensor
350 manifold pressure and temperature sensor

360 in-cylinder pressure sensor

380 coolant and oil temperature and level sensors

400 fuel rail pressure sensor

410 camshaft position sensor

420 crankshaft position sensor

430 exhaust pressure and temperature sensors

440 EGR temperature sensor

445 accelerator pedal position sensor

448 fuel temperature sensor

450 ECU

460 memory system

500 block

501 block

502 block

503 adder

CLAIMS

1. A method of operating a fuel injection system (600) of an internal combustion engine (110), wherein the injection system (600) comprises a fuel injector (160), hydraulically connected to a fuel rail (170), for injecting the fuel into a cylinder (125) of the engine, the method comprising the following steps:

– determining a nominal energizing time (ET_N) indicative of a nominal fuel quantity (Q_N) to be injected into the cylinder (125),

-determining a first energizing time correction (ΔET_1) as a function of the nominal energizing time (ET_N) and a fuel rail pressure (P_{RAIL}),

- determining a second energizing time correction (ΔET_2) as a function of the first energizing time correction (ΔET_1), the fuel rail pressure (P_{RAIL}), and a fuel temperature (T_{FUEL}),

- calculating a target energizing time (ET_{TARGET}) by adding the nominal energizing time (ET_N) and the first and second correction (ΔET_1, ΔET_2),

- activating the fuel injector (160) for the target energizing time (ET_{TARGET}) to inject the nominal fuel quantity (Q_N).

2. A method according to claim 1, wherein the second energizing time correction (ΔET_2) is determined by means of a function ($\Delta ET(T)$) representing an injector fuel quantity dispersion.

3. A method according to claim 2, wherein the injector fuel quantity dispersion function ($\Delta ET(T)$) is expressed by the following equation:

$$\Delta ET\ (T) = a \cdot T + b \cdot T + c \cdot P_{RAIL}{}^{2}$$

wherein a , b , c are statistically evaluated indexes, T indicates the fuel temperature and P_{RAIL} is the fuel rail pressure .

4. A fuel injection system (600) for an internal combustion engine, comprising a fuel injector (160), for injecting the fuel into a cylinder (125) of the engine (110),said fuel injector being hydraulically connected to a fuel rail (170), an electronic control unit (450) connected to the injector (160), and a fuel temperature sensor (448) wherein the electronic control unit (450) is configured to operate according to any of the claims from 1 to 3.

5. An internal combustion engine (110) comprising an engine block (120) defining a cylinder (125) and a fuel injection system (600) according to claim 4 arranged to inject fuel into the cylinder (125).

6. An apparatus for operating an internal combustion engine (110) according to claim 5, the apparatus comprising:

- means for determining a nominal energizing time (ET_N) indicative of a nominal fuel quantity (Q_N) to be injected into the cylinder (125),
- means for determining a first energizing time correction (ΔET_1) as a function of the nominal energizing time (ET_N) and a fuel rail pressure (P_{RAIL}),
- means for determining a second energizing time correction (ΔET_2) as a function of the first energizing time correction (ΔET_1), the fuel rail pressure (P_{RAIL}), and a fuel temperature (T_{FUEL}),
- means for calculating a target energizing time (ET_{TARGET}) by adding the nominal energizing time (ET_N) and the first and second correction ($\Delta ET_1, \Delta ET_2$),
- means for activating the fuel injector (160) for the target energizing time (ET_{TARGET}) to inject the nominal fuel quantity (Q_N).

7. An automotive system (100) comprising an internal combustion engine (110) according to claim 5 and an Electronic Control Unit (450), wherein the Electronic Control Unit (450) is configured to:

- determining a nominal energizing time (ET_N) indicative of a nominal fuel quantity (Q_N) to be injected into the cylinder (125),
- determining a first energizing time correction (ΔET_1) as a function of the nominal energizing time (ET_N) and a fuel rail pressure (P_{RAIL}),
- determining a second energizing time correction (ΔET_2) as a function of the first energizing time correction (ΔET_1), the fuel rail pressure (P_{RAIL}), and a fuel temperature (T_{FUEL}),
- calculating a target energizing time (ET_{TARGET}) by adding the nominal energizing time (ET_N) and the first and second correction ($\Delta ET_1, \Delta ET_2$),
- activating the fuel injector (160) for the target energizing time (ET_{TARGET}) to inject the nominal fuel quantity (Q_N).

8. A computer program comprising a computer code suitable for performing the method according to any of the claims from 1 to 3.

9. A computer program product on which the computer program of claim 8 is stored.

10. An electromagnetic signal modulated as a carrier for a sequence of data bits representing the computer program according to claim 8.

INTELLECTUAL
PROPERTY OFFICE

Application No:	GB1204368.3	**Examiner:**	Mr Alastair Kelly
Claims searched:	1-10	**Date of search:**	15 June 2012

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-10	GB2284908 A [FORD] See abstract and figures and note page 3, line 31 to page 4, line 9
X	1-10	JP09060542 A [HINO] See figures and note abstract attached
X	6 at least	US2011/137541 A1 [MALIKOPOULOS] See abstract and figures
X	6 at least	JP2010180825 A [HONDA] See figures and note abstracts attached
X	6 at least	US2006/037586 A1 [FRITSCH] See abstract and figures

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F02D

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	**Subgroup**	**Valid From**
F02D	0041/40	01/01/2006
F02D	0041/38	01/01/2006