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(54) Title: METHOD AND DEVICE FOR DETERMINING AMOUNT OF FUEL INJECTED INTO A CYLINDER SPACE OF AN INTERNAL COMBUSTION ENGINE

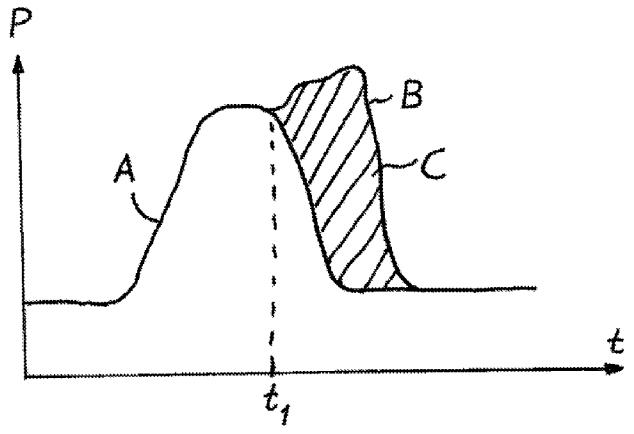


Fig. 2

(57) Abstract: At a method for the determination of an amount of fuel injected, during a working cycle with combustion, into a cylinder chamber of a cylinder in a combustion engine, movements in a cylinder head of the cylinder are detected. Pressure changes in the cylinder chamber are calculated, based upon the result of the detection, and then compared with stored data relating to pressure changes in the cylinder chamber in the absence of combustion. Subsequently, based on this comparison the amount of energy generated by way of the combustion is calculated, and based on this the amount of injected fuel is determined.

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# *Method and device for determining amount of fuel injected into a cylinder space of an internal combustion engine*

## FIELD OF THE INVENTION

The present invention relates to a method and a device for the determination of an amount of fuel injected, during a working cycle with combustion, into a cylinder chamber of a cylinder in a combustion engine.

## BACKGROUND

There is a constant aspiration to achieve control of a combustion engine, in such a manner that fuel used therein is burned in the engine's cylinders, while generating a maximum amount of energy/fuel mass output from the engine and a minimum amount of emissions. It is important, in this aspiration, to have knowledge of the amount of fuel supplied into the respective cylinders' cylinder chambers at the operation of a combustion engine. Information about this may among others be used to control the injection nozzles' opening times, in order to compensate for wear of valves and production differences in injectors. With this knowledge regarding all the cylinders of the combustion engine, it is also possible to ensure that substantially the same amount of fuel is always injected into the respective cylinders.

Prior art provides for a relatively rough estimate of said amount of injected fuel, based on the flywheels' derivative and the change of the pressure in the accumulator volume at injection of fuel in a cylinder chamber. However, it is not possible, based on

these parameters, to calculate the amount of injected fuel with the desired accuracy.

US 7 559 230 describes a method and a device for determination of an amount of fuel injected, during a working cycle with combustion, into a cylinder chamber of a cylinder in a combustion engine. The document describes how a so-called knock sensor is arranged on the combustion engine's block, and the "knock" arising at combustion is measured. The high-frequency knock sensor signals have an amplitude, which is dependent on the amount of energy generated through the combustion in the cylinder chamber and thus also the amount of injected fuel, but an extensive filtering and processing of the measured knock sensor signals is required to determine said fuel amount. This leads to a method, which is both expensive and which leaves something to be desired in terms of reliability.

## SUMMARY OF THE INVENTION

The objective of the present invention is to provide a method and a device, which are improved in at least some respect.

This objective is achieved with the invention as defined in the enclosed claims.

Surprisingly, it has been shown that by detecting movements in a cylinder head of a cylinder or in parts adjacent thereto in the engine, generated by pressure changes in the cylinder chamber, said pressure changes in the cylinder chamber may be detected indirectly. Thus, e.g. the development over time of the gas pressure in the cylinder chamber of the relevant cylinder in the en-

gine may be derived reliably. The movements that may be detected in this manner are generated by pressure changes in a cylinder chamber (combustion chamber) and may, for example, be vibrations, noise, i.e. gas movements, various types of shape changes, such as protrusions, in said cylinder head or in adjacent parts in the engine.

By comparing these calculated pressure changes with stored pressure changes in the cylinder chamber during working cycles without combustion, the amount of energy generated through combustion in the cylinder chamber may be calculated, and based thereupon the amount of fuel injected in the cylinder chamber during said working cycle may be determined.

This is possible without any filtering of the measured signal from said movements being required, since this will very well describe the pressure change taking place inside the cylinder chamber when the piston moves in the same, especially in the compression and the expansion strokes.

Since the amount of injected fuel may be determined with high reliability without complex calculation algorithms, it becomes possible to control the amount of fuel supplied and the status over time of the injection nozzle's opening in the desired manner. Through the innovative method it is also possible to detect that combustion actually takes place in the cylinder chamber. Likewise, the time required for production calibration of a novel engine type may be reduced.

In one embodiment, a method is provided for the determination of an amount of fuel injected, during a working cycle with combustion, into a cylinder chamber of a cylinder in a combustion engine. The method includes

- detecting movements in a cylinder head of said cylinder or in parts adjacent thereto in the engine, generated by pressure changes in said cylinder chamber,
- calculating said pressure changes based on the result of the detection of said movements,
- comparing the calculated pressure changes with stored data relating to pressure changes in said cylinder chamber during working cycles without combustion, and
- based on said comparison, calculating the amount of energy generated through said combustion in the cylinder chamber, and based thereupon determining the amount of fuel injected into the cylinder chamber during said working cycle.

According to one embodiment of the invention, said movements have a frequency of ≤ 250 Hz, 0.5 Hz-250 Hz or 0.5 Hz-200 Hz, which is detected. Thus, movements that occur with a relatively low frequency are detected, and the basic frequency of variations in the gas pressure inside said cylinder chamber, which is the same as the combustion engine's engine speed, lies within these intervals, which e.g. may typically be 60 revolutions per minute (1 Hz) for a marine diesel engine and as high as 12 000 revolutions per minute (approximately 200 Hz) for an otto engine in a motorbike. By detecting movements within these frequency areas, information about the amount of fuel supplied may be extracted from the information about the movements attributable to the pressure changes in the cylinder chamber.

According to another embodiment of the invention, the steps according to the method are carried out for several or all of the cylinders in the engine. By carrying out the steps for determination of the injected amount of fuel in all the cylinders of the engine, it becomes possible to, in an optimal manner, control the fuel injection in each cylinder to compensate for wear, potentially differentially, in different valves and for production differences in injectors. It also becomes unnecessary to have regard to the worst cylinder in order to comply with applicable emission regulations, and instead it becomes possible to operate all the cylinders in an optimal manner, from an emissions point of view.

According to another embodiment of the invention, based on said comparison, the timing of the start of a differential pressure change determined at combustion in the cylinder chamber is determined relative to a working cycle without combustion, and based thereupon the timing for the start of the combustion in the cylinder chamber is determined. Thus, it may be verified whether combustion starts where it is requested, and if not, measures may be taken to move the timing of the start of combustion to the desired point in time.

According to another embodiment of the invention, based on said comparison, the crank angle of said cylinder's working cycle is determined, at which a determined fraction, such as 5%, 10%, 50%, 90% or 95% of the fuel has been burned during the working cycle in the cylinder chamber.

The above mentioned objective is achieved, regarding the device, by providing such a device with the features in the characterising portion of the enclosed independent device claims. The discussion above about the different embodiments of the innovative method identifies what may be achieved thanks to such a device, and the advantages thereof.

According to one embodiment of the invention, the device is adapted to be arranged in an engine with a common cylinder head for several cylinders in the engine, and the device comprises at least one said sensor element, adapted to be placed and to detect and differentiate between movements derived from pressure changes in several said cylinder chambers, and the device is adapted to determine said amount of injected fuel for several cylinders in the engine.

According to another embodiment of the invention, the device comprises several said sensor elements adapted to jointly detect movements generated by pressure changes in all the cylinder chambers separately, and the unit is adapted to determine the amount of injected fuel in all the cylinders of the engine.

The invention also relates to a combustion engine with a device according to the invention.

The invention also relates to a computer program, a computer program product, an electronic control device, and a motor vehicle which uses the method and the device.

The invention is not limited to any specific type of combustion engine, but encompasses Otto engines as well as compression ignited engines, nor to any specific fuel, non-exhaustive examples of which may comprise fuel in the form of petrol, ethanol, diesel and gas.

Likewise, the invention comprises combustion engines intended for all types of use, such as in industrial applications, in crushing machines and various types of motor vehicles, wheeled motor vehicles as well as trucks and buses, and boats and crawlers or similar vehicles.

Other advantageous features and advantages with the invention are set out in the description below.

## BRIEF DESCRIPTION OF THE DRAWINGS

Below are descriptions of an example embodiment of the invention with reference to the enclosed drawings, in which:

Fig. 1a is a schematic view illustrating a part of a combustion engine according to one embodiment of the invention,

Fig. 1b shows an alternative possible placement of a sensor element,

Fig. 2 is a diagram showing the development of the pressure over time in the cylinder chamber of a cylinder in a combustion engine according to the invention in case there is no combustion, and in case of combustion, of fuel injected into the cylinder chamber,

Fig. 3 is a flow chart showing a method according to one embodiment of the invention, and

Fig. 4 is a diagram of an electronic control device for the implementation of a method according to the invention.

## DETAILED DESCRIPTION OF AN EMBODIMENT ACCORDING TO THE INVENTION

Fig. 1a illustrates very schematically a combustion engine 1 according to one embodiment of the invention, which is here arranged in an implied motor vehicle 2, for example a truck. The engine is equipped with a device 3, indicated with a dashed line, adapted to determine the amount of fuel injected, during a working cycle with combustion, into a cylinder chamber of a cylinder in the engine. The device has sensor elements 4, adapted to detect pressure changes in the cylinder chambers 5 of the combustion engine's cylinders 6, which are here six in number, but may be any number.

More specifically, the device has a sensor element 4 per cylinder 6, and this sensor element is arranged separately from the associated cylinder chamber 5, on the cylinder's cylinder head 7. The sensor elements in this case consist of piezo resistive sensors adapted, to detect pressure changes in the relevant cylinder chambers, for example in the form of vibrations, generated by movements propagated in the cylinder head,.

The device 3 also comprises a device 8, which may consist of the vehicle's electronic control device, adapted to receive informa-

tion from the sensor elements 4 about the movements detected, and based thereupon to calculate pressure changes generated in said cylinder chamber during the combustion, to compare calculated pressure changes with stored data relating to pressure changes in said cylinder chamber at working cycles without combustion, and based thereupon to calculate the amount of energy generated through the combustion, and based upon the calculated energy amount to determine the amount of fuel which is injected into the cylinder chamber during the relevant working cycle.

It has been shown that, by arranging such sensor elements in the manner described, so that they have the ability to detect movements propagating in the cylinder head or in parts adjacent thereto in the engine, derived from pressure changes in the cylinder chamber, high quality signals may be obtained, which signals do not require filtering or further processing, or alternatively, which require a simple filtering or processing to function as measuring values for pressure changes in the relevant cylinder chamber. The sensor elements are preferably adapted to detect movements, which propagate in the relevant cylinder head 7 or in parts adjacent thereto in the engine, with a relatively low frequency, for example within the interval 0.5 Hz-250 Hz.

Fig. 1b shows another placement of the sensor element 4. The sensor element is here placed on a section adjacent to the cylinder head. In this example, the sensor element is placed on the engine, specifically on the engine block. The sensor elements/sensors 4 may be of a suitable type, e.g. piezo resistive or piezo electrical elements or optical sensors. The sensor element

may here be placed on the engine, in an area adjacent to the outlet of the exhaust channel from a cylinder. For example on a surface on the engine block next to the outlet, on the engine, of the exhaust channel from a cylinder. The surface where the sensor 4 is placed may be substantially vertical. The sensor may be arranged to detect movements, which are perpendicular to the movements of the piston. The sensor may also be arranged to detect movements, which are perpendicular both in relation to the piston's direction of movement and in relation to the engine's longitudinal direction. In one embodiment, the sensor is located on the engine's long side. The sensor may be arranged to detect movements in a direction, which is perpendicular in relation to the surface on which it is placed.

In another embodiment (not displayed) the sensor element 4 may be placed in a corresponding manner as when placed on the engine at the outlet of the exhaust channel from a cylinder, but instead placed in a corresponding location on the engine, at the suction channel's inlet to a cylinder.

The signal detected by the sensor element 4 may be treated in various ways. For example, the following signal treatment steps may be carried out. First the sensor's electrical signal is entered into a control device/signal treatment device. The signal is filtered with a bandpass filter in order to remove superfluous information, which does not belong to the frequency range around which information is required. The signal is evened out by way of filtering, averaging or by being replaced with one or several continuous function(s) with good likeness. Subsequently, the signal is scaled, e.g. with the help of the correlation between pressure

and volume at compression. Subsequently, (a) suitable part(s) of the signal is/are transformed to the pressure domain. Supplemental modelling closes gaps in the signal's reliability, in order to form a pressure curve. The thus formed pressure curve is used to calculate different values at engine control. In some embodiments one or several of the steps above may be omitted.

Fig. 2 illustrates, in a diagram, the theoretical development of the pressure P over the time t during a working cycle in a cylinder chamber, partly without combustion in the engine 1 using diesel as fuel during operation and working in four strokes (suction, compression, combustion and exhaust stroke), and partly when such combustion takes place during the cylinders' combustion stroke.

It has been shown that it is possible to obtain a signal, with a sensor element 4 adapted and arranged in the manner described above, which with only simple processing (the calculation step b) of the innovative method) will have an appearance that is very close to the appearance of the pressure curves displayed in Fig. 2. The appearance of the displayed pressure curves may thus be achieved with good accuracy from the sensor element, and via the device's 8 calculation. Thus, the pressure curve A, which displays a working cycle without combustion, may be stored in the device 8, and by obtaining the pressure curve B at combustion in the cylinder chamber, the fuel amount injected into the cylinder chamber may be determined. The fuel amount is proportionate to the energy amount which is generated by the combustion, and this energy amount may be calculated as the integral of

the extra pressure increase that occurs through the combustion, i.e. according to customary heat release calculation methods.

In addition to the amount of injected fuel, by thus obtaining the pressure curves displayed in Fig. 2, the timing $t_i$ for the start of combustion may also be obtained. The crank angle for various fractions of burned fuel, e.g. 50%, may also be obtained. These magnitudes may be the basis for control of the injector, for injection of fuel into the relevant cylinder chamber.

Thanks to the fuel amount diagnosis which may thus be reliably produced, the control of various aggregates in the combustion engine may be optimised. For example, the air inlet and the fuel injection at the combustion engine's operation may be controlled based on this information. When the method is carried out in all cylinders, it becomes possible to use the information to ensure that the same amount of fuel is supplied at the same point in time in the working cycle, and/or the same air surplus (lambda) in all cylinders if this is desired. It also becomes possible to compensate for wear in parts, and for production differences in injectors at the supply of fuel, since a receipt is obtained, indicating how much fuel is actually injected.

Additionally, it may be detected that combustion really does take place, because the innovative method may naturally also be carried out for a zero-amount of injected fuel, and a pressure curve corresponding to the pressure curve A will then be calculated based on the sensor element's signal.

Fig. 3 shows a flowchart illustrating an embodiment of a method according to the present invention, for the determination of an amount of fuel injected, during a working cycle with combustion, into a cylinder chamber of a cylinder in a combustion engine. In a first step $S_1$ movements in a cylinder head are detected. In a second step $S_2$ pressure changes are then calculated based on said detection. Subsequently, in step $S_3$ the calculated pressure changes are compared with stored data relating to pressure changes without combustion, whereupon in a fourth step $S_4$ the amount of energy generated through the combustion is calculated, and the amount of injected fuel is then determined based on this comparison.

A computer program code for the implementation of a method according to the invention is suitably included in a computer program, loadable into the internal memory of a computer, such as the internal memory of an electronic control device of a combustion engine. Such a computer program is suitably provided via a computer program product, comprising a data storage medium readable by an electronic control device, which data storage medium has the computer program stored thereon. Said data storage medium is e.g. an optical data storage medium in the form of a CD-ROM, a DVD, etc., a magnetic data storage medium in the form of a hard disk drive, a diskette, a cassette, etc., or a Flash memory or a ROM, PROM, EPROM or EEPROM type memory.

Fig. 4 very schematically illustrates an electronic control device 8 comprising execution means 9, such as a central processor unit (CPU), for the execution of computer software. The execution means 9 communicates with a memory 10, e.g. a RAM memory,

via a data bus 11. The control device 8 also comprises a data storage medium 12, e.g. in the form of a Flash memory or a ROM, PROM, EPROM or EEPROM type memory. The execution means 9 communicates with the data storage means 12 via the data bus 11. A computer program comprising computer program code for the implementation of a method according to the invention is stored on the data storage medium 12.

The invention is obviously not limited in any way to the embodiment described above, but numerous possible modifications thereof should be obvious to a person skilled in the area, without such person departing from the spirit of the invention as defined by the appended claims.

Claims

1. Method for the determination of an amount of fuel injected, during a working cycle with combustion, into a cylinder chamber (5) of a cylinder (6) in a combustion engine (1), **characterised** by

   a) detecting movements in a cylinder head (7) of said cylinder (6) or in parts adjacent thereto in the engine, generated by pressure changes in said cylinder chamber,

   b) calculating said pressure changes based on the result of the detection of said movements,

   c) comparing the calculated pressure changes with stored data relating to pressure changes in said cylinder chamber (5) at working cycles without combustion, and

   d) based on said comparison, calculating the amount of energy generated through said combustion in the cylinder chamber, and based thereupon determining the amount of fuel injected into the cylinder chamber during said working cycle.

2. Method according to claim 1, **characterised** in that said movements with a frequency ≤ 250 Hz, 0.5 Hz-250 Hz or 0.5 Hz-200 Hz are detected.

3. Method according to claim 1 or 2, **characterised** in that steps a)-d) are carried out for several or all cylinders (6) in the engine (1).

4. Method according to any of claims 1 - 3, **characterised in that** the detection is carried out in or on said cylinder head (7).

5. Method according to any of claims 1 - 3, **characterised in that** the detection is carried out on the engine, in an area adjacent to the outlet of the exhaust channel from a cylinder.

6. Method according to any of claims 1 - 3, **characterised in that** the detection is carried out on the engine, in an area adjacent to the inlet of the suction channel to a cylinder.

7. Method according to any of the previous claims, **characterised** in that based on said comparison the timing ($t_1$) for the start of a differential pressure change, determined at combustion in the cylinder chamber (5), is determined relative to a working cycle without combustion, and based thereupon the timing of the start of combustion in the cylinder chamber is determined.

8. Method according to any of the previous claims, **characterised** in that based on said comparison the crank angle of the working cycle of said cylinder (6) is determined, at which crank angle a specific fraction, such as 5%, 10%, 50%, 90% or 95% of fuel burned during the working cycle in the cylinder chamber (5) is burned.

9. Device adapted to determine an amount of fuel injected, during a working cycle with combustion, into a cylinder chamber (5) of a cylinder (6) in a combustion engine (1), **character-**

**ised** in that it comprises at least one sensor element (4), adapted to be arranged separately from said cylinder chamber (5) on a part of a cylinder head (7) or on parts adjacent thereto in the engine, and adapted to detect propagating movements, generated by pressure changes in said cylinder chamber, in said cylinder head (7) or said parts, and a device (8) adapted, based upon measured data from the sensor element (4) relating to said movements, to calculate pressure changes generated in said cylinder chamber (5) during the combustion, to compare the calculated pressure changes with stored data relating to pressure change in said cylinder chamber (5) at working cycles without combustion, and based thereupon to calculate the amount of energy generated through said combustion, and based upon the calculated energy amount to determine said fuel amount.

10. Device according to claim 9, **characterised** in that said sensor element (4) is adapted to be arranged in or on said cylinder head (7).

11. Device according to claim 9, **characterised** in that said sensor element (4) is placed on the engine, in an area adjacent to the outlet of the exhaust channel from a cylinder.

12. Device according to claim 9, **characterised** in that said sensor element (4) is placed on the engine, in an area adjacent to the inlet of the suction channel to a cylinder.

13. Device according to any of claims 9 - 12, **characterised** in that said sensor element (4) is adapted to detect movements

with a frequency of ≤ 250 Hz. 0.5 Hz-250 Hz or 0.5 Hz-200 Hz.

14. Device according to any of claims 9-13, **characterised** in that is adapted to be arranged in an engine (1), which has a cylinder head (7) that is common to several cylinders (6) in the engine, and in that it comprises at least one said sensor element (4), adapted to be placed and to detect and distinguish movements derived from pressure changes in several said cylinder chambers (5), and that the device (8) is adapted to determine said amount of fuel injected for several cylinders in the engine.

15. Device according to any of claims 9-14, **characterised** in that it comprises several said sensor elements (4), adapted to jointly separately detect movements generated by pressure changes in all cylinder chambers (5) of the engine (1), and that the unit (8) is adapted to determine the amount of injected fuel in all the cylinders of the engine.

16. Combustion engine, **characterised in that** it comprises a device (3) according to any of claims 9-15.

17. Computer program which may be downloaded directly to the internal memory of a computer, which computer program comprises a computer program code in order to make the computer control the steps according to any of claims 1-8 when said computer program is executed in the computer.

18. Computer program product comprising a data storage medium which is readable by a computer, the computer program code of a computer program according to claim 17 being stored on the data storage medium.

19. Electronic control device (8) for a combustion engine (1), comprising an execution means (9), a memory (10) connected to the execution means and a data storage medium (12) connected to the execution means (9), the computer program code in a computer program according to claim 17 being stored on said data storage medium (12).

20. Motor vehicle, **characterised in that** it comprises a combustion engine (1) according to claim 16.

21. Motor vehicle according to claim 20, **characterised** in that it is a wheeled motor vehicle (2), such as a truck or a bus, or a boat or a crawler.

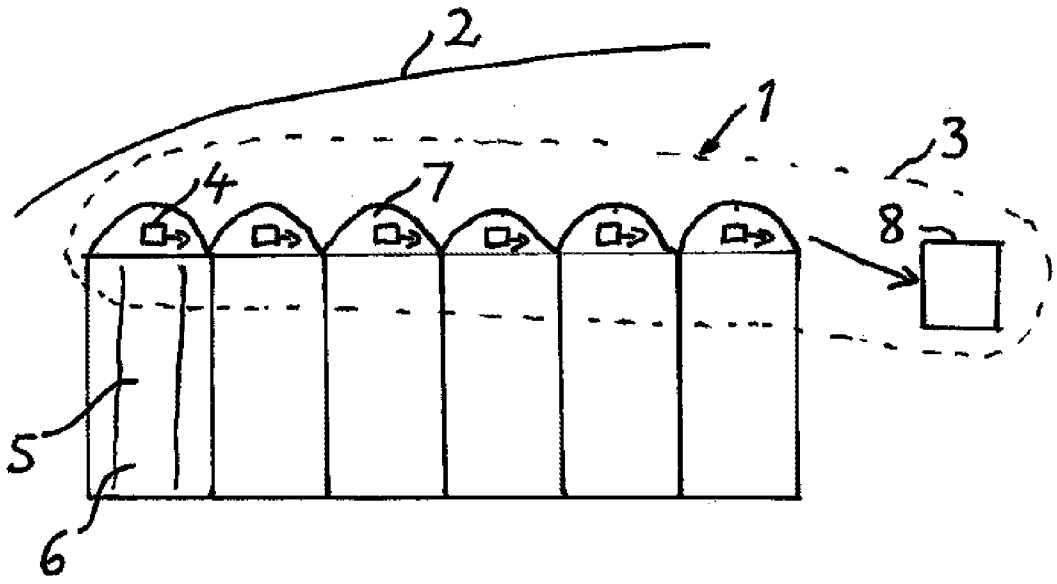


Fig. 1a

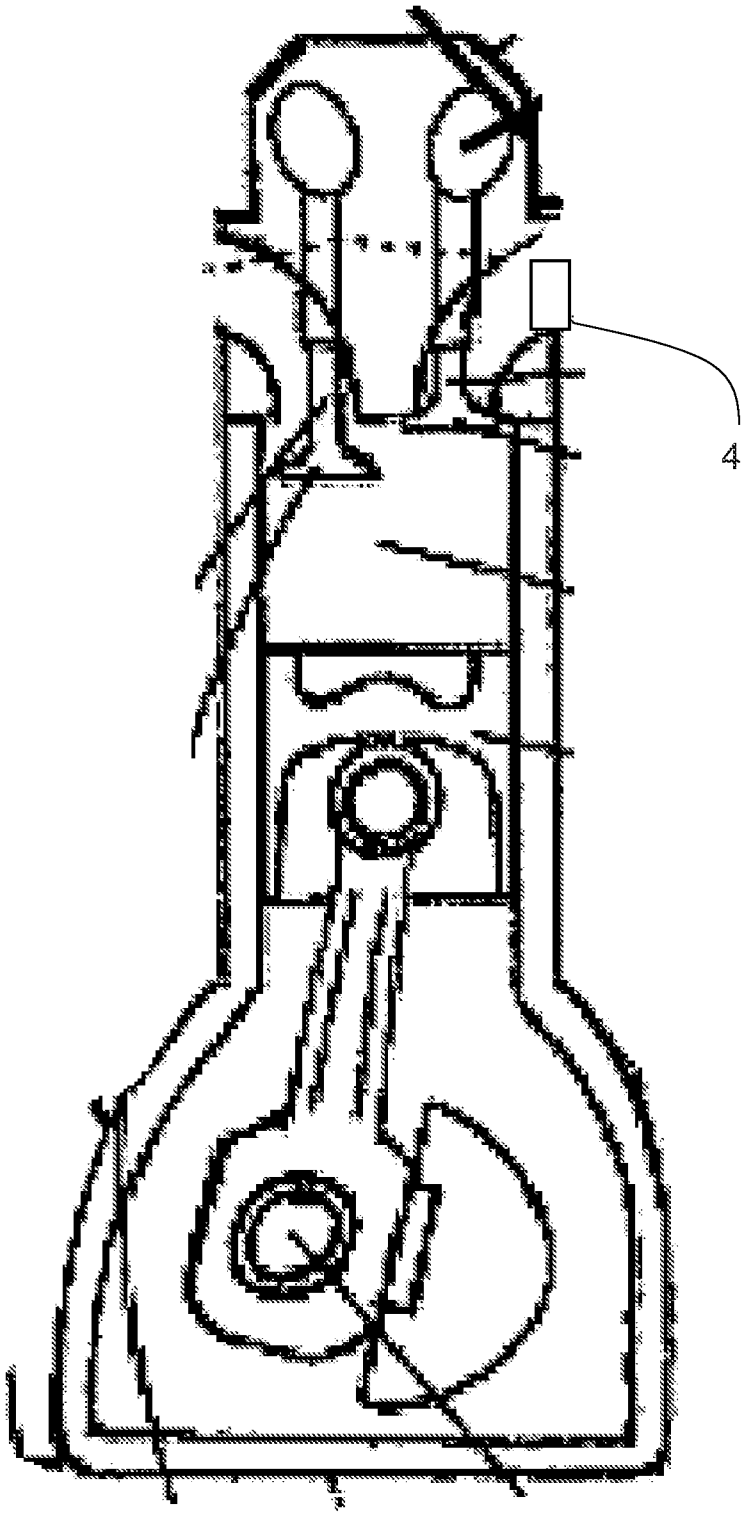


Fig. 1b

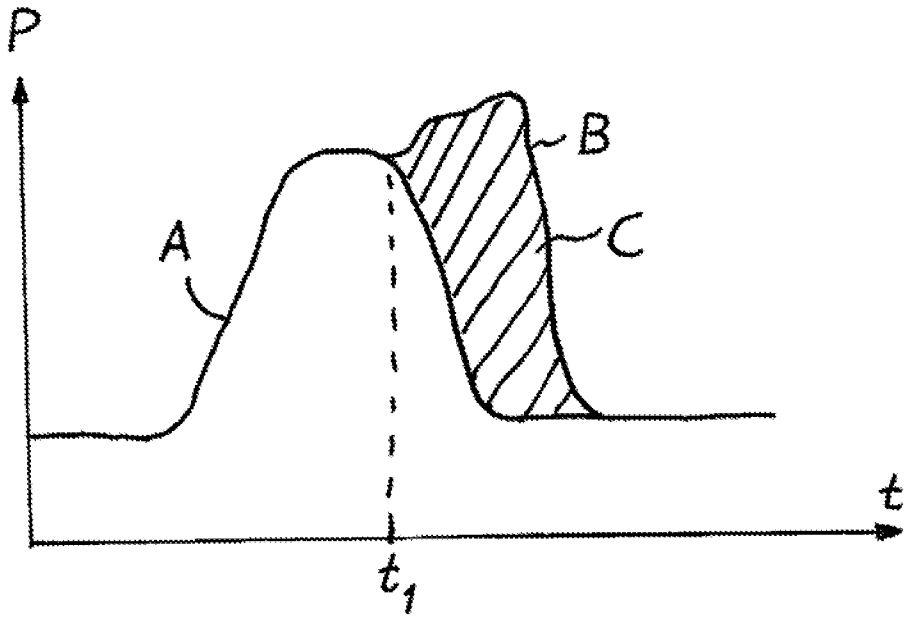


Fig. 2

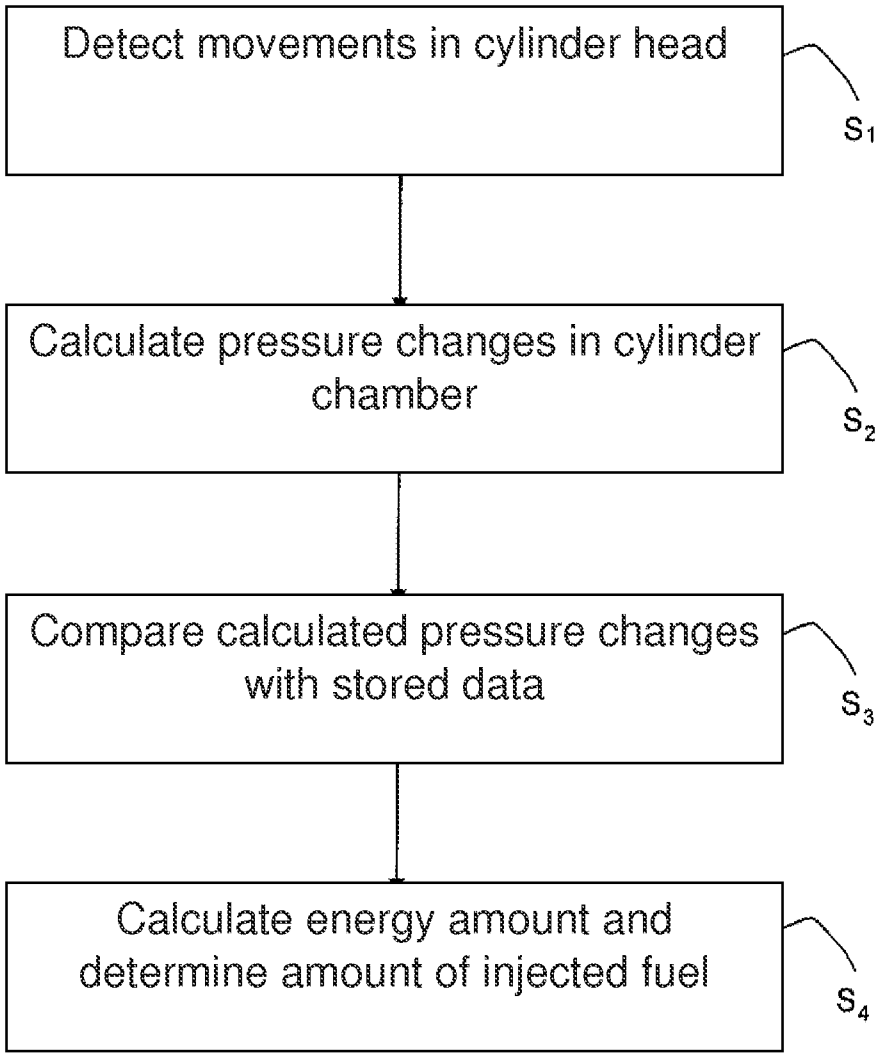
Detect movements in cylinder head
S1
Calculate pressure changes in cylinder chamber
S2
Compare calculated pressure changes with stored data
S3
Calculate energy amount and determine amount of injected fuel
S4

Fig. 3

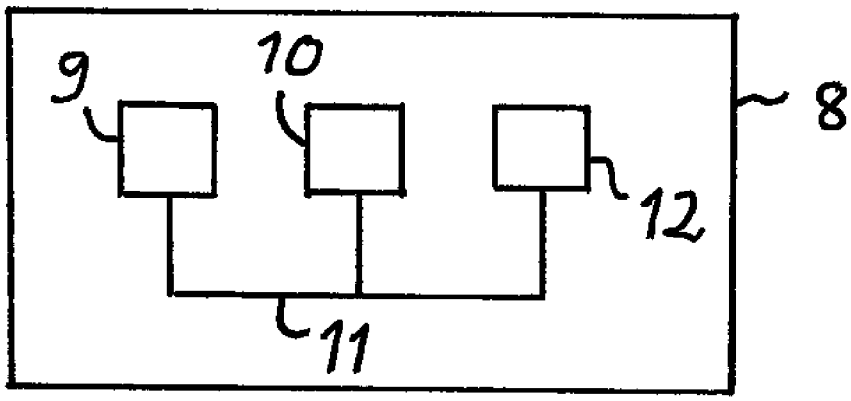
9
10
8
12
11

Fig. 4

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/SE2015/050705

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: F02D, G01M

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 20070251507 A1 (MUELLER KARL ET AL), 1 November 2007 (2007-11-01); paragraphs [0005], [0011]-[0013], [0021]-[0024] | 1-21 |
| | -- | |
| Y | GB 2331154 A (BOSCH GMBH ROBERT), 12 May 1999 (1999-05-12); page 2, line 4 - line 12 | 1-21 |
| | -- | |
| Y | CA 2809291 A1 (HUANG JIAN ET AL), 21 May 2013 (2013-05-21); abstract; paragraphs [0003]-[0005], [0014] | 1-21 |
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 26-10-2015 | 26-10-2015 |


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**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/SE2015/050705

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