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(54) **Minimum fuel mass adaptation using cylinder pressure sensor**

(57) It is described a method for adapting injector characteristics of fuel injectors (30, 32) of a multi-cylinder internal combustion engine (10) having combustion chambers (12, 14) with direct fuel injection, which injector characteristics are adapted for each injector (30) individually to compensate for deviations the individual injectors (30, 32) have from standard injectors (30), wherein fuel is injected by each injector (30) and the operation of the engine resulting therefrom is evaluated, and wherein the method further comprises: determining for each cylinder a value of the peak pressure or the indicated mean pressure, which pressure value occurs during a combustion cycle in the cylinder's combustion chamber (12, 14), and modifying the injector characteristics individually for each injector (30, 32) to minimize differences between the pressure values over said cylinders.

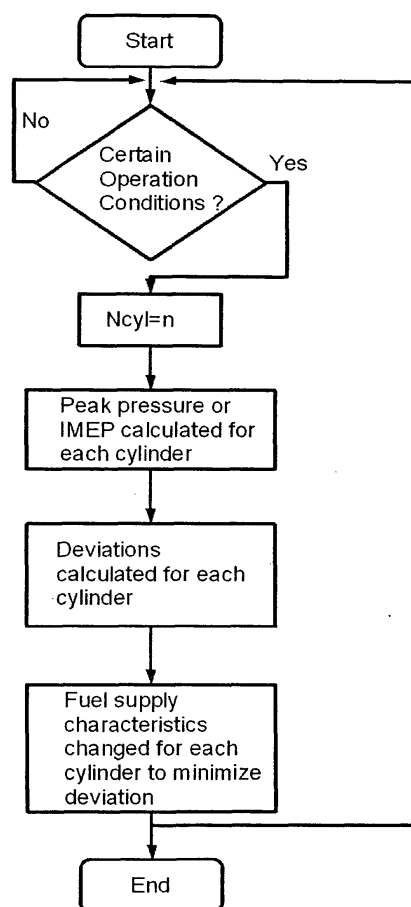


FIG. 2

Description

[0001] The invention relates to a method and an apparatus for adapting injector characteristics of fuel injectors of a multi-cylinder internal combustion engine having combustion chambers with direct fuel injection, which injector characteristics are adapted for each injector individually to compensate for deviations the individual injectors have from standard injectors, wherein fuel is injected by each injector and the operation of the engine resulting therefrom is evaluated.

[0002] In internal combustion engines having direct fuel injection, the fuel supply is controlled by means of injectors to provide the combustion chambers of the engine with the optimal quantity of fuel at each operation point. In modern direct injecting diesel engines fuel is injected which is stored in a fuel rail. The dosing of fuel into the combustion chambers is performed by controlling the injectors accordingly. In most cases, the control is on a time basis with the fuel metering being performed by opening the injector for a certain amount of time and closing it thereafter. A controller of the engine defines the moment of opening which is the start of injection and the length of opening and inputs a respective control signal to the injector.

[0003] For determining the length of injection, the controller uses a correlation or mapping between the length of opening and the quantity of fuel metered thereby by each injector. For this purpose, a map is stored in a storage of the controller, which map is referred to as injector characteristics and gives the injected fuel quantity as a function of several parameters, among others length of injection, fuel pressure, and temperature in the fuel rail.

[0004] The injector characteristics assume a standard injector which conforms to certain specifications. However, the performance of each injector generally deviates from the standard more or less. This leads to deviations of the fuel quantity an individual injectors deliver for any given injection control as compared to a standard injector. Such deviations lead to an uncomfortable operation of the engine and, in particular, an increased fuel consumption and disadvantageous emissions.

[0005] Theoretically, it would be possible to avoid such disadvantages by manufacturing the injectors with very close tolerances. Apart from the fact that this is rather costly, inevitable wear and tear still lead to deviations between the actual injector performance and the standard injector performance during the operation lifetime.

[0006] To compensate for deviations between actual injector performances and standard injector performance, several methods are known to the person skilled in the art:

[0007] DE 19720009 A1 and DE 10011690 A2 adapt the injector characteristics when the engine is idling. These publications propose to instruct the injectors to inject some extra amount of fuel and evaluate the effect this extra amount has on the engine speed. Similar approaches are taken by DE 10257686 A1 during fuel cut-

off operation phases of the engine.

[0008] It exists, therefore, a need to provide a method and an apparatus for adapting the injector characteristics for direct fuel injection engines, without restriction to certain operation conditions.

[0009] According to the present invention, there is provided a method for adapting injector characteristics of fuel injectors of a multi-cylinder internal combustion engine having combustion chambers with direct fuel injection, which injector characteristics are adapted for each injector individually to compensate for deviations the individual injectors have from standard injectors, wherein fuel is injected by each injector and the operation of the engine resulting therefrom is evaluated, and wherein the method further comprises: determining for each cylinder a value of the peak pressure or the indicated mean pressure, which pressure value occurs during a combustion cycle in the cylinder's combustion chamber, and modifying the injector characteristics individually for each injector to minimize differences between the pressure values over said cylinders.

[0010] The invention uses a pressure value to adapt the injector characteristics. The peak pressure can be employed as pressure value, which peak pressure is particularly easy to determine by simply registering the maximum pressure which occurs in a combustion chamber during a combustion cycle.

[0011] Whereas the peak pressure is a suitable parameter for adapting injector characteristics, an improvement may be gained by using the mean pressure, usually called the indicated mean pressure, within the combustion chamber during a combustion or working cycle. This, however, requires to monitor the pressure during this cycle in order to calculate the mean pressure value.

[0012] In all cases, the invention uses a pressure value measured within the combustion chamber and is, therefore, not restricted to special operation conditions of the engine, but provides a quantity which is a basis to adapt the injector characteristics.

[0013] Moreover, the invention aims at unifying injector performances for all injectors by minimizing differences between the injector performances. This approach is different from the state of the art which tries to adapt the individual injector characteristics by correction parameters to have the individual injectors working like standard injectors when controlled by the combination of standard injector characteristics and the correction parameter. Thus, the invention does not evaluate the difference any given injector shows in performance as compared to a standard injector, but compares the injectors with each other. Due to statistic effects this approach simultaneously results in all injectors performing as close as possible to standard injectors.

[0014] A possible measure for such comparison may be an error value which is determined for each cylinder by comparing the pressure value of this cylinder with a target value, which preferably is obtained from averaging the pressure values of all of the cylinders. Of course, the

error value may be based on any suitable error function, which, in particular, may be non-linear.

[0015] The minimizing of differences between the pressure values over said cylinders, i. e. the adapting of the individual injector characteristics to have all injectors showing identical performances may be done using a controller to which the target value and the pressure values are fed and which acts for each injector on the respective injector characteristics or on a correction factor therefore. This allows to employ the invention in cases where a correction factor is already used in controlling the operation of the engine. In particular, the invention may substitute prior art methods or apparatuses which had determined such correction factors only during or for special operation conditions.

[0016] One example for a correction factor which may be used in connection with the invention is a cylinder individual offset to a control factor used for controlling the cylinders' injectors. In particular, the control factor may modify the injection length or the start of injection which is used to control the respective injector.

[0017] These determinations and computations can be done on-line during the pressure measurement. To ease the computation load on a controller it is, however, advantageous to first record the respective data and to perform the determinations and computations later. This "off-line" approach results in a slower procedure. As variations in the injector performance occur only on a long term scale, such slower process is unproblematic.

[0018] The present invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a fragmented and block diagrammatic view of an automobile two-cylinder internal combustion engine, and

Fig. 2 is a flow diagram of a method used to adapt the cylinder injector characteristics for the engine according to figure 1.

[0019] Referring now to Figure 1, there is shown an automobile engine 10 according to a preferred embodiment of the invention. As shown, engine 10 includes several combustion cylinders having combustion chambers 12, 14. In each cylinder a piston 16, 18 is displaceable and coupled by connecting rods 26, 28 to arms 22, 24 of a rotatable crankshaft 20. While a two-cylinder engine is shown, it should be appreciated that additional and substantially identical cylinders may be included within a typical automobile engine and that the foregoing invention is equally and substantially identically applicable to a multi-cylinder internal combustion engine having any plurality of cylinders or cylinder arrangements.

[0020] As further shown in Figure 1, each chamber 12, 14 respectively communicates with a conventional and commercially available fuel injector assembly 30, 32. Particularly, each injector 30, 32 is communicatively and selectively coupled to a source of gasoline or fuel 34 and

selectively and controllably receives and injects fuel into the respective cylinders 12, 14. The injected fuel is typically mixed with a certain amount of ambient air, selectively traversing through an intake manifold 35. In the combustion chambers, this mixture is combusted due to compression (in case of Diesel engines) or by use of a spark plug (in case of Otto engines) or other types of combustion assemblies (not shown), thereby creating a certain pressure within each of the combustion chambers 12, 14 before being exhausted into an exhaust manifold 33.

[0021] Particularly, this created combustion pressure causes the respective pistons 16, 18 to displace during a combustion cycle from a upper dead center to a lower dead center with the pistons 16, 18 respectively moving away from the injectors 30, 32 and cause the rods 26, 28 to create a torque which rotates the crankshaft 20 in the direction of an arrow 21. In automotive applications the rotating crankshaft 20, which is normally deployed within a crank case 23, transfers the created rotational torque or force to an automobile drive train 29, thereby allowing the automobile to be driven. Of course, the engine's use is not limited to automotive applications but it can also be installed at any other vehicle or even at a fixed site.

[0022] A piston movement cycle is completed when the pistons 16, 18 return to their upper dead center during an exhaust cycle as it is known to the person skilled in the art of 4-stroke engines.

[0023] As further shown in Figure 1, the engine 10 includes a controller 36 which is operating under stored program control and which is controllably and communicatively coupled to the fuel injectors 30, 32, and which is effective to control the fuel supply system 34 and, thus, the amount of fuel injected by the injectors 30, 32 into the chambers 12, 14. The controller 36 may comprise a conventional and commercially available microprocessor and the communication between controller 36 and the fuel system 34 and the fuel injectors 30, 32 may occur by use of a data bus 37. In the described embodiment, the controller 36 is adapted to receive signals corresponding to the instantaneous speed of the engine, such signals being available, by way of example and without limitation, by use of a conventional tachometer bus (not shown) which is typically present within the engine when the latter is installed in an automobile. The controller 36 is further coupled, e.g. via the bus 47, to conventional and commercially available sensors 41, 43 which respectively measure and provide the controller 36 with the pressure within crankcase 23 and the crank angle which will be described later.

[0024] The engine 10 further includes pressure sensors 38, 40 which are respectively resident within each of the combustion chambers 12, 14 and which each sense the pressure respectively and combustably created in each of the chambers 12, 14 at substantially small and substantially regular sample steps or intervals. These sensors 38, 40 create and communicate respec-

tive signals, representative of the respectively sensed pressures, to the controller 36 by use of a data transmission channel, e.g. a bus 39. The sensors 38, 40 may comprise conventional and commercially available piezoelectric sensors or optical sensors. Non-limiting examples of such sensors 38, 40 include the sensor type described in US 5329809, sensor model number 6125 of Kistler Corporation and optical sensors available from Bookham Technologies, Inc.

[0025] In operation of the engine, the controller 36 controls the injectors 30, 32 to inject a prescribed quantity of fuel with a certain timing regarding the rotation of the crankshaft 20, i. e. regarding to the operation cycles of the individual cylinders. In this embodiment, the fuel supply system 34 comprises a high-pressure fuel rail which stores pressurized fuel and feeds it to the injectors 30, 32 which inject the fuel fed from this reservoir into the combustion chambers 12, 14. Thus, the start of injection and the length of injection are, in combination with fuel pressure in the fuel rail, decisive to the quantity of fuel which is metered into the combustion chamber. The fuel pressure in the rail can not be adjusted on a short time scale and, in particular, not individual for each cylinder. The controller 36 selects the opening and closing parameters for each injector 30, 32 according to the actual and desired operating condition of the engine and controls the injectors 30, 32 accordingly by instructing start of injection and length of injection at the electric controlled injectors 30, 32.

[0026] When determining the quantity of fuel required for the next injection, the controller 36 must convert the value of fuel quantity into a value describing the length of injection. For this purpose, the controller 36 is equipped with a pre-stored map called the injector characteristics which holds the length of injection as a function of many parameters, in particular the desired amount of fuel or fuel quantity. For controlling the injectors 30, 32, the controller 32 accesses this injector characteristics in order to determine the length of injection which leads to a desired amount of fuel in the next injection(s). As it is known to a person skilled in the art of internal combustion engines, the such received length of injection may be modified by a correction factor which addresses individual deviations of a given injectors performance from standard performance on which the pre-stored injector characteristics are based. Of course, the correction can also be performed on the level of mass of fuel, i.e. prior to converting fuel mass to length of injection.

[0027] Initially, the correction factor is set to a value which effects no correction, i. e. is set to an ineffective value. During operation of the engine, however, the value may be changed by means of an adaption which addresses both, differences of an individual injector from a standard injector due to manufacturing tolerances, and variations which may occur through wear during the operation lifetime. The controller 36 comprises an adaptive control unit which receives for each injector 30, 32 a target value and injector individual values and outputs a controlled

variable which is the correction factor.

[0028] The controller 36 determines the target value and the cylinder individual values or pressure values from pressure measurements using the pressure sensors 38 and 40 in the combustion chambers 12 and 14. In one embodiment, the injector individual values are the peak pressure values P within the respective combustion chamber and the target value T is the average peak pressure value A obtained from calculating the mean over the individual peak pressure values of the cylinders. In an alternative embodiment, the indicated mean pressure P -IMEP is used which is obtained by averaging the pressure within a combustion chamber 12, 14 during a combustion cycle. The respective target value T -IMEP is then the average of all indicated mean pressures values P -IMEP determined.

[0029] Of course, the set point can be an average value, but also a cylinder individual one due to dispersion within the engine.

[0030] The action of the control unit influences individually for each injector 30, 32 the effective injection characteristics used for controlling the injectors 30, 32 are such that the cylinders equipped with the respective injectors 30, 32 exhibit a unified peak pressure or indicated mean pressure.

[0031] The controller 36 performs the determination and unification of the pressure value for all cylinders of the multi-cylinder engine 10. Obviously the invention is not limited to the two cylinder engine 10 depicted in Figure 1. This results in pressure values P for each cylinder. Those pressure values P are then compared. For instance, the controller 36 calculates an average pressure value A from the cylinder individual peak pressure values P . For each cylinder, a difference between the average value A and the pressure value P is used in a feed-back control controlling an injector individual offset used for the injectors 30, 32. The controller 36 effects a change in fuel delivery to the individual cylinders to minimize the pressure differences between the cylinders

[0032] The controller, thus, performs a method which is shown in Figure 2 in form of a flow diagram.

[0033] Figure 2 presents a flow diagram of the adaption method for the injectors, performed by the apparatus described. After start of the engine 10, it is first checked, whether certain operation conditions are met, which are required or suitable to perform the adaption. One condition may be, that the engine has reached a certain operation temperature. If the certain operation conditions are given, a number n of cycles is defined, for which the data are recorded and evaluated. Then, the combustion chamber peak pressure P is recorded for each cylinder over $N_{cyl} = n$ cycles. For each cylinder, the thus obtained peak pressure values P are averaged to reduce noise.

[0034] In a next step, the average peak pressure A of all cylinders of the multi-cylinder engine is computed.

[0035] The next step determines differences for each cylinder between the average peak pressure A and the cylinder's individual peak pressure P .

[0036] For adapting the injector characteristics, the fuel supply offset is changed for each cylinder to minimize peak pressure differences. That means, that the fuel control reduces fuel for a cylinder having a peak pressure P above the average pressure value A. The offset is raised, however, if the cylinder exhibits a peak pressure which is below average.

[0037] The procedure is then repeated.

[0038] Of course, it is possible to activate the procedure only at certain time intervals or instances. Due to the fact that variations in the injector performance may be caused by wear or a built-up of soot at the cylinder's fuel injector 30, 32, variations may occur relatively slowly. Hence, it may be sufficient to adapt the injector characteristics only at certain time intervals or upon special requests, i.e. when the engine 10 is at a scheduled maintenance.

[0039] The following modifications/additional features may be used in combination with embodiments of the invention:

[0040] Instead of the difference between the individual cylinder pressure value P and the average pressure value A, a different error function may be used, which, in particular, may use a non-linear function.

[0041] The number of cycles N_{cyl}, over which the peak pressure P is determined for the individual cylinders may, of course, also be equal 1.

[0042] Instead of the average torque A, a differently obtained target pressure value may be used which may be received from a predetermined map which was obtained from a test bed run of an engine.

[0043] The correction of injectors control must not rely on an offset value. However, any suitable action resulting in a modified effective injector characteristics may be used.

[0044] The adaption can be performed at special operation conditions, i.e. at steady state operation points comprising a predetermined engine speed or load. Alternatively, the adaption can be performed continuously, i.e. at almost every engine operating condition.

[0045] Instead of a peak pressure the adaption may be based on the indicated mean pressure or the indicated mean effective pressure IMEP which is computed as the mean of the pressure during a combustion or working cycle. The indicated mean pressure not only replaces the peak pressure for each individual cylinder but, of course, also the respective pressure value in the target pressure value, e. g. the average of the individual pressure values of the cylinders.

ally to compensate for deviations the individual injectors (30, 32) have from standard injectors (30), wherein fuel is injected by each injector (30) and the operation of the engine resulting therefrom is evaluated, and wherein the method further comprises:

determining for each cylinder a value of the peak pressure or the indicated mean pressure, which pressure value occurs during a combustion cycle in the cylinder's combustion chamber (12, 14), and

modifying the injector characteristics individually for each injector (30, 32) to minimize differences between the pressure values over said cylinders.

2. The method of claim 1, wherein an error value is determined for each cylinder by comparing the pressure value with a target value, which preferably is obtained from averaging the pressure values of all of the cylinders.
3. The method of claim 2, wherein the target value and the pressure values are fed to a controller which acts for each injector on the injector characteristics or on a correction factor therefor.
4. The method of claim 3, wherein the correction factor is a cylinder individual offset of a control factor used for controlling the cylinders' injectors (30, 32).
5. An internal combustion engine control apparatus for controlling an multi-cylinder internal combustion engine (10), wherein the apparatus (36) performs the method of any of claims 1 to 4.

Claims

1. A method for adapting injector characteristics of fuel injectors (30, 32) of a multi-cylinder internal combustion engine (10) having combustion chambers (12, 14) with direct fuel injection, which injector characteristics are adapted for each injector (30) individu-

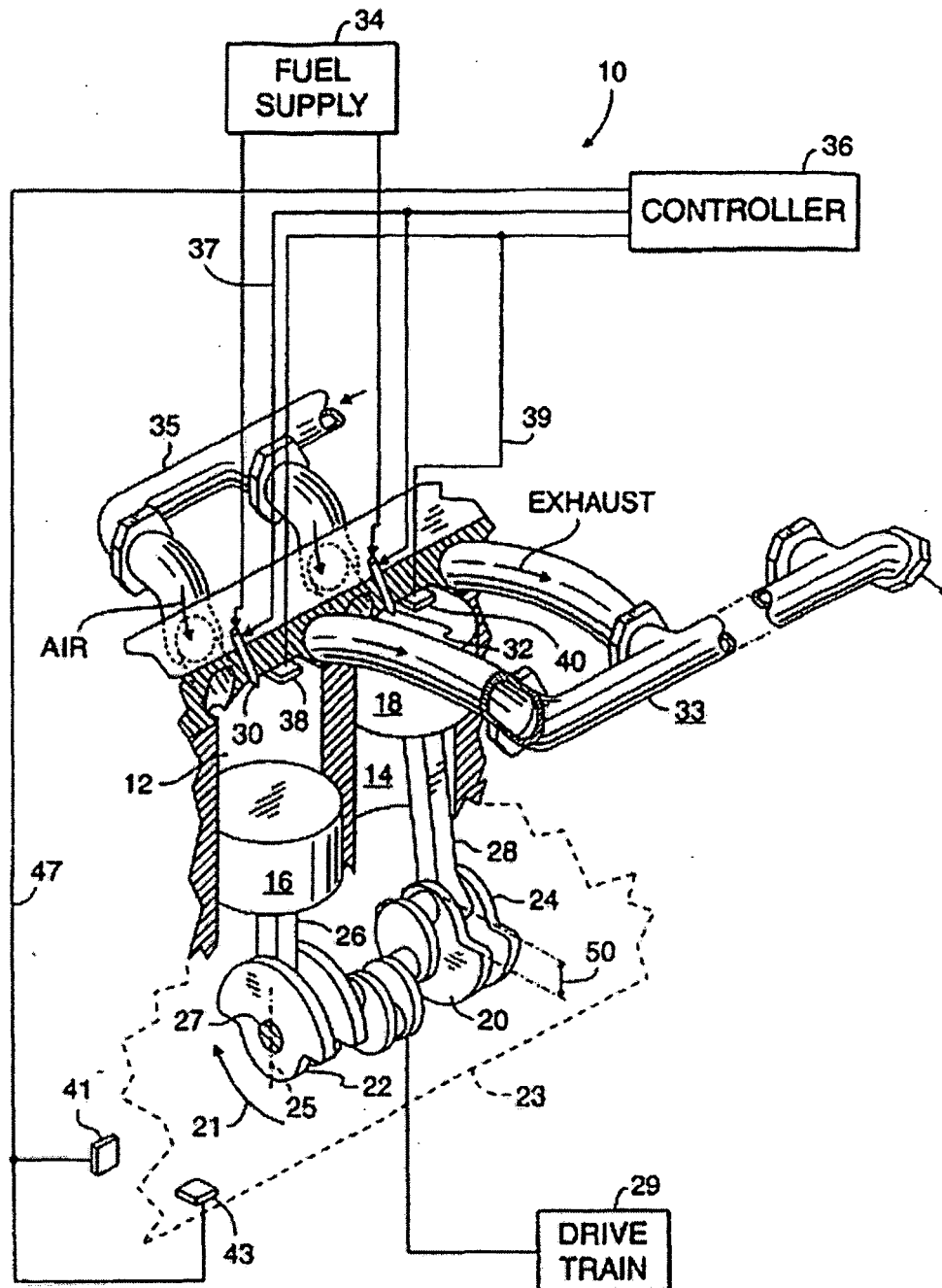


FIG. 1

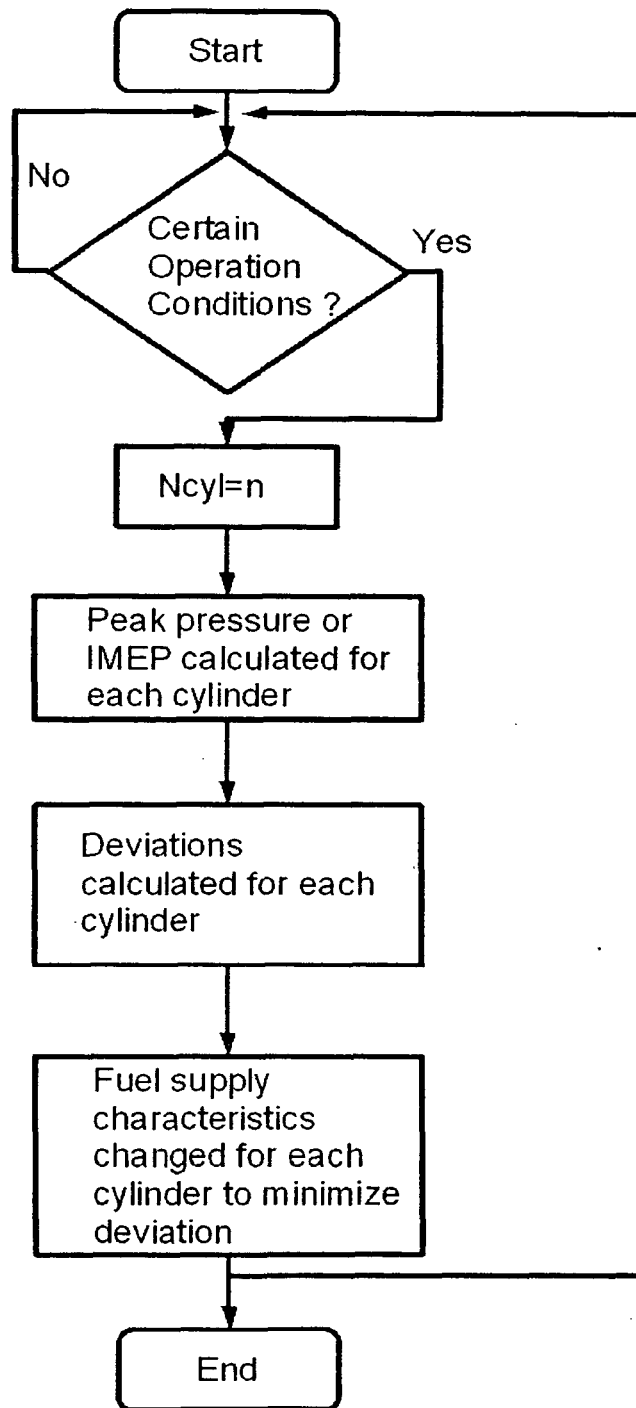


FIG. 2



EUROPEAN SEARCH REPORT

Application Number
EP 08 01 1167

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 5 December 2008	Examiner De Vita, Diego
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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