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(54) **Title:** FUEL CONTROL SYSTEM

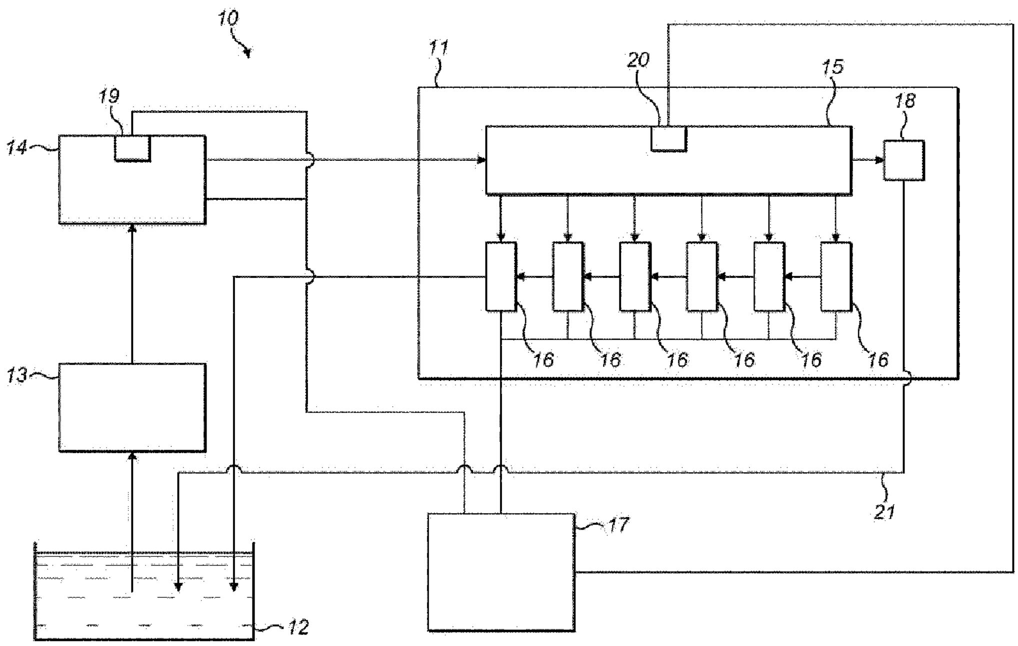

FIG. 1

(57) **Abstract:** The present disclosure relates to improvements in the control of a fuel system in an engine such as a combustion engine, and in particular to a method of controlling a pressure relief valve, the fuel system comprising a source of high pressure fuel and an electronically controlled pressure relief valve. A plurality of engine operating parameters are monitored, including an actual fuel pressure in the source of high pressure fuel source and a target pressure for the source high pressure fuel is determined according to engine performance maps. Where it is determined that one of the plurality of predetermined operating conditions exists, at least one control map is used to determine an opening duration for the pressure relief valve. The opening duration is that which enables the actual fuel pressure to be maintained at the target pressure or to be brought into line with the target pressure. The pressure relief valve is then opened for the determined opening duration.

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DESCRIPTION

FUEL CONTROL SYSTEM

Technical Field

The present disclosure relates to improvements in the control of a fuel system in an engine such as a combustion engine, and in particular to a method of controlling a pressure relief valve.

Background

Many different fuel systems may be utilised to introduce fuel into the combustion chamber(s) of an engine. One type of fuel system is known as the common rail system. A typical common rail fuel system may utilise one or more pumping mechanisms (such as a high pressure pump) to pressurise fuel, and may direct the pressurised fuel to a common rail, which provides a source of pressurised fuel. A plurality of fuel injectors draw pressurised fuel from the common rail and inject one or more shots of fuel per operating cycle into the combustion chambers. In order to optimise engine operation, fuel within the common rail may be maintained within a desired pressure range through control of the pumping mechanisms, in particular the high pressure pump.

Situations may arise in which this control is interrupted and pressure fluctuations or spikes occur, or various portions of the fuel system fail. In these situations there may be a possibility that fuel pressures within the common rail could reach levels that have the potential to damage the components of the fuel system or affect the emissions and performance. One way to protect the common rail from such excessive pressures may be to selectively drain fuel from the common rail when the pressure of the fuel within it exceeds a predetermined maximum threshold value. However, if too much fuel is drained, the pressure of the fuel within the common rail may drop below a minimum pressure at which the fuel injectors and engine are able to continue operating in at least a limited operational mode ("limp home" mode) and the engine may shut off. If the engine shuts off suddenly the machine, truck, or other piece of equipment powered by the engine may be left in an undesirable operational state, position or location. Moreover, depending on the problem or problems that may have led to the excessive pressure within the fuel system, the rate at which the fuel may need to be drained from the common rail to maintain a required target pressure may vary.

The incorporation of a pressure relief (or limiter) valve (also known as a PRV) into such a fuel system may help to mitigate, reduce, or even eliminate the adverse effects of excessive fluid pressure on the common rail. When the pressure of the fluid within the common rail exceeds a maximum threshold value, the pressure relief valve may be mechanically or electronically actuated to open to allow fluid to drain from the common rail, thereby lowering the pressure of the fluid within the common rail. The pressure relief valve may be controlled, usually by an engine control module (ECM), such that pressure of the fluid may be lowered just enough to protect the common rail without creating instability or completely disabling the system. This means that the engine may still operate.

US-B-8291889 describes a pressure relief valve which may be used to assist in pressure control in a common rail fuel system. It describes the use of the pressure relief valve to dampen overshoots and to reduce pressure when the engine transitions from a high to a low load condition. It also describes the use of the pressure relief valve to reduce pressure when the rail pressure exceeds a predetermined maximum operating pressure.

Summary

According to the disclosure, there is provided a method of controlling a fuel system of an engine comprising the steps of:

monitoring a plurality of engine operating parameters, including measuring an actual fuel pressure;

determining a target pressure for the actual fuel pressure according to at least one engine performance map for the plurality of engine operating parameters;

determining whether at least one of a plurality of predetermined engine operating conditions exist; and

where it is determined that at least one of the plurality of predetermined engine operating conditions exists, determining from at least one control map an opening duration for a pressure relief valve to remain in an open position to establish the actual fuel pressure at the target pressure;

sending a signal to open the pressure relief valve for the determined opening duration.

The plurality of predetermined engine operating conditions may comprise:

where a reduction in a fuel requirement of the engine is determined;

where a reduction in the target pressure is demanded;

where the actual fuel pressure exceeds a predetermined pressure limit;

where the engine is shut down;

where an increase in the target pressure is demanded; and

where the engine overruns or has a very low fuel requirement.

According to the present disclosure there is also provided a fuel system for an engine comprising:

a source of high pressure fuel;

an electronically controlled pressure relief valve coupled to the source of high pressure fuel, said pressure relief valve having an open position, in which fuel is drained from the source of high pressure fuel to reduce the pressure in the source of high pressure fuel, and a closed position in which fuel is not drained from the source of high pressure fuel; and

a controller configured to monitor a plurality of engine operating parameters, said controller comprising a memory configured to store at least one engine performance map and at least one control map, wherein the controller is configured to determine the opening duration for the pressure relief valve from the at least one control map and to open the pressure relief valve for the opening duration in accordance with the aforementioned .method

Brief Description of the Drawings

Aspects of the present disclosure are described below, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a fuel system incorporating a pressure relief valve with an electronic control module programmed to operate the method of the present disclosure;

Figure 2a illustrates the change in common rail pressure where there is a sudden reduction in engine fuel requirement in a fuel system having an electronic control module which is not programmed to operate the method of the present disclosure;

Figure 2b illustrates the change in common rail pressure where there is a sudden reduction in engine fuel requirement in a fuel system having an electronic control module which is programmed to operate the method of the present disclosure;

Figure 3a illustrates the change in common rail pressure where there is a requested reduction in the target pressure in a fuel system having an electronic control module which is not programmed to operate the method of the present disclosure;

Figure 3b illustrates the change in common rail pressure where there is a requested reduction in the target pressure in a fuel system having an electronic control module which is programmed to operate the method of the present disclosure;

Figure 4 illustrates the change in common rail pressure where the common rail pressure exceeds a predetermined rail pressure limit in a fuel system having an electronic control module which is programmed to operate the method of the present disclosure;

Figure 5a illustrates the change in common rail pressure where an overshoot of the common rail pressure above the target pressure occurs following a transient increase in the target pressure in a fuel system having an electronic control module which is not programmed to operate the method of the present disclosure;

Figure 5b illustrates the change in common rail pressure where an overshoot of the common rail pressure above the target pressure is prevented following a transient increase in the target pressure in a fuel system having an electronic control module which is programmed to operate the method of the present disclosure;

Figure 6a illustrates the change in common rail pressure where an engine overrun is determined in a fuel system having an electronic control module which is not programmed to operate the method of the present disclosure; and

Figure 6b illustrates the change in common rail pressure where an engine overrun is determined in a fuel system having an electronic control module which is programmed to operate the method of the present disclosure;

Detailed Description

Figure 1 illustrates an exemplary embodiment of a fuel system 10 for operating the method of the present disclosure. The fuel system 10 may be designed to deliver fuel (e.g. diesel, gasoline, heavy fuel, etc.) from a location where fuel is stored to the combustion chamber(s) of an engine 11 for combustion. The energy released by the combustion process may be used to generate a mechanical source of power. Although Figure 1 shows a fuel system which may be suitable for a diesel engine, the fuel system 10 of the present disclosure may be the fuel system of other types of engine. The fuel system 10 of Figure 1 may include a fuel source, such as a tank 12, a transfer pump 13, a high pressure pump 14, a source of high pressure fuel, such as a common rail 15, a plurality of fuel injectors 16, a controller, such as an electronic control module 17, and a pressure relief valve 18.

It should be noted that any references herein to “common rail”, both on its own and in relation to parameters and associated parts, should be interpreted to include other sources of high pressure fuel. The use of the term common rail is therefore not to be interpreted as restrictive.

The tank 12 may be a storage container that stores the fuel that the fuel system 10 may utilise in the combustion process.

The transfer pump 13 may pump fuel from the tank 12 and deliver it at a generally low pressure to the high pressure pump 14.

The high pressure pump 14 may pressurise the fuel to a high pressure and deliver the high pressure fuel to the common rail 15. Regulation of the flow of fuel through the high pressure pump 14 may be achieved by means of a fuel metering control valve 19 which may be controlled by the electronic control module 17 to control the flow of fuel into or out of the high pressure pump 14.

The common rail 15, which may be intended to be maintain the fuel at the high pressure generated by high pressure pump 14, may thus serve as a source of high pressure fuel for each of the fuel injectors 16. In one example of an engine used in industrial applications, such as in an excavator, backhoe loader or motor grader, the operating common rail pressure (P_{cr}) range may be in the range of 30 to 200MPa. When the engine is running under high load at, say, 2200rpm the pressure may be in the region of 180 to 200MPa. However, the operating common rail pressure (P_{cr}) range is dependent, inter alia, on the engine design (which may vary from manufacturer to manufacturer) and its application. The electronic control module 17 may monitor the actual common rail pressure (P_{cr}) by means of a common rail pressure sensor 20 which may generate signals to the electronic control module 17.

The fuel injectors 16 may be located within the engine 11 in a position that enables the fuel injectors 16 to inject high pressure fuel into the combustion chamber(s) of the engine 11 or into pre-chambers or ports upstream of the combustion chamber in some cases. The fuel injectors 16 may generally serve as metering devices that control when fuel is injected into the combustion chamber, how much fuel is injected and the manner in which the fuel is injected (e.g. the angle of the injected fuel, the spray pattern etc.). Each fuel injector 16 may be continuously fed fuel from the common rail 15, such that any fuel injected by a fuel injector 16 may be quickly replaced by additional fuel supplied by common rail 15. The fuel injectors 16 may be solenoid operated injectors. The fuel injectors 16 may also be in communication with the electronic control module 17, which may generate command signals determining the timing and length of injection events by the fuel injectors 16 in order to meet the engine fueling requirement. The quantity of each injection may be controlled by the duration of the current signal.

The controller may be an electronic control module 17 which may continuously determine a target (desired) pressure (P_t) according to the current engine operating conditions and control the operation of the high pressure pump 14, fuel injectors 16 and pressure relief valve 18 to bring the actual common rail pressure (P_{cr}) as quickly as possible to match the target pressure (P_t) as the operating conditions of the engine 10 vary. The target pressure (P_t) is a value which may be based on current engine operating parameters, such as engine speed, engine torque, engine load, fuel demand and temperature. Where the normal operating common rail pressure (P_{cr}) range is in the range of 30 to 200MPa, the target pressure (P_t) range may be in the order of 0 – 200 MPa, although as indicated previously this may vary according to, inter alia, the power demand of the engine 10, the design of the engine 10 and its application. The target pressure (P_t) may be a pressure value determined from one or more engine performance maps (some of which are known as fuel maps, efficiency maps and consumption maps).

Engine performance maps may used to represent the desired performance of the engine 10, and target pressures (P_t) at combinations of different loads and operating conditions and may enable engine output parameters to be predicted based on engine input parameters. These engine performance maps may thus be used to control the engine performance to meet the desired engine performance, which may include meeting customer demands, for example as to transient performance requirements which may vary according to the application of the engine, and to meet legislation, for example emissions requirements. The electronic control module 17 may comprise memory configured to store such engine performance maps.

The electronic control module 17 may be configured to receive input signals from a plurality of sensors associated with various systems and parts of the engine 11 (including the fuel system 10). Such signals may be a direct measurement of, or may be used to calculate, engine operating parameters, for example common rail pressure, fuel temperature, throttle/accelerator position, engine speed and the engine intake air. The electronic control module 17 may continuously use the engine operating parameters, together with data from the engine performance maps, to determine the current engine load, the engine fuelling requirement and the target rail pressure (P_t) and to generate command signals (engine output parameters) to control the fuel system 10 and to meet the target rail pressure (P_t). This may include changing the rate of fuel flow through the high pressure pump 14 and the rate of fuel injection by the fuel injectors 16. For example, an engine performance map may contain the necessary information to estimate the fuel consumption by an engine 11 given its current load and speed. The electronic control module 17 may use this data to determine the target pressure (P_t) which would provide the desired engine performance and to control the operation of the high pressure pump 14 and the fuel injectors 16 to ensure that the correct amount of fuel is supplied to suit the amount of air that the engine 11 ingests at that given point.

The pressure relief valve 18 may be an electronically controlled component or an assembly that is coupled to the common rail 15 and may be operable to open and close. It may have an open position, in which fuel may drained from the common rail 15 to the tank 12 via a drain line 21 to reduce the pressure in the common rail 15, and a closed position in which fuel may not drain from the common rail 15. The pressure relief valve 18 may be a solenoid operated valve that may use the same type of current driver as is used for the fuel injectors 16. Alternatively a pressure relief valve 18 which uses a pulse width modulated (PWM) method may also be used. The electronic control module 17 may automatically open pressure relief valve 18 in response to the determination of the existence of one of a number of predetermined engine operating conditions and close the pressure relief valve 18 again after a period of time according to control logic defined in a plurality of calibrated control maps stored in its memory.

The control maps may be produced by a calibration process, which may include running an engine 11 under test conditions at different speeds, with different fuelling and common rail pressures, with different high pressure pump speeds, and with the pressure relief valve 18 open and closed. Various engine input and output parameters are measured, such as the common rail pressure and engine fuel flow. From the various measured parameters, other parameters may be extrapolated to provide the control maps. These control maps may include a spill map which may provide spill quantities, i.e. quantities of fuel to be removed from the common rail 15 to achieve different pressure reductions, under different engine operating conditions; and a duration map which may provide an opening duration (T_o) during which the pressure relief valve 18 must remain open to drain different spill quantities from the common rail 15. One or more different control maps may be used by the electronic control module 17 to control the opening and closing of the pressure relief valve 18 at any particular time. Different control maps may be provided for each of the operating conditions which cause the electronic control module 17 to automatically trigger the opening of the pressure relief valve 18 and to determine the opening duration (T_o).

These predetermined engine operating conditions which may cause the electronic control module 17 to automatically trigger the opening of the pressure relief valve 18 may include a sudden reduction in the engine fuel requirement, a reduction in common rail pressure requirement (i.e. a reduction on target pressure (P_t)), a predetermined common rail pressure limit being exceeded, shut down of the engine, a transient increase in the common rail pressure requirement which may result in a pressure overshoot and an engine overrunning condition. These are described in more detail below.

Reduction in the Engine Fuel Requirement

If the electronic control module 17 determines that there is a sudden reduction in the engine fuel requirement, for example if the electronic control module 17 determines that there is a reduced power or load demand on the engine which may cause an increase in engine speed, the electronic control module 17 may determine that a reduction in fuel is required to return the engine speed to a target speed. To effect this, the electronic control module 17 may normally reduce the flow of fuel through the fuel injectors 16 and reduce the flow of fuel through the high pressure pump 14 to the common rail 15 by issuing appropriate command signals. However, the response of the high pressure pump 14 to the command signals may be slower than the response of the fuel injectors 16, which may lead to a rise in the actual common rail pressure (P_{cr}). The change in actual common rail pressure (P_{cr}) relative to the target pressure (P_t) where the electronic control module 17 is not programmed to operate in accordance with the method present disclosure is shown in Figure 2a. From this it can be seen that there may be a small temporary increase in the actual common rail pressure (P_{cr}) above the target pressure (P_t) at the point that the fuel demand reduces. This may occur as the high pressure pump 14 may take time to reduce its fuel output, whereas the fuel injectors 16 may respond more rapidly to reduce the fuel injected. The electronic control module 17 may therefore be programmed to anticipate this in accordance with the method of the present disclosure and open the pressure relief valve 18 on determination that there is a sudden reduction in fuel demand to reduce the actual common rail pressure (P_{cr}) before the actual common rail pressure (P_{cr}) rises above the target pressure (P_t). This is illustrated in Figure 2b.

The electronic control module 17 may determine the opening duration (T_o) that the pressure relief valve 18 should remain open in this situation. The electronic control module 17 may use the engine speed, load and/or torque data from the signals output by the relevant sensors and data from the engine performance maps to determine the reduced power output of the engine 10 following the reduction in fuel demand. Based on the continuous measurements of the actual common rail pressure (P_{cr}), the electronic control module 17 may determine the current quantity of fuel in the common rail 15. The electronic control module 17 may then determine from the control maps the spill quantity required to maintain the actual common rail pressure (P_{cr}) at the target pressure (T_p) at the reduced power output. The electronic control module 17 may generate a command signal which may open the pressure relief valve 18 for the determined opening duration (T_o) to remove the determined spill quantity. When the command signal is off, the pressure relief valve 18 may close. The determination of the opening duration (T_o) may be made repeatedly at every injection cycle whilst the pressure relief valve 18 is open, to ensure that if the engine operating parameters change, the correct opening duration (T_o) is used and target pressure (P_t) is not exceeded. If the target pressure (P_t) is not achieved at the next cycle, a new spill quantity and therefore opening duration (T_o) may be determined.

A Reduction in Common Rail Pressure Requirement

Under certain engine operating conditions, the electronic control module 17 may determine that a lower (second) target pressure (P_{t2}) is required than the current (first) target rail pressure (P_{t1}), whilst maintaining the same engine fuelling requirement. Such a target pressure reduction may be desirable to change the way in which the fuel behaves when delivered into the combustion chamber by the fuel injectors 16. Such a change may be determined by the engine performance maps, for example for performance/emissions reasons. If the electronic control module 17 determines that a lower target pressure (P_{t2}) is desirable/required, the electronic control module 17 may normally reduce the flow of fuel through the high pressure pump 14 to the common rail 15. This may also be required if the actual common rail pressure (P_{cr}) is higher than the first target pressure (T_{p1}). The electronic control module 17 may be programmed to only activate the pressure relief valve 18 if the actual common rail pressure (P_{cr}) is higher than the first target pressure (T_{p1}) and the difference between the first and second target pressures (P_{t1}), (P_{t2}) is greater than a predetermined threshold, for example 3 to 5MPa. The actual value may depend on the calibration of the engine 11 and may help to avoid excessive usage of the pressure relief valve 18.

However, as discussed above, the response of the high pressure pump 14 may be slower than the ability of the fuel injectors 16 to remove fuel from the common rail 15, which may mean that there is a delay in the common rail pressure (P_{cr}) reaching the lower target pressure (P_{t2}). Figure 3a illustrates the delay in response where the electronic control module 17 is not programmed to operate in accordance with the method present disclosure. In accordance with the method of the present disclosure, the electronic control module 17 may be programmed to anticipate this and proactively open the pressure relief valve 18 to reduce the common rail pressure (P_{cr}) as soon as it determines that the lower target pressure (P_{t2}) is required. Figure 3b illustrates the response when the pressure relief valve 18 is opened according to the method of the present disclosure.

On determining that a lower target pressure (P_{t2}) is required, the electronic control module 17 may determine from the control maps the required spill quantity and the opening duration (T_o) that the pressure relief valve 18 should remain open to remove the spill quantity to reach the lower target pressure (P_{t2}) with the current engine operating parameters. The electronic control module 17 may generate a command signal which may open the pressure relief valve 18 for the determined opening duration (T_o). When the command signal is off, the pressure relief valve 18 may close. The determination of the opening duration (T_o) may be made repeatedly at every injection cycle whilst the common rail pressure (P_{cr}) is greater than the lower target pressure (P_{t2}), to ensure that if the engine operating parameters change, the correct opening duration (T_o) is used and that the lower target pressure (P_{t2}) is achieved. If the lower target pressure (P_{t2}) is not achieved at the next cycle, a new spill quantity and therefore opening duration (T_o) may be determined.

A Common Rail Pressure Limit Being Exceeded

The electronic control module 17 may be programmed with a predetermined rail pressure limit (P_l), which may be set according to known limitations of the common rail 15 and/or associated components of the engine 10. It may be a predetermined limit, operating at pressures above which may be likely to lead to mechanical failure. In one example where the normal maximum expected operating limit of the common rail 15 is 200MPa, the rail pressure limit (P_l) may be around 220MPa. If the electronic control module 17 determines from the common rail pressure sensor 20 that the common rail pressure (P_{cr}) exceeds the rail pressure limit (P_l), the electronic control module 17 may be programmed to immediately open the pressure relief valve 18 to reduce the common rail pressure (P_{cr}) to a target pressure (P_t) which is below the rail pressure limit (P_l). This is illustrated in Figure 4.

Again, the electronic control module 17 may determine from the control maps the required spill quantity and the opening duration (T_o) that the pressure relief valve 18 should remain open to remove the spill quantity to reach target pressure (P_t). The electronic control module 17 may generate a command signal which may open the pressure relief valve 18 for the determined opening duration (T_o). When the command signal is off, the pressure relief valve 18 may close. The determination of the opening duration (T_o) may be made repeatedly at every injection cycle whilst the common rail pressure (P_{cr}) is greater than the target pressure (P_t), to ensure that if the engine operating parameters change, the correct opening duration (T_o) is used and that the target pressure (P_t) is achieved. If the target pressure (P_t) is not achieved at the next cycle, a new spill quantity and therefore opening duration (T_o) may be determined.

Engine Shut Down

The electronic control module 17 may further be programmed to open the pressure relief valve 18 when it detects engine shut down to remove residual rail pressure. This may be convenient in a case where the fuel system 10 is to be serviced and may avoid the need for a subsequent release of pressure. The electronic control module 17 may be programmed with a shut down threshold target pressure (P_{th1}), which may be a threshold of a few MPa. Again, the electronic control module 17 may determine from the control maps the required spill quantity and the opening duration (T_o) that the pressure relief valve 18 should remain open to remove the spill quantity to reach the shut down threshold target pressure (P_{th1}). The electronic control module 17 may generate a command signal which may open the pressure relief valve 18 for the determined opening duration (T_o). This may be repeated at time intervals until the common rail pressure (P_{cr}) reaches the shut down threshold target pressure (P_{th1}). The common rail 15 may remain full of fuel at the end of this process.

A Transient Increase in the Common Rail Pressure Requirement

Under certain engine operating conditions, the electronic control module 17 may determine that a higher (second) target pressure (P_{t2}) is required than the current (first) target rail pressure (P_{t1}). This may be as a result of an increase in engine load and/or speed. If the electronic control module 17 determines that the engine operating conditions demand a higher (second) target rail pressure (P_{t2}), the electronic control module 17 may normally increase the flow of fuel through the high pressure pump 14 to the common rail 15 to increase the common rail pressure (P_{cr}) to the higher target rail pressure (P_{t2}). However, as a result of the increased fuel flow, where the electronic control module 17 is not programmed to operate in accordance with the method present disclosure, the common rail pressure (P_{cr}) may overshoot the higher target rail pressure (P_{t2}). This is shown in Figure 5a. In one example, an overshoot may be in the order of 3 to 20MPa. However the actual amount of acceptable overshoot may depend on the calibration of the engine 10 and how tightly the performance is intended to be controlled. An overshoot may occur due to slow operation of the fuel metering control valve (not shown), which controls the fuel intake volume to the high pressure pump 14. The electronic control module 17 may be programmed according to the method of the present disclosure to anticipate whether an overshoot is likely to occur based on the demanded increase in target pressure, and the electronic control module 17 may be programmed to immediately open pressure relief valve 18 to reduce the pressure in the common rail 15 to minimise the overshoot. The latter is illustrated in Figure 5b.

Again, the electronic control module 17 may determine from the control maps the required spill quantity and the opening duration (T_o) that the pressure relief valve 18 should remain open to remove the spill quantity to ensure that the common rail pressure (P_{cr}) does not exceed the higher target pressure (P_{t2}) by more than a predetermined limited amount. The electronic control module 17 may generate a signal which may open the pressure relief valve 18 for the determined opening duration (T_o). When the signal is off, the pressure relief valve 18 closes. The determination of the opening duration (T_o) may be made repeatedly at every injection cycle whilst the pressure relief valve 18 is open, to ensure that if the engine operating parameters change, the correct opening duration (T_o) is used and that the target pressure (P_{t2}) is reached. If the target pressure (P_{t2}) is not achieved at the next cycle, a new spill quantity and therefore opening duration (T_o) may be determined.

Engine Overrunning Conditions

The electronic control module 17 may also be programmed to open the pressure relief valve 18 where engine overrunning conditions are determined or the fuel requirement is at a very low level Engine overrunning conditions may occur, for example, where the crankshaft of the engine 11 may be rotating at a high speed but demand for fuel by the fuel injectors 16 is low. This may occur where the machine or vehicle, in which the engine 10 is used, continues to drive the engine, or the inertia of the engine 10 keeps it turning past when the fuel supply is turned off. A very low fuel requirement may be determined when the fuel requirement is below that requires to provide positive power to the machine or vehicle when it is descending a shallow slope. In this situation the electronic control module 17 may normally reduce the flow of fuel through the fuel injectors 16 and reduce the flow of fuel through the high pressure pump 14 to the common rail 15 since the high pressure pump 14 may be slower to respond than the fuel injectors 16. The response where the electronic control module 17 is not programmed to operate in accordance with the method present disclosure is shown in Figure 6a. In this situation it can be seen that the common rail pressure (P_{cr}) may drop from the current (first) target rail pressure (P_{t1}) after a short delay but may not reach a lower (second) target pressure (P_{t2}) which is determined by the electronic control module 17 to be the correct target pressure for the current engine overrunning condition. This may be due to the fact that it may not be possible to reduce the flow of fuel through the high pressure pump 14 sufficiently to achieve a very low target pressure which may be required in this situation (i.e. the flow demand maybe “negative”). In this scenario, the electronic control module 17 may be programmed to open the pressure relief valve 18 to simulate negative pump demand to enable the common rail pressure (P_{cr}) to be reduced to the lower target pressure (P_{t2}). This is shown in Figure 6b. The opening of the pressure relief valve 18 may be constrained until the flow required from the pressure relief valve 18 exceeds a threshold flow or a threshold pressure error (P_{cr} greater than P_{t2}) to minimise use and wear of the pressure relief valve 18.

Again, the electronic control module 17 may determine from the control maps the required spill quantity and the opening duration (T_o) that the pressure relief valve 18 should remain open to remove the spill quantity to ensure that the common rail pressure (P_{cr}) reaches the lower target pressure (P_{t2}). The electronic control module 17 may generate a command signal which may open the pressure relief valve 18 for the determined opening duration (T_o). When the command signal is off, the pressure relief valve 18 closes. The determination of the opening duration (T_o) may be made repeatedly at every injection cycle whilst the common rail pressure (P_{cr}) is greater than the lower target pressure (P_{t2}), to ensure that if the engine operating parameters change, the correct opening duration (T_o) is used and that the lower target pressure (P_{t2}) is reached. If the target pressure (P_{t2}) is not achieved at the next cycle, a new spill quantity and therefore opening duration (T_o) may be determined.

The electronic control module 17 may be programmed with a number of predetermined threshold conditions, some of which have been mentioned above. These may comprise predetermined thresholds and limits, which must be met to determine whether the pressure relief valve 18 is opened in response to the determination of the existence of one of the predetermined operating conditions described above. For example, the electronic control module 17 may be programmed with an overrun threshold rail pressure (P_{th2}) and may not open the pressure relief valve 18 if the common rail pressure (P_{cr}) is above the overrun threshold rail pressure (P_{th2}), even if engine overrunning conditions are determined. The electronic control module 17 may be programmed with a fuel reduction threshold rail pressure (P_{th3}) and may not open the pressure relief valve 18 if the common rail pressure (P_{cr}) is below the fuel reduction threshold rail pressure (P_{th3}), even if it is determined that there is a sudden reduction in fuel required.

The electronic control module 17 may also be programmed with a maximum and a minimum opening duration ($T_{omax,}$ T_{omin}). The maximum opening duration (T_{omax}) may be set, for example, to 15000μs and the minimum opening duration (T_{omin}) may be set, for example, to 250 μs. However the value of the minimum opening duration (T_{omin}) may vary as a function of the common rail pressure (P_{cr}).

These limits and thresholds may be designed to prevent overuse of the pressure relief valve 18.

Industrial Applicability

The method of controlling the fuel system 10 as described above has wide application in a variety of engine types, including, for example, diesel and gasoline engines. The general purpose of the fuel system 10 may be to ensure that the fuel is constantly fed to the engine 11 in the appropriate amounts, at the right times, and in the right manner to support the operation of the engine 11. The method of the present disclosure may assist in preventing unnecessary or unwanted increases in the common rail pressure. This may help to prolong the life of the common rail 15 and other components of the fuel system 10, and to optimise the efficiency of the engine 11.

CLAIMS

1. A method of controlling a fuel system of an engine said method comprising the steps of:

monitoring a plurality of engine operating parameters, including measuring an actual fuel pressure;

determining a target pressure for the actual fuel pressure according to at least one engine performance map for the plurality of engine operating parameters;

determining whether at least one of a plurality of predetermined engine operating conditions exist; and

where it is determined that at least one of the plurality of predetermined engine operating conditions exists, determining from at least one control map, an opening duration for a pressure relief valve to remain in an open position to establish the actual fuel pressure at the target pressure;

sending a signal to open the pressure relief valve for the determined opening duration.

2. The method of claim 1, wherein the plurality of predetermined engine operating conditions comprise:

where a reduction in a fuel requirement of the engine is determined;

where a reduction in the target pressure is demanded;

where the actual fuel pressure exceeds a predetermined pressure limit;

where the engine is shut down;

where an increase in the target pressure is demanded; and

where the engine overruns or has a very low fuel requirement.

3. A method as claimed in claim 2 wherein the at least one control map provides a table of opening durations which would allow different quantities of fuel to drain via the pressure relief valve according to different combinations of engine operating parameters for each predetermined engine operating condition.

4. A method as claimed in claim 2 or claim 3 wherein, where a reduction in a fuel requirement of the engine is determined, the opening duration

which is determined prevents an increase in the actual fuel pressure above the target pressure.

5. A method as claimed in any one of claims 2 to 4 wherein, where a reduction in the target pressure is demanded, the opening duration which is determined reduces the actual fuel pressure to a reduced target pressure whilst maintaining a fuel requirement of the engine.

6. A method as claimed in any one of claims 2 to 5 wherein, where the actual fuel pressure exceeds a predetermined pressure limit, the opening duration which is determined reduces the actual fuel pressure to a target pressure which is below the predetermined pressure limit.

7. A method as claimed in any one of claims 2 to 6 wherein, where the engine is shut down, the opening duration which is determined reduces the actual fuel pressure to a predetermined threshold target pressure.

8. A method as claimed in any one of claims 2 to 7 wherein, where an increase in the target pressure is demanded, the opening duration which is determined minimises any overshoot or prevents an overshoot from occurring.

9. A method as claimed in any one of claims 2 to 8 wherein, where the engine overruns or has a very low fuel requirement, the opening duration which is determined simulates negative fuel flow demand.

10. A method as claimed in any one of the preceding claims wherein, where a predetermined operating condition is determined to exist, the pressure relief valve is not opened if at least one threshold condition or limit for that predetermined engine operating condition is not satisfied.

11. A method as claimed in any one of the preceding claims wherein the method further comprises the step of increasing or reducing a flow of high pressure fuel through a high pressure pump to a source of high pressure fuel to which the pressure relief valve is coupled.

12. A method as claimed in any one of the preceding claims wherein the method further comprises the step of increasing or reducing a quantity and/or timing of injection of high pressure fuel.

13. A method as claimed in any one of the preceding claims wherein the target pressure is determined from a plurality of predetermined engine performance maps according to the engine operating parameters.

14. A fuel system for an engine comprising:

a source of high pressure fuel;

an electronically controlled pressure relief valve coupled to the source of high pressure fuel, said pressure relief valve having an open position, in which fuel is drained from the source of high pressure fuel to reduce the pressure in the source of high pressure fuel, and a closed position in which fuel is not drained from the source of high pressure fuel; and

a controller configured to monitor a plurality of engine operating parameters, said controller comprising a memory configured to store at least one engine performance map and at least one control map, wherein the controller is configured to determine the opening duration for the pressure relief valve from the at least one control map and to open the pressure relief valve for the opening duration where it is determined that one of a plurality of predetermined engine operating conditions exists in accordance with the method claimed in any one of the preceding claims.

15. A fuel system as claimed in claim 14, wherein the fuel system further comprises a high pressure pump configured to provide a flow of high pressure fuel to the source of high pressure fuel and, where it is determined that one of the plurality of predetermined engine operating conditions exists the controller sends a signal to increase or reduce the flow of high pressure fuel through the high pressure pump.

16. A fuel system as claimed in claim 14 or claim 15, wherein the fuel system further comprises fuel injectors configured to inject high pressure fuel from

the source of high pressure fuel into at least one combustion chamber of the engine and, where it is determined that one of the plurality of predetermined engine operating conditions exists, the controller increases or reduces the quantity and/or timing of the injection of high pressure fuel.

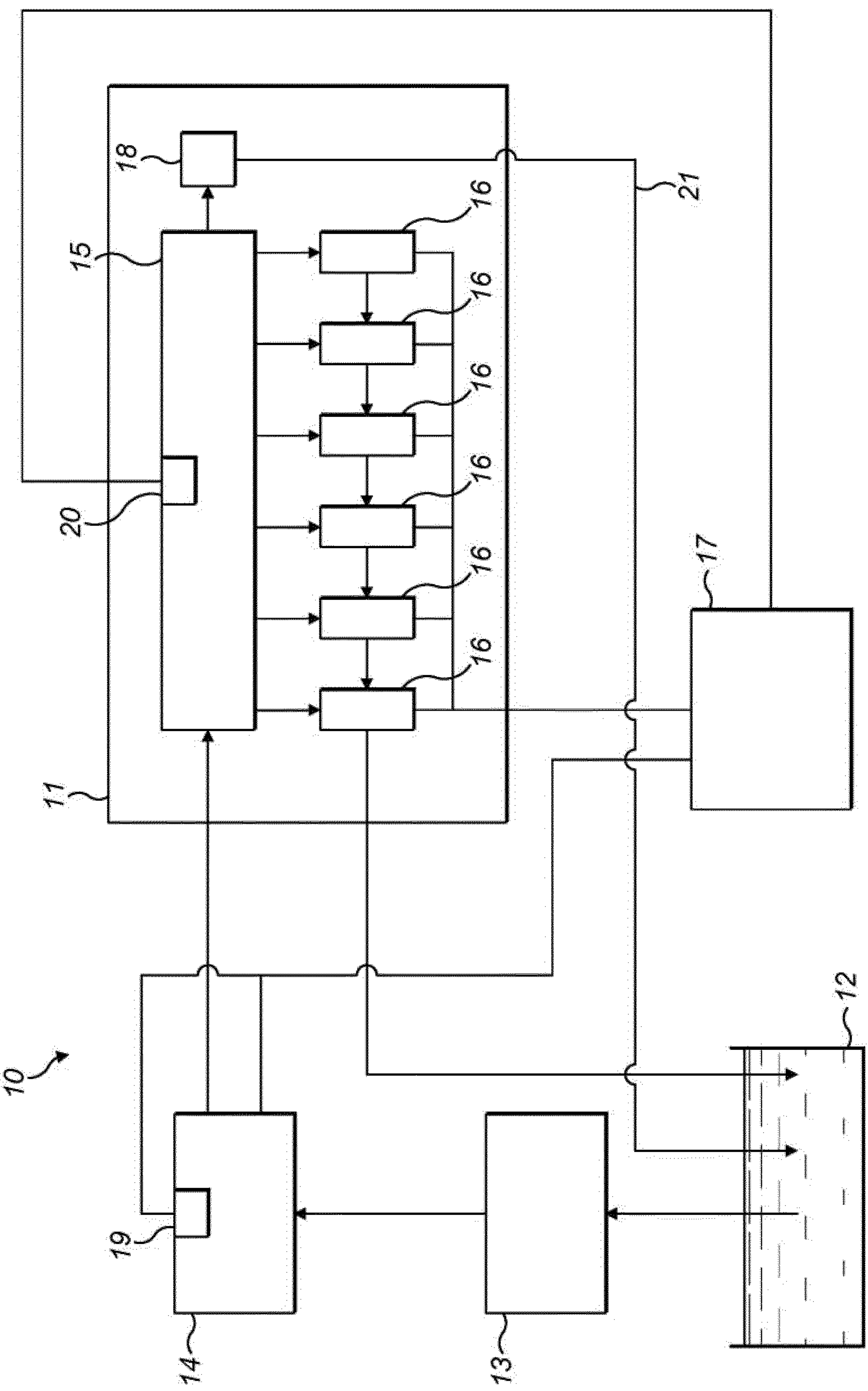


FIG. 1

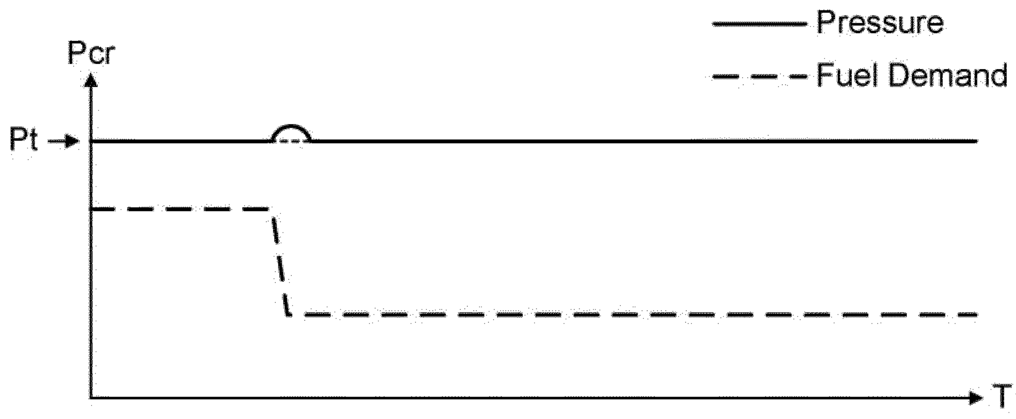

Pressure
Fuel Demand
Pcr
Pt
T

FIG. 2a

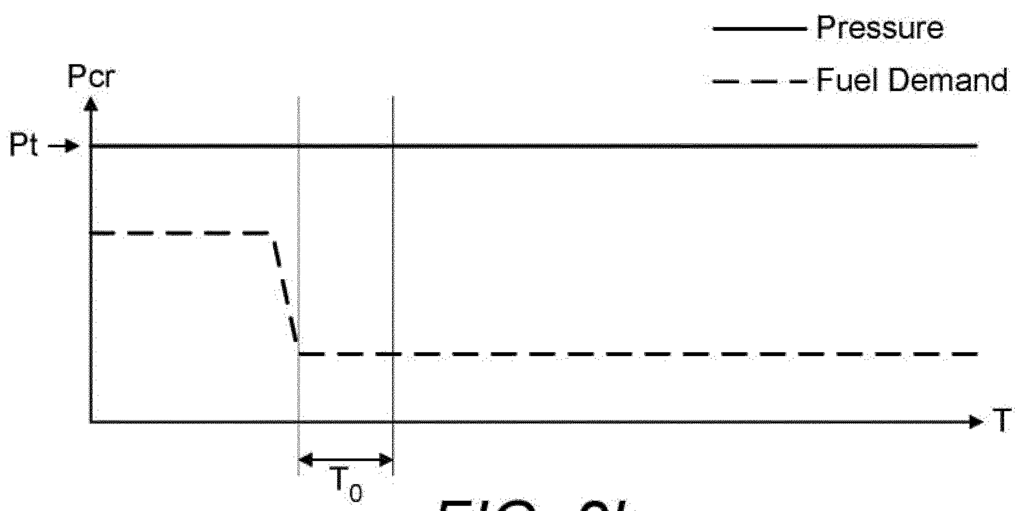

Pressure
Fuel Demand
Pcr
Pt
T
T_0

FIG. 2b

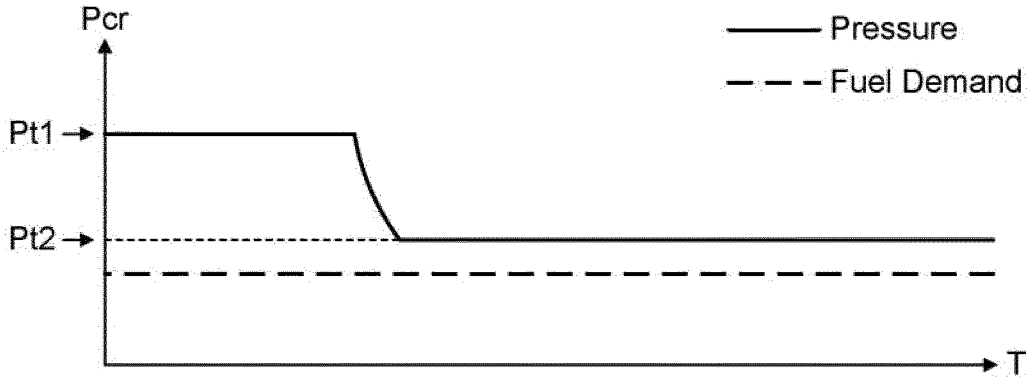


FIG. 3a

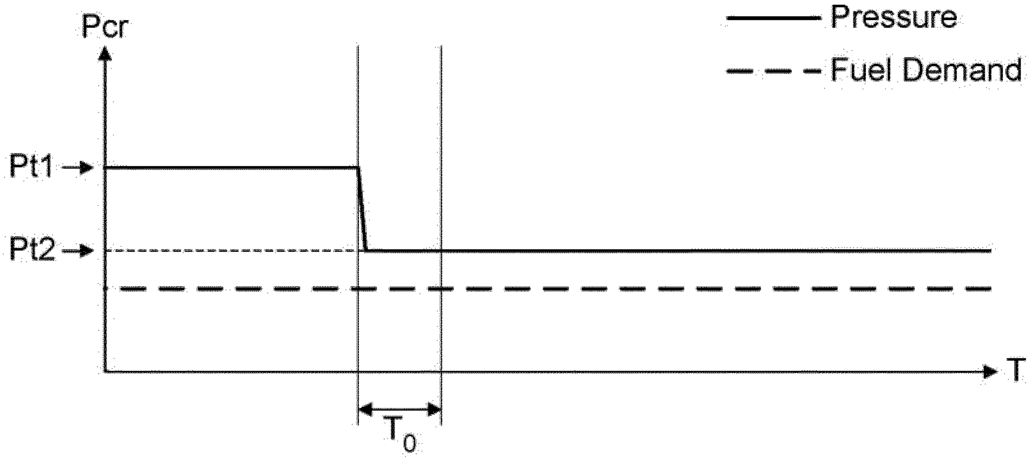


FIG. 3b

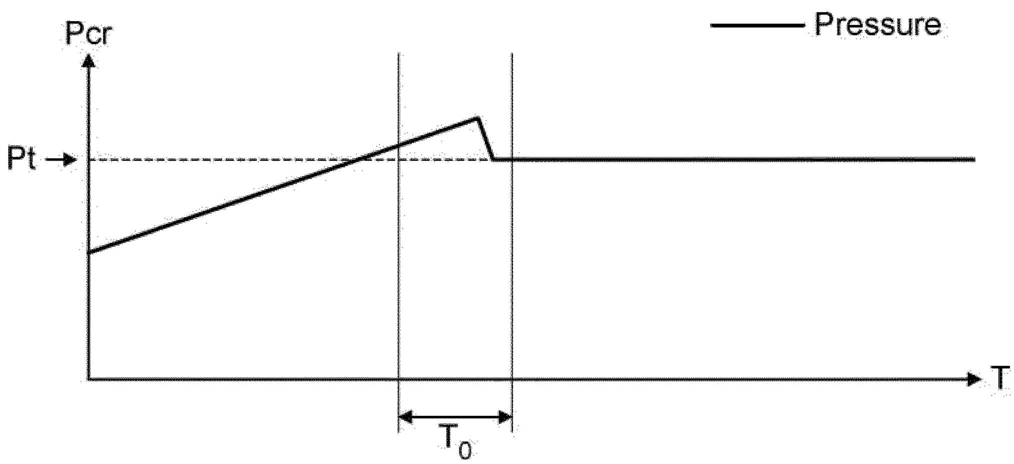


FIG. 4

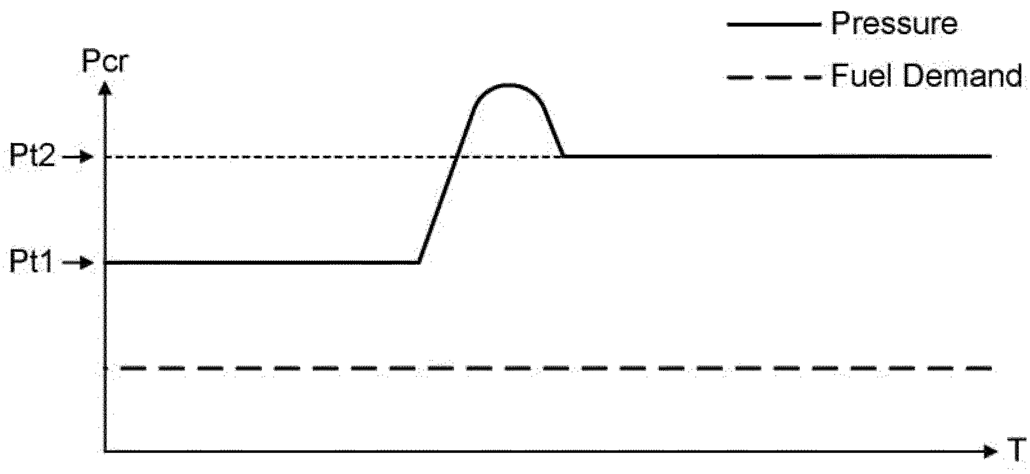
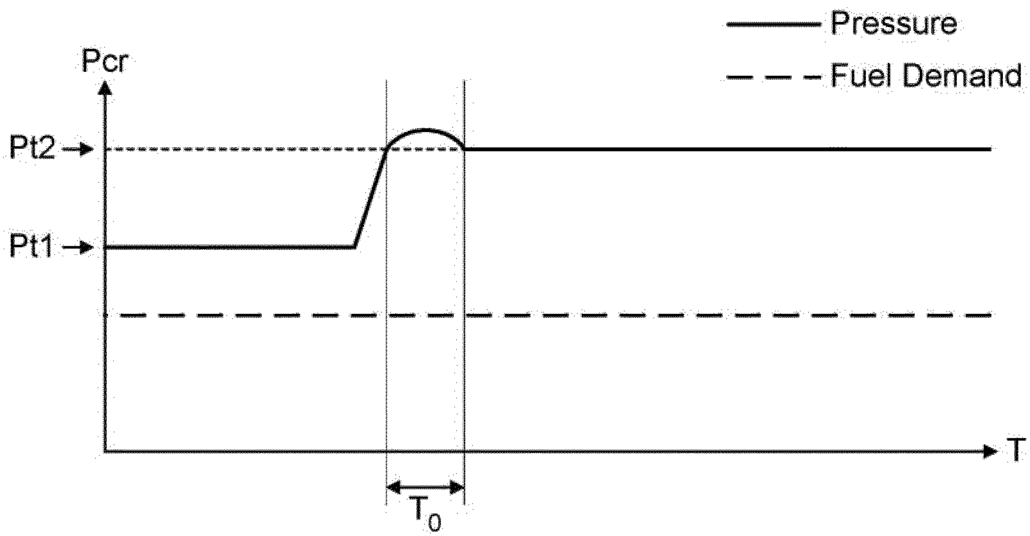

Pressure
Fuel Demand
Pcr
Pt2
Pt1
T

FIG. 5a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Fuel Demand
Pcr
Pt2
Pt1
T
T_0

FIG. 5b

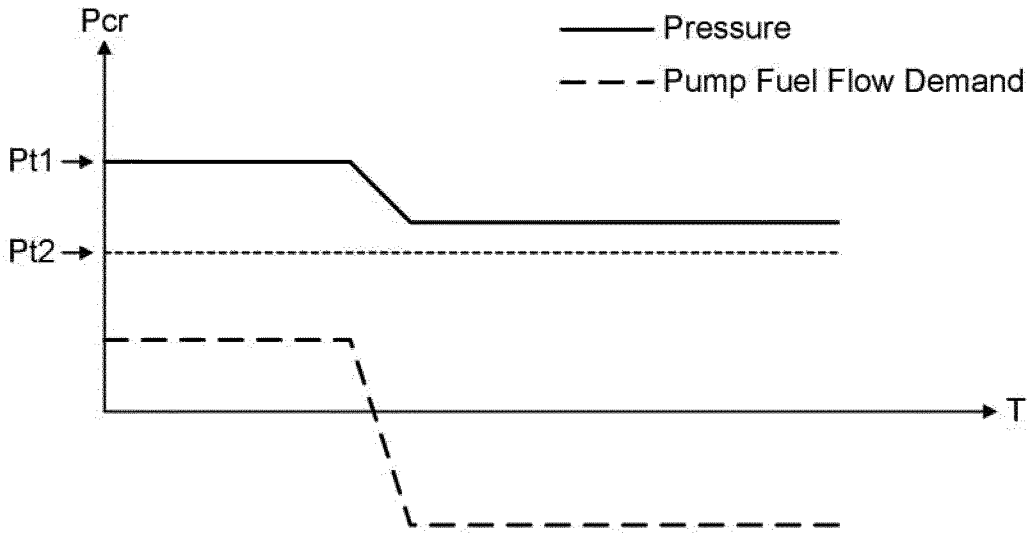
Pcr
Pressure
Pump Fuel Flow Demand
Pt1
Pt2
T

FIG. 6a

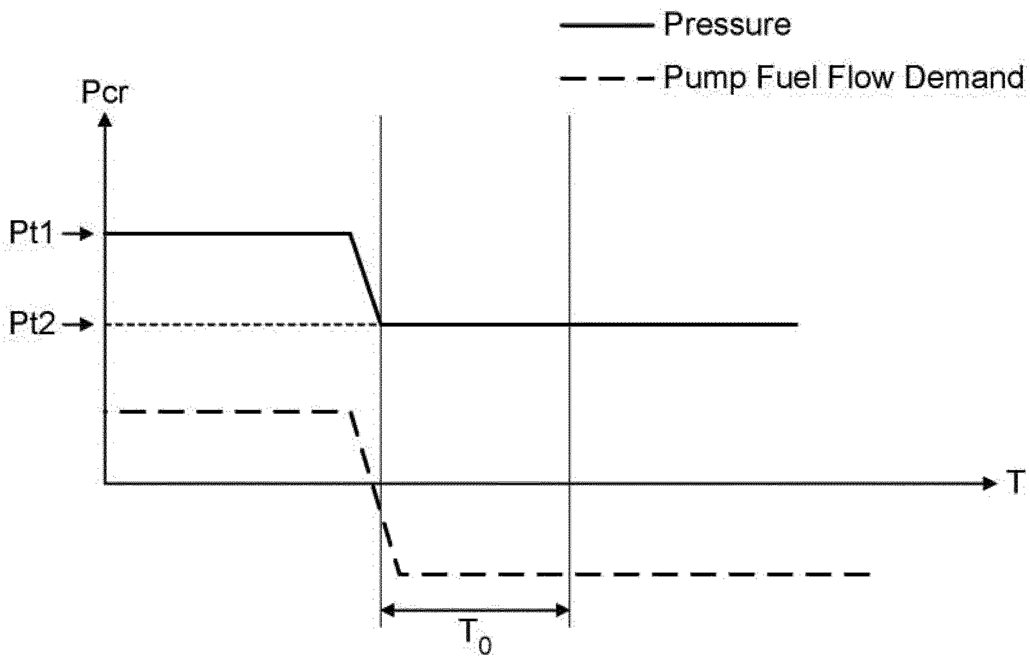
Pressure
Pump Fuel Flow Demand
Pcr
Pt1
Pt2
T
T0

FIG. 6b

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/025365

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02D41/24 F02D41/38
ADD. F02D41/40

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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X	US 2009/188469 A1 (TSUKADA SHINSAKU [JP] ET AL) 30 July 2009 (2009-07-30) paragraphs [0012] - [0017], [0076]; figures 7,9,10 -----	1-16
X	DE 10 2007 047841 A1 (DENSO CORP [JP]) 10 July 2008 (2008-07-10) paragraphs [0049] - [0051]; figure 4 -----	1-16
A	US 2010/282212 A1 (SHAFER SCOTT F [US] ET AL) 11 November 2010 (2010-11-11) paragraphs [0033] - [0039] -----	1-16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 January 2020	28/01/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Le Bihan, Thomas

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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