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(54) Title: A DEVICE AND METHOD TO DETERMINE FUEL PRESSURE AT A FUEL INJECTOR

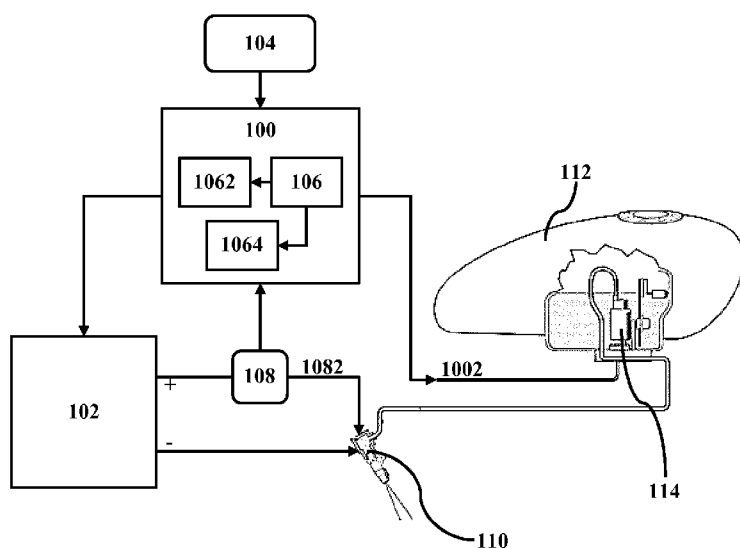


FIG. 1

(57) Abstract: The various embodiments of the
present disclosure provide a device which comprises
a controller 100 to determine the fuel pressure at a
fuel injector 110. The controller 100 is adapted to
measure a signal comprising load current 1082 drawn
by the actuator against time. The controller 100 then
processes the measured signal using a processing
module 1062. A memory element 106 is either integ-
ral to the controller 100 or is externally connected to
the controller 100. The controller 100 compares the
output of the processing module 1062 with a pressure
map 1064 stored in the memory element 106. The
controller 100 then determines/estimates the fuel
pressure of the fuel based on the comparison.



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

Title: A device and method to determine fuel pressure at a fuel injector

Field of the invention:

The present disclosure relates to a device to determine fuel pressure, and particularly relates to a device and method for estimating pressure of a fuel supplied by a Fuel Supply Module (FSM) to a fuel injector.

Background of the invention:

A US patent US7305971 discloses a fuel injection system ensuring operation in event of unusual condition. A common rail fuel injection apparatus for an engine is provided which is equipped with a rail pressure sensor working to measure the pressure of fuel in a common rail, fuel injectors, and a controller. When the operation state of the rail pressure sensor monitored to be unusual, the controller changes the value of electricity supplied to an actuator of one of the fuel injectors to induce a change in a preselected operation characteristic of the engine. Upon appearance of such a change, the controller estimates the value of the rail pressure using the changed value of the electricity and a physical property of balance among forces acting on a valve of one of the fuel injectors which has induced the change in operation characteristic of the engine. The estimated value of the rail pressure is used for subsequent injections of the fuel into the engine.

The fuel subsystem of a vehicle consists of Fuel Supply Module (FSM) and a Fuel Injector. The FSM supplies pressurized fuel to the fuel injector. An Electronic Control Unit (ECU) controls the closing and opening of the injection valve. The functionalities are calibrated to operate at a constant pressure as there is no feedback on the fuel pressure. The FSM is equipped with a pressure regulator module which is basically a mechanical spring. Since the mechanical spring based pressure regulation is inaccurate, there is variations in the supplied fuel to the fuel injector. The variations in the fuel pressure creates variation in the injected fuel quantity.

Hence, there is a need for a low cost solution to determine the fuel pressure. Further, there is a need for a device to estimate the fuel pressure without using a pressure sensor with improved accuracy.

Brief description of the accompanying drawings:

An embodiment of the disclosure is described with reference to the following accompanying drawings,

Fig. 1 illustrates a schematic block diagram of a device to determine fuel pressure at a fuel injector, according to an embodiment of the present disclosure;

Fig. 2 illustrates details of variables associated with fuel injector actuation, according to an embodiment of the present disclosure, and

Fig. 3 illustrates a method for determining fuel pressure at a fuel injector, according to an embodiment of the present disclosure.

Detailed description of the embodiments:

Fig. 1 illustrates a schematic block diagram of a device to determine fuel pressure at a fuel injector, according to an embodiment of the present disclosure. The device determines fuel pressure at a fuel injector 110, where the fuel injector 110 is controlled/ operated by an actuator and driven by a drive circuit (not shown). The actuator is a solenoid or electromagnetic coil. A piezoelectric material is also allowed to be used as the actuator. The drive circuit further receives command from a controller 100. The controller 100 also controls the supply of current from the battery 102.

The device comprises the controller 100 which determines/ estimates the fuel pressure. The controller 100 is either the same controller 100 which commands the drive circuit or a separate controller 100. During runtime of a vehicle, i.e. when the engine is running, the controller 100 is adapted to measure a signal comprising load current 1082 drawn by the actuator against time. The load current 1082 is measured using a current sensing means 108 such as a resistor or any other current sensing circuit/component, which is in electrical connection with the actuator. Alternatively, the voltage developed by current sensing means 108 is the feedback to the controller 100. The controller 100 then processes the measured signal using a processing module 1062. The processing module 1062 is accessed from a memory element 106. The memory element 106 is either integral to the controller 100 or is externally connected to the controller 100. The controller 100 compares the output of the processing module 1062 with a

pressure map 1064 stored in the memory element 106. The controller 100 then determines/estimates the fuel pressure of the fuel based on the comparison.

The processing module 1062 converts/ transforms the signal measured in time domain into a signal in frequency domain. The time domain signal for either the load current 1082 or the voltage which is replication of load current 1082, is converted to frequency domain signal through Fast Fourier Transform (FFT) or Discrete Fourier Transform (DFT). The processing module 1062 uses Fast Fourier Transforms (FFT) or other known techniques for the transformation of the signal from time domain to frequency domain. The processing module 1062 further computes a magnitude of a first frequency such as fundamental frequency. The magnitude is compared with the pressure map 1064 by the controller 100 to derive the fuel pressure.

In accordance to an embodiment of the present disclosure, the processing module 1062 computes magnitude of at least one frequency from the frequency domain signal. For example, in a case where magnitude of two frequency is computed, then the controller 100 compares the magnitude of the first frequency and the second frequency with respective pressure maps 1064. A weighted sum of the two magnitude is then considered to derive to the fuel pressure based on the at least one parameter such as engine speed. Multiple maps corresponding to multiple magnitude of the transformed signal are obtained, and an average or weighted value of the maps is considered in estimating the fuel pressure.

The processing module 1062 further analyzes the load current 1082 for at least one selected from a group comprising a rise time, a magnitude, a decay time, rate of change of load current during said rise time, rate of change of current during decay time.

In accordance to an embodiment of the present disclosure, the controller 100 further comprises measurement and comparison of the at least one parameter selected from a group comprising an engine speed, ambient temperature, manifold temperature, ambient pressure, manifold pressure, voltage of the battery 102, and the like, with the pressure map 1064, during the comparison of the output of the processing module 1062. The at least one parameter is measured by a respective sensing means 104 such as TMAP sensor, air pressure sensor, temperature sensor, speed sensor and the like.

The signal comprising the load current 1082 and the at least one parameter are together measured in real time. The measured signal and the measured value of at least one parameter are processed by the processing module 1062, and the output is compared with the pressure

map 1064 stored in the memory element 106. Based on the comparison, the controller 100 determines/ estimates the fuel pressure of the fuel at the fuel injector 110.

The controller 100 further performs correction of the determined fuel pressure based on the measured at least one parameter in real time.

Before the pressure map 1064 is stored in the memory element 106, the pressure map 1064 is created offline in testing conditions. At regulated injector supply voltage, standard ambient/ manifold temperature and pressure, the magnitude of fuel pressure, the load current 1082 drawn by the fuel injector 110 under the influence of the fuel pressure, at constant engine speed is continuously recorded. The load current 1082 and a corresponding fuel pressure is recorded at every pre-defined time interval for various engine speeds. A fuel pressure sensor is used during the testing. The recorded signal comprising the load current 1082 from the test data is converted or transformed from time domain information to frequency domain information through the processing module 1062. The transformation enables in identifying the change in the injector/ load current 1082 due to change in fuel pressure.

After the transformation, with the information of operating frequency of the fuel injector 110, various frequency components and their magnitudes in a frequency spectrum is mapped to a magnitude of the fuel pressure. At least one selected from a group comprising a rise time, a magnitude, a decay time, rate of change of load current during said rise time, rate of change of current during decay time, and the like are analyzed in the transformed signal. The mapping of frequency domain/ spectrum of the load current 1082 to the fuel pressure is done offline on the test-bench. The pressure map 1064 is then loaded or stored in the memory element 106 of the controller 100.

Now, during runtime condition or actual vehicle running condition, the controller 100 measures the real time signal comprising the load current 1082 against time. Simultaneously, the controller 100 also measures at least one parameter. The processing module 1062 processes the measured signal comprising the load current 1082. The output of the processing module 1062 is compared with the pressure map 1064 for estimating the fuel pressure. Alternatively, the output of the processing module 1062 is compared with the pressure map 1064 along the measured at least one parameter. Still in another alternative embodiment, the output of the processing module 1062 is corrected based on the deviation of the values of the at least one parameter such a low battery voltage, high temperature and the like, and after which the fuel pressure is estimated. In accordance to yet another embodiment, the corrections due to variation

in at least one parameter such as ambient temperature and pressure is added to determined fuel pressure.

The derived/estimated/ determined fuel pressure value is used to correct the injection quantity by controlling the injection duration, thereby achieving close loop control.

In accordance to an embodiment of the present disclosure, a direct driven pump of the FSM 114 is driven more accurately with variations in pressure of pumped fuel to the fuel injector 110. Alternatively, the device is able to control a reciprocating type pump as well without any physical fuel pressure sensor. The controller 100 sends a control signal 1002 to control the FSM 114.

In accordance to another embodiment of the present disclosure, the device is provided for a vehicle with a fuel pressure sensor. The controller 100 of the device starts using the pressure model 1064 upon detection of abnormal condition of the fuel pressure sensor, such as malfunction, failure.

In accordance to an embodiment of the present disclosure, the device is applied for a common rail fuel injection system having diesel as a fuel. In another embodiment, the device is applied for a gasoline fuel injection system. Similarly, the device is applied to fuel injection system with fuel selected from a group comprising gasoline, diesel, flexi-fuel, Compressed Natural Gas (CNG) and the like.

Fig. 2 illustrates details of variables associated with fuel injector actuation, according to an embodiment of the present disclosure. The X-axis 202 represents time in a suitable unit such as milliseconds (ms) and the Y-axis 204 represents voltage in volts, load current 1082 in milliamps (mA), valve lift in millimeters (mm), and switching pulse. A curve 206 represents the voltage. A curve 208 represents valve lift. A curve 210 represents load current 1082. A curve 212 represents the switching pulse. The curve 208 shows that the valve lifts after the load current 1082 is increased to certain value. The load current 1082 does not rise instantaneously, but takes certain rise time t_{ON} 214 due to opposing force from spring and the fuel pressure on the lift valve. The load current 1082 further takes time t_{OFF} 218 in decaying due to fuel pressure at the nozzle and demagnetization of the solenoid coil. A hold time 216 denotes the time within which the load current 1082 is maintained at a hold current level to keep the valve open. The fuel pressure at the fuel injector 110 influences change in magnitude of hold current, change in rate of increase in hold current, rate of change of t_{OFF} 218 voltage and t_{OFF} 218 time, rate of change of load current 1082 during t_{OFF} 218 and the like.

The change in load current 1082 of the fuel injector 110 is a function of actuator force required to act against the fuel pressure and spring force, as described above.

Fig. 3 illustrates a method for determining fuel pressure at a fuel injector, according to an embodiment of the present disclosure. The fuel injector 110 is controlled by the actuator as described above in run time condition. The method comprises a step 302 comprising measuring a signal comprising a load current 1082 drawn by the actuator against time. A step 304 comprises processing the measured signal using the processing module 1062. A step 306 comprises comparing output of the processing module 1062 with a pressure map 1064 stored in the memory element 106. A step 308 comprises determining/ estimating pressure of the fuel at the fuel injector 110. The fuel injector 110 is supplied with the fuel either by a Fuel Supply Module (FSM) 114 or directly by the fuel tank 112 due to gravity.

The processing of measured signal by the processing module 1062 comprises converting/transforming the signal measured in time domain into a signal in frequency domain. The transformation is performed using but not limited to Fast Fourier Transformation (FFT).

The processing of the measured signal further comprises analyzing the load current 1082 for at least one selected from a group comprising a rise time, a magnitude, a decay time, and the like. The output from the processing module 1062 is a value/ magnitude which is then compared with the pressure map 1064 to derive the fuel pressure.

The method further comprises measuring and comparing at least one parameter selected from a group comprising an engine speed, ambient temperature, manifold temperature, ambient pressure, manifold pressure, voltage of the battery 102, and the like, with the pressure map 1064, during comparison of the output of the processing module 1062.

The method further comprises correcting the determined fuel pressure based on the at least one parameter.

Before the above steps are performed, the pressure map 1064 is pre-stored in the memory element 106 based on the test results conducted offline. The pressure map 1064 comprises a magnitude indicating to a fuel pressure corresponding to the load current 1082, engine speed and other parameters.

In accordance to an embodiment of the present disclosure, a device is provided for a direct driven FSM 114. The direct driven FSM 114 signifies that the ECU controls the speed of the pump to adjust the fuel pressure.

In accordance to an embodiment of the present disclosure, a device to determine/ estimate fuel line pressure based on the load current 1082 drawn by the fuel injector 110 is provided. The device provides a very low cost solution, as there is no need/requirement for a fuel pressure sensor, which usually increases the cost of the system. A closed loop control of the fuel supply and injection is obtained. The controller 100 or an Engine Control Unit (ECU) of the vehicle is able to control the injection timing for any change in fuel supply pressure. The device enables to decide a precise injection quantity based on the estimated fuel pressure, especially for a two wheeler vehicles. The pressure map 1064 is used to derive fuel pressure online based on detected frequency spectrum of the load current 1082 of the fuel injector 110. A close loop control of fuel injection based on determined fuel pressure without use of physical pressure sensor is achieved. In a case where no voltage regulation circuit is available, additional corrections due to variation in the voltage of the battery 102 is implemented. With controlled fuel injection the performance of the engine improves and resulting in less emission. The device is further applicable not only for the fuel, but for other liquids such as Diesel Exhaust Fluid (DEF). The device is applied to an engine with single cylinder, two cylinder, multi cylinder, v-type cylinder and the like. Thus the device is applicable to be used for a two-wheeler, three-wheeler, four wheeler, and other vehicles.

It should be understood that embodiments explained in the description above are only illustrative and do not limit the scope of this invention. Many such embodiments and other modifications and changes in the embodiment explained in the description are envisaged. The scope of the invention is only limited by the scope of the claims.

We claim:

1. A device to determine fuel pressure at a fuel injector (110), said fuel injector (110) is controlled by an actuator, said device comprises:
 - a controller (100) adapted to:
 - measure a signal comprising load current (1082) drawn by said actuator against time,
 - process said measured signal using a processing module (1062),
 - compare output of said processing module (1062) with a pressure map (1064) stored in a memory element (106), and
 - determine said fuel pressure of said fuel based on said comparison.
2. The device as claimed in claim 1, wherein said processing module (1062) converts said signal measured in time domain into a signal in frequency domain.
3. The device as claimed in claim 2, wherein said processing module (1062) further analyzes said load current for at least one selected from a group comprising a rise time, a magnitude, a decay time, rate of change of load current during said rise time, rate of change of current during decay time.
4. The device as claimed in claim 1, wherein the controller (100) further performs measurement and comparison of at least one parameter selected from a group comprising an engine speed, ambient temperature, manifold temperature, ambient pressure, manifold pressure, voltage of the battery (102), and the like, with said pressure map (1064), during comparison of said output of said processing module (1062).
5. The device as claimed in claim 4, further performs correction of said determined fuel pressure based on said at least one parameter.
6. A method for determining fuel pressure at a fuel injector (110), said fuel injector (110) is controlled by an actuator, said method comprises the steps of:
 - measuring a signal comprising a load current (1082) drawn by said actuator against time;

- processing said measured signal using a processing module (1062),
 - comparing output of said processing module (1062) with a pressure map (1064) stored in a memory element (106), and
 - determining pressure of said fuel at said fuel injector (110) based on said comparison.
7. The method as claimed in claim 6, wherein said processing of said signal by said processing module (1062) comprises converting said signal measured in time domain into a signal in frequency domain.
8. The method as claimed in claim 7, wherein processing said measured signal further comprises analyzing said load current (1082) for at least one selected from a group comprising a rise time, a magnitude, a decay time, rate of change of load current during said rise time, rate of change of current during decay time.
9. The method as claimed in claim 6, further comprises measuring and comparing at least one parameter selected from a group comprising an engine speed, ambient temperature, manifold temperature, ambient pressure, manifold pressure, voltage of the battery (102), and the like, with said pressure map (1064), during comparison of said output of said processing module (1062).
10. The method as claimed in claim 9, further comprises correcting said determined fuel pressure based on said at least one parameter.

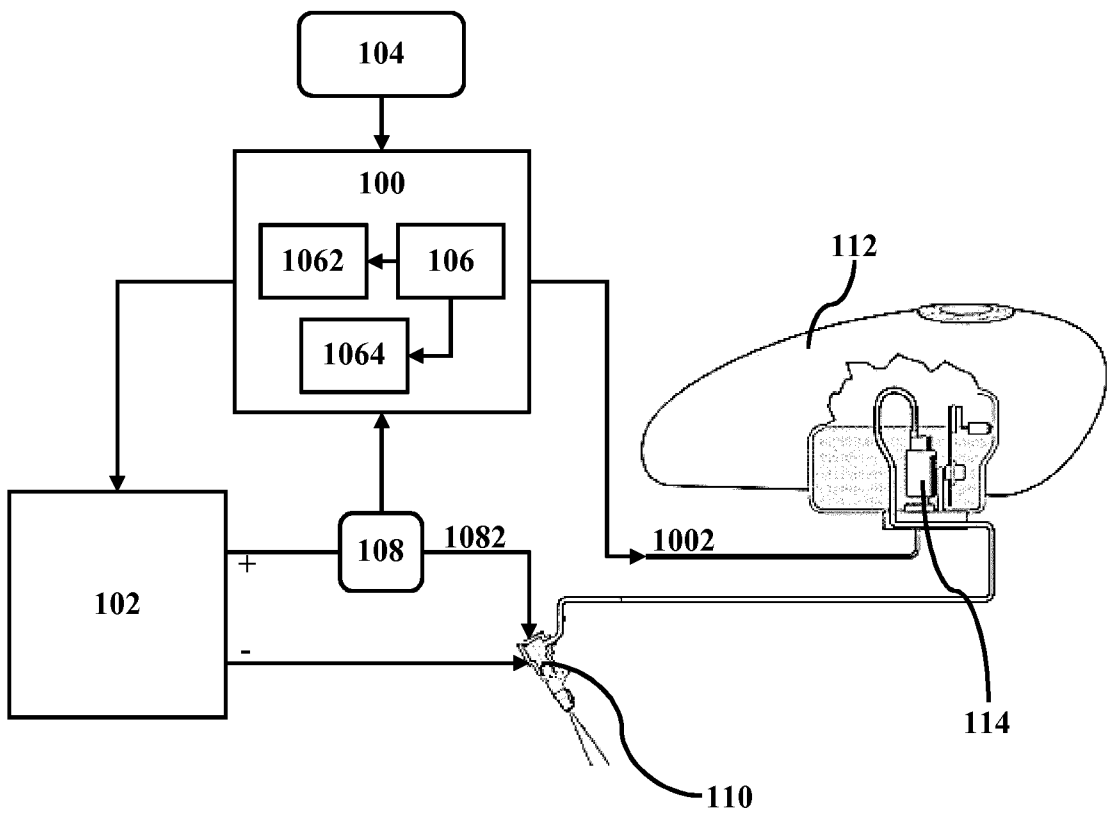


FIG. 1

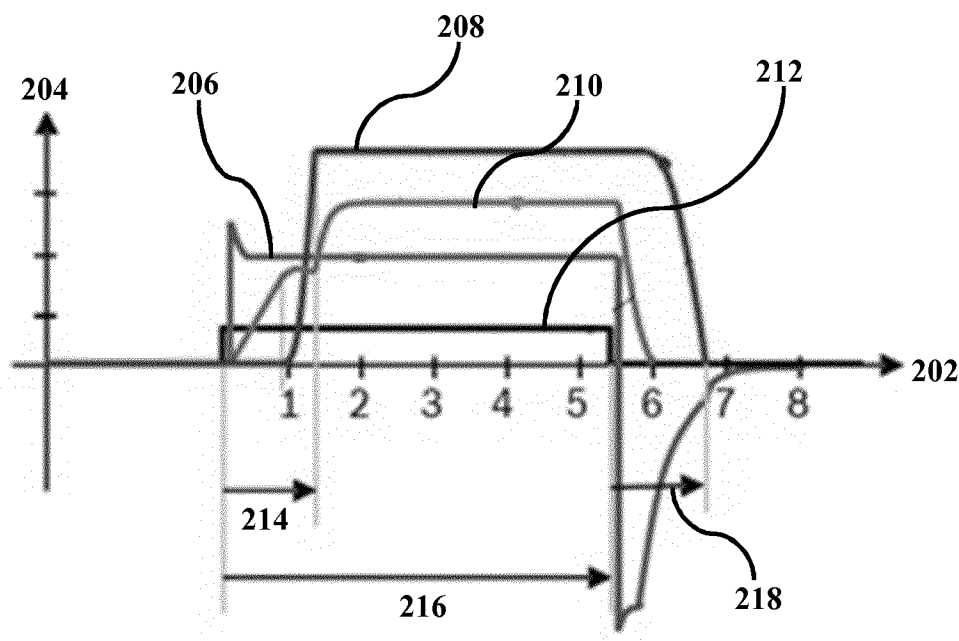


FIG. 2

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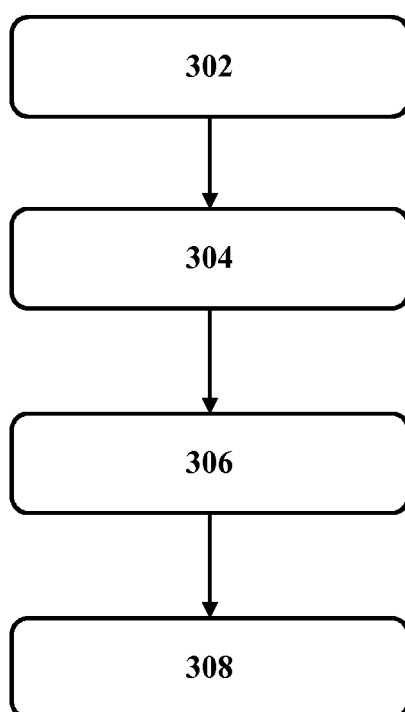


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/050410

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02D41/00 F02D41/20
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	paragraphs [0006], [0008] - [0011], [0020] - [0024], [0029] - [0031]	2,3,7,8
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X	paragraphs [0009], [0016], [0018], [0021], [0022]; figure 3	
X	US 2007/028895 A1 (FUJII HIROTO [JP]) 8 February 2007 (2007-02-08)	1,4-6,9,10
X	cited in the application paragraphs [0013], [0014]; figure 2	
X	DE 198 00 760 A1 (NIPPON SOKEN [JP]) 13 August 1998 (1998-08-13)	1,4-6,9,10
	figures 3,4	
	-/--	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/050410

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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