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(71) Applicant: **Ford Global Technologies, LLC**
Dearborn, MI 48126 (US)

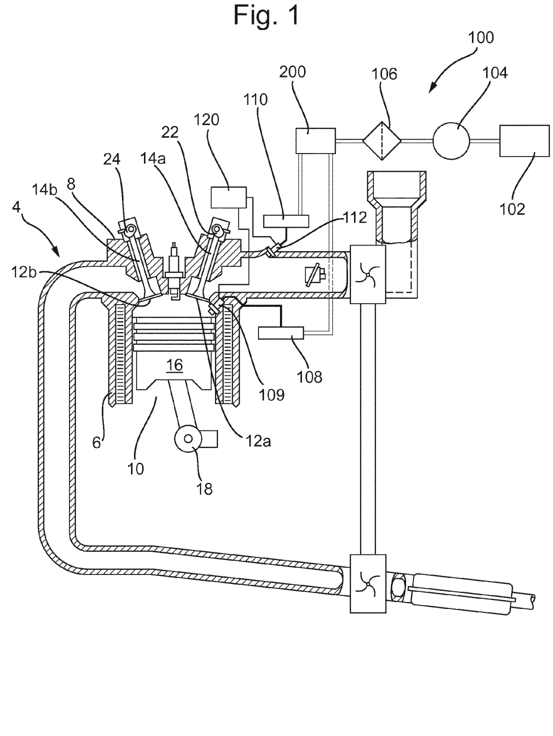
(72) Inventors:
- **SKILLING, Mark, Richard**
  Tonbridge, Kent TN11 9DG (GB)
- **HARRISON-BANFIELD, Rufus**
  London, E10 7PE (GB)

(74) Representative: **Haseltine Lake LLP**
Lincoln House, 5th Floor
300 High Holborn
London WC1V 7JH (GB)

(54) A METHOD AND SYSTEM FOR OPERATING A FUEL INJECTION SYSTEM

(57) A method of operating a fuel injection system for an engine assembly is provided. The fuel injection system comprises a fuel pump assembly in fluidic communication with a fuel rail and a fuel injector configured to selectively permit fuel to flow from the fuel rail into a cylinder of the engine assembly during an injection event. The method comprises:
a) determining a past average operating pressure of fuel within the fuel rail over a first period of operation of the engine assembly;
b) determining a past average injection pressure of fuel within the fuel rail during a past injection event;
c) determining a pressure difference between the past average operating pressure and the past average injection pressure;
d) determining a current average operating pressure of fuel within the fuel rail for a second period of operation of the engine assembly ending after the first period; and
e) predicting a future or current injection pressure of fuel during a future or current injection event by applying the pressure difference to the current average operating pressure. A fuel injection system for an engine assembly is also provided.

Fig. 1



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Description

Technical Field

[0001] The present disclosure relates to a fuel injection method and system for an engine assembly and is particularly, although not exclusively, concerned with a fuel injection method and system configured to improve the accuracy of a fuel injection event performed by the fuel injection system.

Background

[0002] A fuel injection system for an engine assembly typically comprises a fuel pump configured to pump fuel to an appropriate pressure to be injected into cylinders of the engine assembly by one or more fuel injectors. Fuel that has been pressurised by the fuel pump is stored in a fuel reservoir, such as a fuel injection rail, before being injected into the engine cylinders.

[0003] In some engine assemblies, the fuel pump is driven by lobes on a cam shaft of the engine assembly, which displace a piston of the fuel pump to pressurise the fuel. In such arrangements, the pressure of fuel supplied by the fuel pump, and hence, the pressure of fuel within the fuel rail, varies during operating of the engine assembly. In particular, the pressure of fuel varies according to the number and angle of the lobes on the cam driving the fuel pump, as well as the speed of rotation of the cam shaft.

[0004] The duration of a fuel injection event is typically scheduled according to the pressure of fuel within the fuel rail, in order to ensure that the desired quantity of fuel is injected into the engine cylinders. When the pressure of fuel is varying, as described above, determining a suitable duration of each fuel injection event becomes very challenging.

Statements of Invention

[0005] According to an aspect of the present disclosure, there is provided a method of operating a fuel injection system for an engine assembly, the fuel injection system comprising a fuel pump assembly in fluidic communication with a fuel reservoir, e.g. rail and a fuel injector configured to selectively permit fuel to flow from the fuel rail into a cylinder of the engine assembly during an injection event, wherein the method comprises:

a) determining a past average operating pressure of fuel within the fuel rail over a first period of operation of the engine assembly;
b) determining a past average injection pressure of fuel within the fuel rail during a past injection event;
c) determining a pressure difference between the past average operating pressure and the past average injection pressure;
d) determining a current average operating pressure of fuel within the fuel rail for a second period of operation of the engine assembly ending after the first period; and
e) predicting a future or current injection pressure of fuel during a future or current injection event by applying the pressure difference to the current average operating pressure.

[0006] The past injection event may occur during the first period of operation of the engine assembly. The steps of the method may be performed during a continuous period of operation of the engine assembly. In other words, the engine may not be shut down or restarted between the steps of the method being performed. However, it will be appreciated that when the engine is initially started or restarted, the first period of operation of the engine assembly may include a period of operation of the engine assembly before the engine was previously stopped, e.g. until the engine has been operating for a period of time at least as long as the first period.

[0007] The method may further comprise scheduling a future or current injection event, e.g. determining a timing of the future or current injection event, such as a start time, end time and/or duration of the injection event, according to the predicted future or current injection pressure.

[0008] The method may comprise determining a new average operating pressure of fuel within the fuel rail for a third period of operation of the engine assembly ending during the future or current injection event. The method may further comprise updating the predicted future or current injection pressure of fuel by applying the difference to the new average operating pressure. The timing of the future or current injection event may be adjusted based on the updated prediction of the future or current injection pressure.

[0009] The method may further comprise recording a plurality of measurements of the operating pressure of fuel within the fuel rail over the first period of operation of the engine assembly. The past average operating pressure may be determined by calculating an average of the plurality of operating pressure measurements. The plurality of measurements may be recorded prior to the steps of the method and/or may be recorded concurrently with the other steps of the method.

Subsequent iterations of the method may use pressure measurements recorded during previous iterations of the method.

[0010] In some arrangements, the pressure measurements may be recorded separately from the method and may be available for use by the method. The pressure measurements may be recorded substantially constantly whilst the engine is operating. The plurality of measurements of the operating pressure may be captured at a frequency of 1 kHz or greater.

[0011] The first and second periods of operation may be consecutive periods of operation of the engine assembly, e.g. such that the second period follows immediately after the first period. The second period of operation may at least partially overlap with the first period of operation.

[0012] The past average operating pressure may be determined over a period during which a crank shaft of the engine assembly rotates through an angle of 720 degrees. In other words, pressure measurements recording during the last 720 degrees of rotation of the crank shaft or another past period during which the crank shaft rotated through 720 degrees may be used to determine the past average operating pressure.

[0013] The current average operating pressure may be determined over a period during which the crank shaft rotates through an angle of 720 degrees, e.g. prior to the point at which the current average operating pressure is determined. Alternatively, the current average operating pressure may be determined over a period during which the crank shaft rotates through less than 720 degrees.

[0014] The method may be repeated during or close to the future or current injection event, e.g. in order to update the predicted injection pressure during the injection event. A future or current injection event may be rescheduled, e.g. the timing of the future ot current injection event may be adjusted, according to an updated predicted injection pressure.

[0015] The engine assembly may comprise one or more additional fuel injectors configured to selectively permit fuel to flow from the fuel rail into one or more additional cylinders of the engine assembly respectively during injection events of the additional fuel injectors.

[0016] The past average operating pressure may be determined over a period during which the fuel injector and one, more than one or each additional fuel injector may perform one or more injection events. Additionally or alternatively, the current average operating pressure may be determined over a period during which the fuel injector and one, more than one or each of the additional fuel injectors may perform one or more injection events.

[0017] The method, e.g. steps c), d) and e) of the method, may be repeated in order to predict further future or current injection pressures for the or each of the additional fuel injectors. In some arrangements, step a) and/or step b) may also be repeated.

[0018] When the method is repeated, the current average operating pressure calculated during the previous iteration of the method may be used to determine the past average operating pressure for the present iteration of the method. For example, the current average operating pressure from the previous iteration may be used as the past average operating pressure in the next iteration. Alternatively, the current average operating pressure of the previous iteration, pressure measurements used to calculate the current average operating pressure, pressure measurements recorded during the previous iteration of the method and/or other pressure measurements may be used to calculate the past average operating pressure of the present iteration of the method.

[0019] Furthermore, pressure measurements used to calculate the current average operating pressure in the last iteration, pressure measurements recorded during the previous iteration of the method and/or other pressure measurements may be used to calculate the current average operating pressure for the present iteration of the method.

[0020] The timing with which the method is repeated may be determined according to a rotational speed of a crank shaft of the engine assembly. For example, the method may be repeated each time the crank shaft rotates by a predetermined angle of rotation.

[0021] Alternatively, the method may be performed when the angle of the crank shaft is equal to a predetermined value or values.

[0022] The past injection event considered in step b) may be the most recent injection event of the fuel injector and the additional fuel injectors, e.g. of any of the fuel injectors provided in the fuel injection system or engine assembly. Alternatively, the past injection event considered in step b) may be the most recent injection event of the fuel injector or additional fuel injector that is scheduled to inject fuel during the future or current injection event.

[0023] According to another aspect of the present disclosure, there is provided a fuel injection system for an engine assembly, the fuel injection system comprising: a fuel pump assembly in fluidic communication with a fuel rail; a fuel injector configured to selectively permit fuel to flow from the fuel rail into a cylinder of the engine assembly during an injection event; and a controller configured to perform the above-mentioned method.

[0024] The fuel pump assembly may comprise a reciprocating fuel pump driven by a cam shaft of the engine assembly. The fuel pump assembly may be a high pressure fuel pump assembly configured to supply high pressure fuel to a high pressure injection system of the engine assembly.

[0025] The fuel injection system may comprise a further fuel pump. The further fuel pump may be a low pressure fuel pump. The further fuel pump may be configured to supply fuel to the fuel pump assembly.

[0026] The fuel rail may be in fluidic communication with a point between the further fuel pump and a fuel pump of the fuel pump assembly, e.g. the reciprocating fuel pump. The fuel injection system may further comprise a further injector provided downstream of the fuel pump of the fuel pump assembly, e.g. downstream of the reciprocating fuel pump.

[0027] An engine assembly or a motor vehicle may comprise the above-mentioned fuel injection system.

[0028] To avoid unnecessary duplication of effort and repetition of text in the specification, certain features are described in relation to only one or several aspects or embodiments of the invention. However, it is to be understood that, where it is technically possible, features described in relation to any aspect or embodiment of the invention may also be used with any other aspect or embodiment of the invention.

Brief Description of the Drawings

[0029] For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawings in which:

Figure 1 is a schematic view of an engine assembly comprising a fuel injection system according to arrangements of the present disclosure;

Figure 2 is a schematic view of the fuel injection system according to arrangements of the present disclosure;

Figure 3 is a graph showing the pressure of fuel within the fuel injection system of the present disclosure during operating of the engine assembly; and

Figure 4 shows a method of operating a fuel injection system according to arrangements of the present disclosure.

Detailed Description

[0030] With reference to Figure 1, an engine assembly 2, e.g. for a motor vehicle, comprises an engine 4 (such as an internal combustion engine) and a fuel system 100. The engine 4 comprises a cylinder block 6 and a cylinder head 8. The cylinder block 6 defines one or more cylinders 10 of the engine 4. Figure 1 shows a single cylinder 10, however, it will be appreciated that additional cylinders may be provided. For example, the engine 4 may comprise two, three, four, six, eight or any other number of cylinders 10.

[0031] The cylinder head 8 defines one or more inlet and outlet ports 12a, 12b configured to permit inlet and exhaust gases to flow into and out of the cylinders 10. In the arrangement shown, the cylinder head 8 defines a single inlet port 12a and a single 12b for the cylinder 10. However, it is equally envisaged that the cylinder head 8 may define two or more inlet ports 12a and/or two or more outlet ports 12b for each cylinder 10.

[0032] The flow of inlet and exhaust gases passing through the inlet and outlet ports 12a, 12b is controlled by inlet and outlet valves 14a, 14b provided at the inlet and outlet ports 12a, 12b respectively. The positions of the inlet valves 14a are controlled by an inlet camshaft 22, which comprises a cam associated with each of the valves 12b. The cams are configured to act against valve stems of the valves as the cam shaft rotates and open the valves the valve are otherwise be biased into a closed position. The positions of the outlet valves 14b are controlled by an outlet camshaft 24 in the same way.

[0033] Inlet gases are introduced into each of the cylinders 10 via the corresponding inlet port 12a. Fuel is also introduced into the cylinder by the fuel system 100, as described in more detail below, and is mixed with the inlet air. The mixture of inlet air and fuel is combusted within the cylinder 10 and the expanding combustion gases produced through the combustion event act on a piston 16 within the cylinder 10. The piston 16 is operatively coupled to a crank shaft 18 of the engine, which is rotatably driven by the movement of the piston 16 within the cylinder 10 caused by the expanding combustion gases.

[0034] The crank shaft 18 is operatively coupled to the inlet and outlet camshafts 22, 24, such that the rotation of the cam shafts 22, 24 is synchronised with rotation of the crank shaft 18. For example, the crank shaft 18 may be coupled to the camshafts via a belt drive, chain drive, gear drive and/or any other mechanical drive. The inlet and outlet valves 14a, 14b can thereby be positioned appropriately according to the angle of the crank shaft and the positions of the pistons 16 within the cylinders 10.

[0035] The fuel is introduced into the cylinders 10 by the fuel system 100 of the engine assembly 2. In the arrangement shown in Figure 1, the fuel system 100 is a combined Port Fuel Injection (PFI) system and Direct Injection (DI) system.

[0036] The fuel system 100 comprises a fuel tank 102, a Low Pressure (LP) fuel pump 104, a fuel filter 106 and a High Pressure (HP) fuel pump assembly 200. The LP fuel pump 104 is configured to draw fuel from the fuel tank 102 at a first pressure and deliver the fuel to the HP fuel pump assembly 200 at a second pressure, which is greater than the first pressure.

[0037] The LP fuel pump 104 may be an electrically driven fuel pump. Alternatively, the LP fuel pump 104 may be a mechanically driven fuel pump driven by the engine 4. The LP fuel pump 104 may be directly driven by the engine. Alternatively, the LP fuel pump may be driven via a belt, chain or gear drive, or any other form of mechanical drive.

[0038] The HP fuel pump assembly 200 is configured to increase the pressure of fuel to a third pressure that is suitable for injecting directly into the engine cylinders 16. The HP fuel pump assembly 200 supplies fuel at the third pressure to a DI fuel rail 108 of the fuel system 100. One or more DI injectors 109 are arranged in fluid communication with the DI fuel rail. The DI injectors 109 are configured to selectively inject fuel directly into the cylinders 10 to be combusted.

[0039] A controller 120 is configured to control the operation of the DI injectors 109, e.g. to control the timing with which fuel is injected into the cylinders by the DI injectors 109. The controller 120 may control the point at which the DI injector begins to inject the fuel and the duration of the fuel injection event. The controller 120 may be a dedicated controller of the fuel system 100. Alternatively, the controller may be provided as part of another system of the engine assembly 2 or motor vehicle in which the engine assembly is installed. For example, the controller 120 may be an engine control unit, a power train control unit or any other controller of the engine assembly or motor vehicle.

[0040] The HP fuel pump assembly 200 also supplies fuel to a PFIfuel rail 110 of the fuel system 100. One or more PFI injectors 112 are arranged in fluid communication with the PFI fuel rail 110. As shown in Figure 1, the PFI injectors 112 are configured to selectively inject fuel into the inlet ports 12a of each of the cylinders 18. The controller 120 is configured to control the operation of the PFI injectors 112, e.g. to control the timing with which fuel is injected by the PFI injectors 112 into the cylinders 18.

[0041] With reference to Figure 2, the HP fuel pump assembly 200 comprises an inlet 202 configured to receive fuel from the LP fuel pump 104. The HP fuel pump assembly 200 may further comprise an inlet filter 204 provided at or close to the inlet 202. Fuel entering the HP fuel pump via the inlet 202 may pass through a damper chamber 206 before reaching a piston chamber 208. A piston 210 is provided within the piston chamber 208 and is configured to reciprocate within the chamber to vary a volume of the piston chamber 208 that is in fluid communication with the damper chamber 206. Reciprocation of the piston 208 acts to draw fuel into the piston chamber 208 and compress the fuel within the piston chamber 208 such that fuel within the chamber is pumped to the third pressure.

[0042] As shown in Figure 2, the motion of the piston 210 is driven by fuel pump cam 211. In the arrangement shown, the fuel pump cam 211 is provided on the exhaust cam shaft 24 of the engine 4. However, in other arrangements, the fuel pump cam 211 may be provided on any other cam shaft of the engine assembly, such as the inlet cam shaft 22. In the arrangement shown in Figure 2, the fuel pump cam 211 comprises three lobes. However, it is equally envisaged that the fuel pump cam may comprise one, two, four or any other desirable number of lobes.

[0043] Fuel pressurised by the action of the piston 210 may leave the piston chamber 208 and may be output from the HP fuel pump assembly 200 via an HP outlet 212. As depicted in Figure 2, fuel leaving the HP fuel pump via the HP outlet 212 may be delivered to the DI fuel rail 108 in order to be injected directly into the engine cylinders 10 by the DI injectors 109.

[0044] As shown in Figure 2, a valve assembly 214 may control the flow of fuel from the piston chamber 208 to the HP outlet 212. When the valve assembly 214 is in a first (e.g. open) condition, pressurised fuel may flow from the piston chamber 208 to the HP outlet 212. When the valve assembly 214, is in a second (e.g. closed) condition, the fuel that is pressurised within the piston chamber 208 may flow back into the damper chamber 206.

[0045] The valve assembly 214 may comprise one or more valves, such as a non-return valve and/or a pressure release valve. The condition of the valve assembly may depend on a difference in pressure between the DI fuel rail 108 and the piston chamber 208. In some arrangements of the disclosure, the valve assembly 214 may be configured such that pressurised fuel returns from the piston chamber 208 to the damper chamber 206 if the pressure of fuel within the DI fuel rail 108 is at or close to an HP outlet pressure of the HP fuel pump assembly 200. This may occur, for example, if the amount of fuel currently being injected by the DI injectors 109 is low.

[0046] The HP fuel pump assembly 200 further comprises an LP outlet 214, e.g. prior to the piston 210. The LP outlet 214 is in fluid communication with the damper chamber 206. Fuel may be output from the damper chamber 206 via the LP outlet 214. Fuel output from the HP fuel pump via the LP outlet 214 may be delivered to the PFI fuel rail 110 to be injected into the inlet ports 12a of the cylinders 18 by the PFI injectors 112.

[0047] As mentioned above, fuel that is pressurised within the piston chamber 208 may flow back into the damper chamber 206. Hence, the pressure of fuel within the damper chamber 206 may vary depending on the amount of fuel flowing back from the piston chamber 208 to the damper chamber 206. Furthermore, the pressure of fuel within the damper chamber 206 may vary as the piston 210 reciprocates within the piston chamber 208. For example, the pressure within the damper chamber 206 may drop as the piston moves to increase the operative volume of the piston chamber 208 and may increase as the piston moves to reduce the operative volume of the piston chamber 208. The extent to which the pressure within the damper chamber 206 varies as the piston moves within the piston chamber 208 may depend on the condition of the valve assembly 214. For example, if the valve assembly 214 is in the second condition, the pressure of fuel within the damper chamber 206 may vary more than if the valve assembly 214 is in the first condition.

[0048] As the pressure of fuel within the damper chamber 206 varies, the pressure of fuel at the LP outlet 214 of the HP fuel pump assembly 200 and the pressure of fuel within the PFI fuel rail 110 may vary in a similar way. Additionally, the pressure of fuel within the PFI fuel rail 110 may be affected due to the injection of fuel into the engine cylinders 10 from the PFI fuel rail 110. For example, when fuel is injected from the PFI fuel rail, the pressure of fuel within the PFI fuel rail 110 may be reduced.

[0049] With reference to Figure 3, curve P shows values of fuel pressure within the PFI fuel rail 110 captured every millisecond, e.g. at a sample rate of 1kHz, during a period of operation of the fuel system 100. The pressure of fuel supplied to the PFI fuel rail 110 from the HP Pump 200 varies between a minimum supply pressure P_1 and a maximum supply pressure P_2 due to the action of the piston 210. Further, at times T_1, T_2, T_3 and T_4 the pressure of fuel within the PFI rail is reduced due to the fuel being injected from the PFI rail into the engine cylinders. As shown, when fuel is injected from the PFI rail, the pressure of the fuel within the rail may be reduced below the minimum supply pressure P_1.

[0050] The recorded values of pressure of fuel within the PFI fuel rail 110 may be stored within a memory associated with the controller 120, or another controller. The recorded values may be used within a method 400, described below, in order to improve the accuracy with which fuel is injected into the cylinders 10 of the engine 4.

[0051] With reference to Figure 4, the controller 120 is configured to operate the PFI injectors according to a method 400. The method comprises a first step 402 in which a past average operating pressure of fuel $\overline{P}_{\Delta tp}$ within the PFI fuel rail 110 is determined over a first period of operation of the engine assembly 2.

[0052] The past average operating pressure $\overline{P}_{\Delta tp}$ may be calculated by taking an average of the measurements of pressure, such as those shown in the graph of Figure 3. The pressure measurements may be captured substantially constantly during operation of the engine assembly to be used in the method 400 or another method.

[0053] The first period of operation of the engine assembly may be a period during which each of the fuel injectors, e.g. the PFI fuel injectors 112, of the fuel system 100 performs one or more fuel injection events, e.g. such that fuel is injected into each of the cylinders 10 of the engine 4. For example, the first period of operation may be a period during which the crank shaft 18 rotates through 720 degrees. The first period of operation may be a period that ends substantially immediately before the first step 402 of the method is performed. Alternatively, the first period may end prior to the method 400 being performed.

[0054] The period of operation during which the past average operating pressure $\overline{P}_{\Delta tp}$ is determined may be defined between predetermined angles of the crank shaft 18. For example, the first period may begin at a predetermined period start angle, such as 0 degrees and end at a predetermined period end angle, e.g. after the crank shaft has rotated through 720 degree or another desired angle. When the method 400 is performed, the past average operating pressure $\overline{P}_{\Delta tp}$ may be determined by referring the last suitable period of operation performed by the engine.

[0055] The method 400 comprises a second step 404 in which a past average injection pressure $\overline{P}_{\Delta tpi}$ of fuel within the fuel rail 110 during a past injection event is determined. The past injection event may have occurred during the period over which the past average operating pressure $\overline{P}_{\Delta tp}$ is determined in the first step 402. The past average injection pressure $\overline{P}_{\Delta tpi}$ may be the average pressure of fuel within the fuel rail during the last injection event performed by one of the fuel injectors provided in the fuel system 100. Alternatively, the past average injection pressure may be the average pressure of fuel within the fuel rail during the last injection event performed by the fuel injector that is due to perform the next fuel injection event.

[0056] The method 400 comprises a third step 406, in which a difference $\Delta\overline{P}$ between the past average operating pressure $\overline{P}_{\Delta tp}$ and the past average injection pressure $\overline{P}_{\Delta tpi}$ is determined, e.g. using equation (1).

$$\Delta\bar{P} = \bar{P}_{\Delta tp} - \bar{P}_{\Delta tpi} \qquad (1)$$

[0057] In a fourth step 408 of the method, a current average operating pressure $\overline{P}_{\Delta tc}$ of fuel within the PFI fuel rail 110 is determined during a second period of operation of the engine assembly. The second period of operation may end after the first period of operation. The first and second periods of operation may be consecutive periods. For example, the second period may follow substantially immediately after the first period. Alternatively, the second period may at least partially overlap with the first period. In some arrangements, the second period may end when the method 400, e. g. the fourth step 404 of the method, is performed. The second period may have the same duration, e.g. extend over a period during which the crank shaft rotates through the same angle, as the first period. Alternatively, the second period may be shorter that the first period.

[0058] The second period may be the period between the last time that the crank shaft was at the pre-determined period start position and the time when the method 400, e.g. the fourth step 408 of the method, is performed. The length of the second period may therefore vary depending on the angle of the crank shaft 18 when the method 400 is performed.

[0059] The method 400 comprises a fifth step 410 in which a future injection pressure $P_{\Delta tci}$ for a future injection event is predicted by applying the pressure difference $\Delta\overline{P}$, e.g. as determined in the third step 406, to the current average operating pressure $\overline{P}_{\Delta tc}$, e.g. as determined in the fourth step 408. For example, the future injection pressure $P_{\Delta tci}$ may be calculated according to equation (2).

$$P_{\Delta tci} = \bar{P}_{\Delta tc} - \Delta\bar{P} \quad (2)$$

[0060] Alternatively, the future injection pressure $P_{\Delta tci}$ may be predicted by determining a difference between the past average operating pressure $\bar{P}_{\Delta tp}$ and the current average operating pressure $\bar{P}_{\Delta tc}$ and applying the difference to the past average injection pressure $\bar{P}_{\Delta tpi}$, e.g. to account for any transient changes in the average pressure of fuel within the fuel rail in the average injection pressure.

[0061] In some arrangements, the method may be performed during the future injection event. In other words, the future injection event may be a current injection event.

[0062] The predicted future or current average injection pressure may be used to schedule the future or current injection event, e.g. to determine a suitable timing, such as a start time and duration or end time of the injection event. In this way, the accuracy of the amount of fuel injected during the injection event may be improved.

[0063] If the method 400 is performed before the future injection event, the method 400 may comprise a further step in which a new average operating pressure is determined for a third period of operation of the engine assembly ending during the future injection event. The predicted average injection pressure for the future injection event may be updated by applying the pressure difference to the new average operating pressure and the scheduling of the future injection event may be updated accordingly.

[0064] Alternatively, instead of performing the further step, the method 400 may be repeated such that the second period ends during the future injection event.

[0065] As described above, the engine 4 may comprise any desirable number of cylinders, each provided with one or more PFI injectors 112. The method 400 may be repeated in order to predict a future or current injection pressure for each of the PFI fuel injectors 112. When performing the second step 404, the past injection event considered may be the last injection event performed by any of the PFI fuel injectors 112. Alternatively, the past injection event considered in the second step 404 may be a past injection event of the fuel injector for which the future or current injection pressure is being predicted by the method 400, e.g. for the same cylinder.

[0066] The method 400 may be repeated after the crank shaft 18 has rotated through a predetermined angle. Alternatively, the method 400 may be performed and repeated when the angle of the crank shaft is at a predetermined value or predetermined values.

[0067] In this way, the method may be performed an appropriate number of times, e.g. depending on the number of cylinders 10 or PFI fuel injectors 112, in order to predict the average injection pressure for each fuel injection event performed by the fuel system 100.

[0068] In the arrangement shown in Figure 3, the variation of pressure within the PFI fuel rail 110 has been measured for an engine having three cylinders 10 and a fuel pump cam 211 having three lobes. As the timing with which fuel is injected into the cylinders of the engine is determined at least partially according to the position, e.g. angle, of the crank shaft 18 and the cam shaft driving the HP fuel pump assembly 200 is rotated synchronously with the crank shaft 18, the pressure of fuel within the PFI fuel rail 110 may be at substantially the same value at the start of each fuel injection event. Furthermore, the effect of the injection of fuel on the variation of fuel pressure is substantially the same for each injection event for each cylinder of the engine assembly. However, in other arrangements, the pressure of fuel within the fuel rail may vary between the start of one or more injection events performed by the fuel system 100 and may differ between injection events of the same fuel injector, e.g. into the same cylinder. This effect may occur if the number of cylinders 10 of the engine 4 is not equal to the number of lobes on the fuel pump cam 211.

[0069] The following additional statements of invention are also included within this specification and form part of the present disclosure:

Statement 1. A method of operating a fuel injection system for an engine assembly, the fuel injection system comprising a fuel pump assembly in fluidic communication with a fuel rail and a fuel injector configured to selectively permit fuel to flow from the fuel rail into a cylinder of the engine assembly during an injection event, wherein the method comprises:

a) determining a past average operating pressure of fuel within the fuel rail over a first period of operation of the engine assembly;
b) determining a past average injection pressure of fuel within the fuel rail during a past injection event;
c) determining a pressure difference between the past average operating pressure and the past average injection pressure;
d) determining a current average operating pressure of fuel within the fuel rail for a second period of operation

of the engine assembly ending after the first period; and

e) predicting a future or current injection pressure of fuel during a future or current injection event by applying the pressure difference to the current average operating pressure.

Statement 2. The method of statement 1, wherein the method further comprises scheduling a future or current injection event according to the predicted future or current injection pressure.

Statement 3. The method of statement 1 or 2, wherein the method further comprises:

determining a new average operating pressure of fuel within the fuel rail for a third period of operation of the engine assembly ending during the future or current injection event; and

updating the predicted future or current injection pressure of fuel by applying the difference to the new average operating pressure.

Statement 4. The method of any of the preceding statements, wherein the method comprises, recording a plurality of measurements of the operating pressure of fuel within the fuel rail over the first period of operation of the engine assembly; wherein the past average operating pressure is determined by calculating an average of the plurality of operating pressure measurements.

Statement 5. The method of statement 4, wherein the plurality of measurements of the operating pressure are captured at a frequency of 1 kHz or greater.

Statement 6. The method of any of the preceding statements, wherein the first and second periods of operation are consecutive periods of operation of the engine assembly.

Statement 7. The method of any of the preceding statements, wherein the second period of operation at least partially overlaps with the first period of operation.

Statement 8. The method of any of the preceding statements, wherein the past average operating pressure is determined over a period during which a crank shaft of the engine assembly rotates through an angle of 720 degrees.

Statement 9. The method of any of the preceding statements, wherein the method is repeated during the future or current injection event.

Statement 10. The method of any of the preceding statements, wherein the engine assembly comprises one or more additional fuel injectors configured to selectively permit fuel to flow from the fuel rail into one or more additional cylinders of the engine assembly respectively during injection events of the additional fuel injectors.

Statement 11. The method of statement 10, wherein the past average operating pressure is determined over a period during which the fuel injector and the or each additional fuel injector performs one or more injection events.

Statement 12. The method of statement 10 or 11, wherein the method is repeated in order to predict further future or current injection pressures for the or each of the additional fuel injectors.

Statement 13. The method of statement 12, wherein the timing with which the method is repeated is determined according to a rotational speed of a crank shaft of the engine assembly.

Statement 14. The method of statement 12 or 13, wherein the method is repeated after a crankshaft of the engine assembly has rotated by a predetermined angle.

Statement 15. The method of any of statements 10 to 14, wherein the past injection event considered in step b) is the most recent injection event of the fuel injector and the additional fuel injectors.

Statement 16. The method of any of statements 10 to 15, wherein the past injection event considered in step b) is the most recent injection event of the fuel injector or additional fuel injector that is scheduled to inject fuel during the future or current injection event.

Statement 17. A fuel injection system for an engine assembly, the fuel injection system comprising:

a fuel pump assembly in fluidic communication with a fuel rail;
a fuel injector configured to selectively permit fuel to flow from the fuel rail into a cylinder of the engine assembly during an injection event; and
a controller configured to perform the method according to any of the preceding statements.

Statement 18. The system of statement 17 or method of any of statements 1 to 16, wherein the fuel pump assembly comprises a reciprocating fuel pump driven by a cam shaft of the engine assembly.

Statement 19. The system of statement 17 or 18 or method of any of statements 1 to 16 or 18, wherein the fuel pump assembly is a high pressure fuel pump assembly configured to supply high pressure fuel to a high pressure injection system of the engine assembly.

Statement 20. The system of any of statements 17 to 19 or method of any of statements 1 to 16, 18 or 19, wherein the fuel injection system comprises a further fuel pump.

Statement 21. The system or method of statement 20, wherein the fuel rail is in fluidic communication with a point between the further fuel pump and a fuel pump of the fuel pump assembly.

Statement 22. The system of any of statements 17 to 21 or method of any of statements 1 to 16 or 18 to 21, wherein the fuel injection system further comprises a further injector provided downstream of a fuel pump of the fuel pump assembly.

Statement 23. An engine assembly or motor vehicle comprising the fuel injection system according to any of statements 17 to 22.

[0070] It will be appreciated by those skilled in the art that although the invention has been described by way of example, with reference to one or more exemplary examples, it is not limited to the disclosed examples and that alternative examples could be constructed without departing from the scope of the invention as defined by the appended claims.

Claims

1. A method of operating a fuel injection system for an engine assembly, the fuel injection system comprising a fuel pump assembly in fluidic communication with a fuel rail and a fuel injector configured to selectively permit fuel to flow from the fuel rail into a cylinder of the engine assembly during an injection event, wherein the method comprises:

a) determining a past average operating pressure of fuel within the fuel rail over a first period of operation of the engine assembly;
b) determining a past average injection pressure of fuel within the fuel rail during a past injection event;
c) determining a pressure difference between the past average operating pressure and the past average injection pressure;
d) determining a current average operating pressure of fuel within the fuel rail for a second period of operation of the engine assembly ending after the first period; and
e) predicting a future or current injection pressure of fuel during a future or current injection event by applying the pressure difference to the current average operating pressure.

2. The method of claim 1, wherein the method further comprises:

determining a new average operating pressure of fuel within the fuel rail for a third period of operation of the engine assembly ending during the future or current injection event; and
updating the predicted future or current injection pressure of fuel by applying the difference to the new average operating pressure.

3. The method of claim 1 or 2, wherein the first and second periods of operation are consecutive periods of operation of the engine assembly.

4. The method of any of the preceding claims, wherein the second period of operation at least partially overlaps with the first period of operation.

5. The method of any of the preceding claims, wherein the past average operating pressure is determined over a period during which a crank shaft of the engine assembly rotates through an angle of 720 degrees.

6. The method of any of the preceding claims, wherein the engine assembly comprises one or more additional fuel injectors configured to selectively permit fuel to flow from the fuel rail into one or more additional cylinders of the engine assembly respectively during injection events of the additional fuel injectors.

7. The method of claim 6, wherein the past average operating pressure is determined over a period during which the fuel injector and the or each additional fuel injector performs one or more injection events.

8. The method of claim 6 or 7, wherein the method is repeated in order to predict further future or current injection pressures for the or each of the additional fuel injectors.

9. The method of claim 8, wherein the method is repeated after a crankshaft of the engine assembly has rotated by a predetermined angle.

10. The method of any of claims 6 to 9, wherein the past injection event considered in step b) is the most recent injection event of the fuel injector and the additional fuel injectors.

11. The method of any of claims 6 to 10, wherein the past injection event considered in step b) is the most recent injection event of the fuel injector or additional fuel injector that is scheduled to inject fuel during the future or current injection event.

12. A fuel injection system for an engine assembly, the fuel injection system comprising:

a fuel pump assembly in fluidic communication with a fuel rail;
a fuel injector configured to selectively permit fuel to flow from the fuel rail into a cylinder of the engine assembly during an injection event; and
a controller configured to perform the method according to any of the preceding claims.

13. The system of claim 12 or the method of any of claims 1 to 11, wherein the fuel injection system comprises a further fuel pump, wherein the fuel rail is in fluidic communication with a point between the further fuel pump and a fuel pump of the fuel pump assembly.

14. The system of claim 12 or 13, or the method of any of claims 1 to 11 or 13, wherein the fuel injection system further comprises a further injector provided downstream of a fuel pump of the fuel pump assembly.

15. An engine assembly or motor vehicle comprising the fuel injection system according to any of claims 12 to 14.

Fig. 1

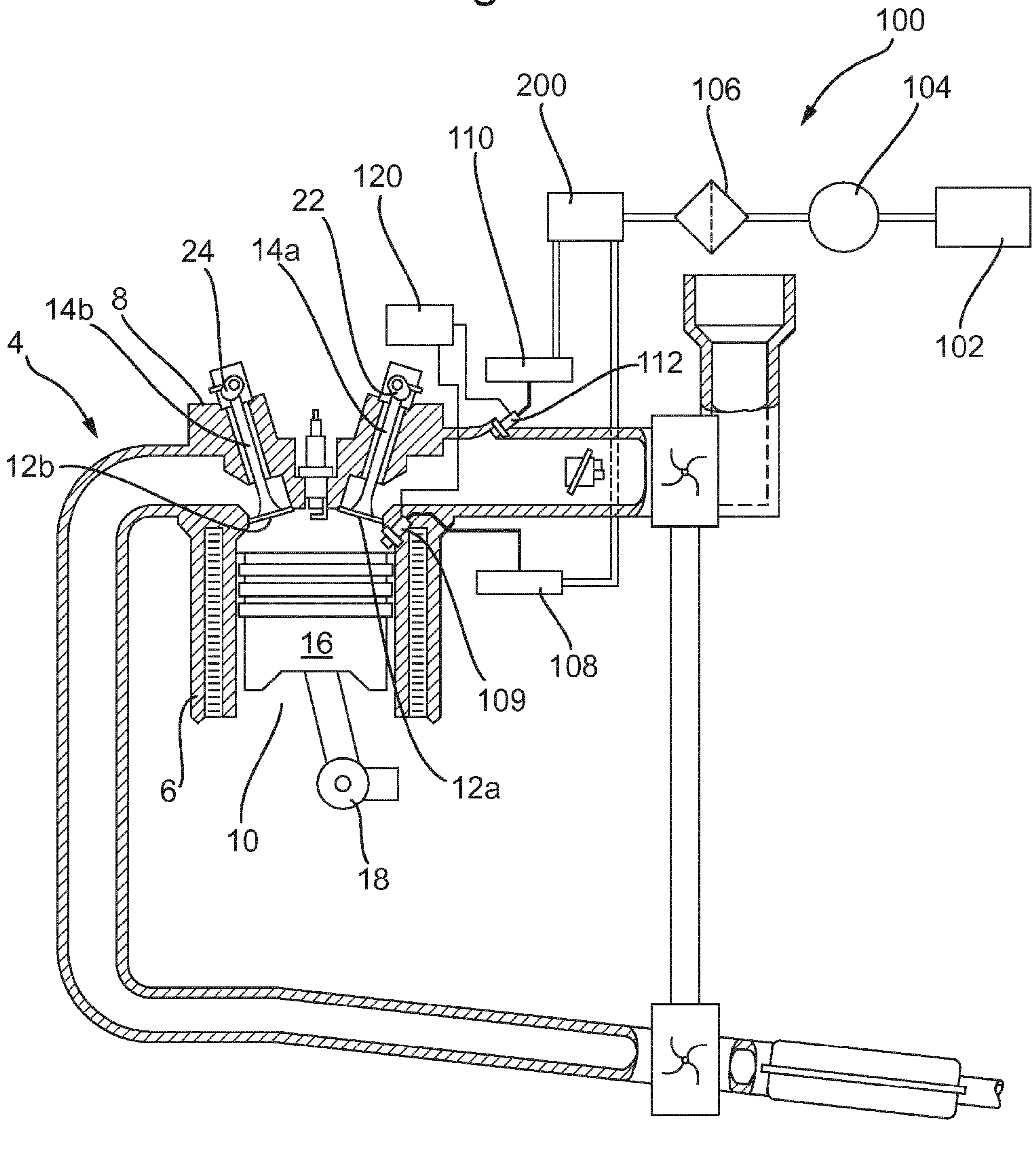

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Fig. 2

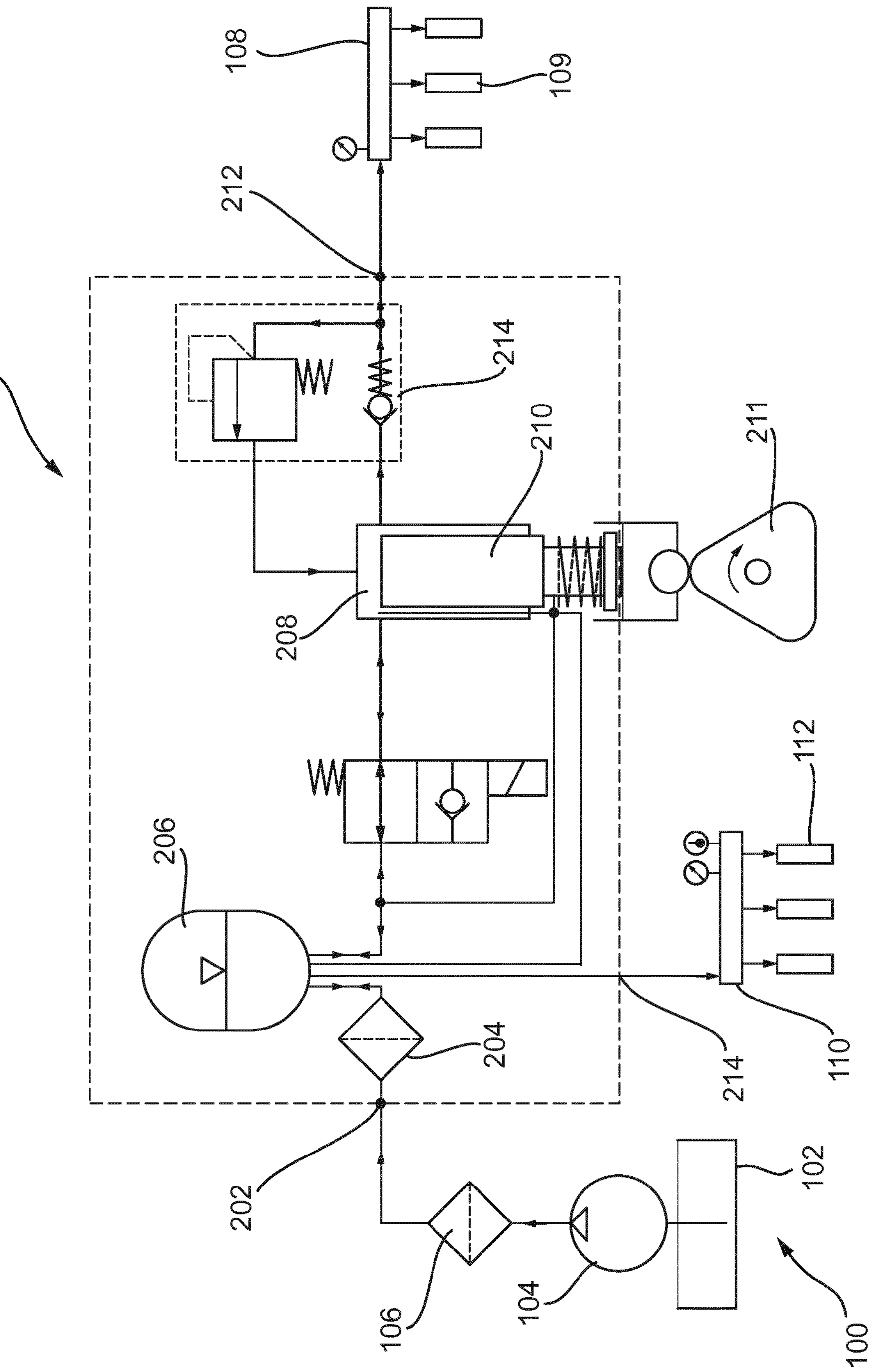
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Fig. 3

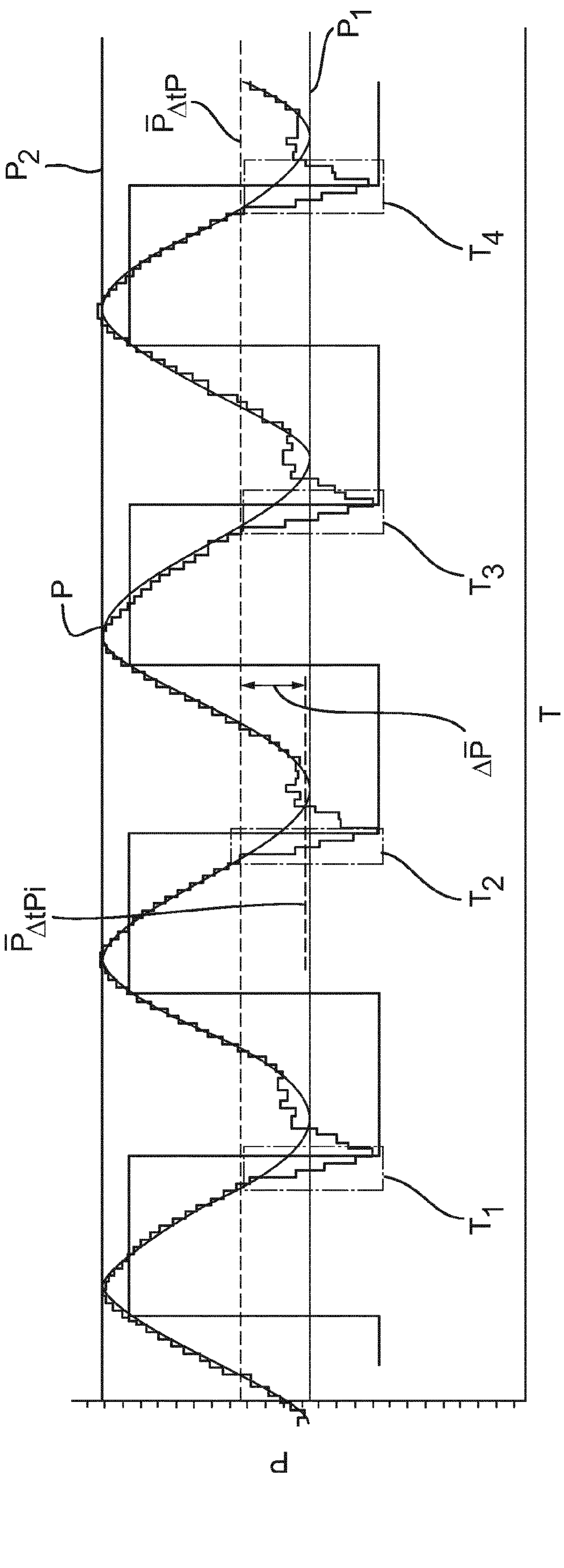
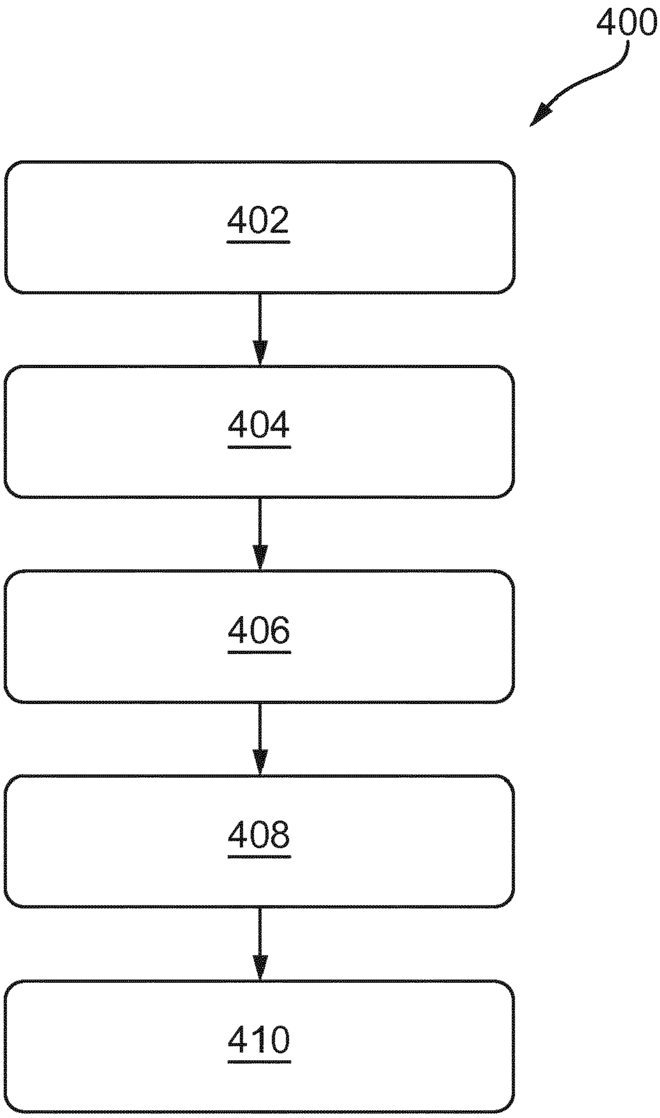


Fig. 4



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EUROPEAN SEARCH REPORT

Application Number
EP 18 17 0608

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	GB 2 357 583 A (DELPHI TECH INC [US]) 27 June 2001 (2001-06-27) * abstract * * claims 1, 14, 15 * * page 11, last paragraph * -----	1-15	
A	DE 197 00 738 C1 (DAIMLER BENZ AG [DE]) 16 April 1998 (1998-04-16) * abstract * * column 2, line 11 - line 34 * -----	1-15	TECHNICAL FIELDS SEARCHED (IPC) F02D F02M

The present search report has been drawn up for all claims

4

Place of search	Date of completion of the search	Examiner
The Hague	22 October 2018	Kämper, Fabian

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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L : document cited for other reasons
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