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(56) Documents Cited
EP 0859149 A2 **EP 0115807 A2** **US 5156126 A**
US 4928653 A

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INT CL^6 **F02D 41/40 , F02P 5/15 5/153**
Online: WPI, JAPIO

(54) Abstract Title
Method of determining a combustion-dependent magnitude in an internal combustion engine

(57) A method of determining a form factor for energy conversion in the combustion chamber of a cylinder of an internal combustion engine comprises the steps of measuring the combustion chamber pressure course by means of a pressure sensor (14 to 17) and also engine crankshaft angle (α), and comparing the pressure course, after correlation with crankshaft angle, with a combustion chamber pressure course to be expected in towed operation. The obtained difference pressure course is then evaluated for the formation of a form factor which is formed with the aid of geometric relationships (fig.4, not shown), which are so chosen that the difference pressure integral is replicated as accurately as possible, by means of regulation of the fuel injection.

Fig. 1

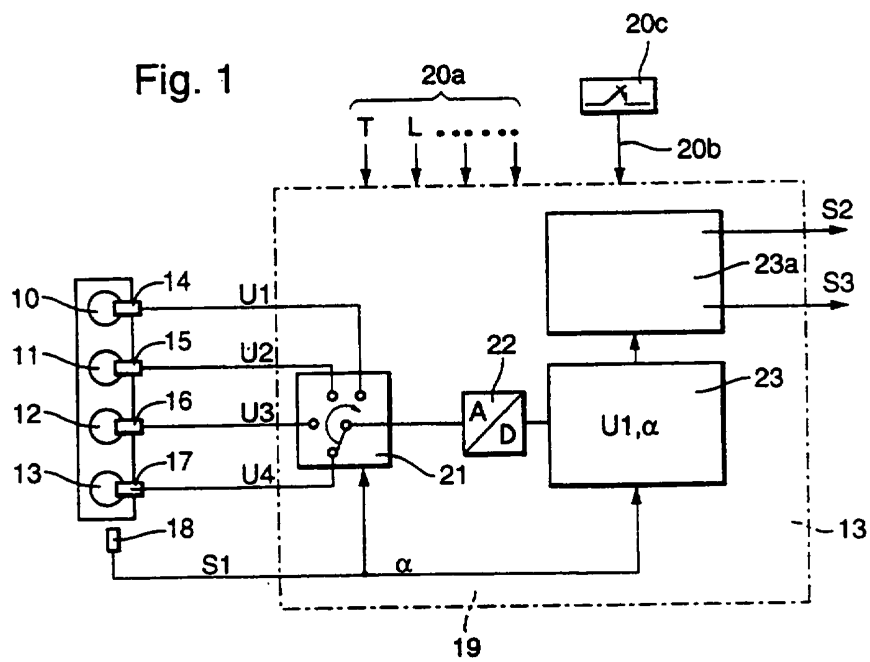

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Fig. 1

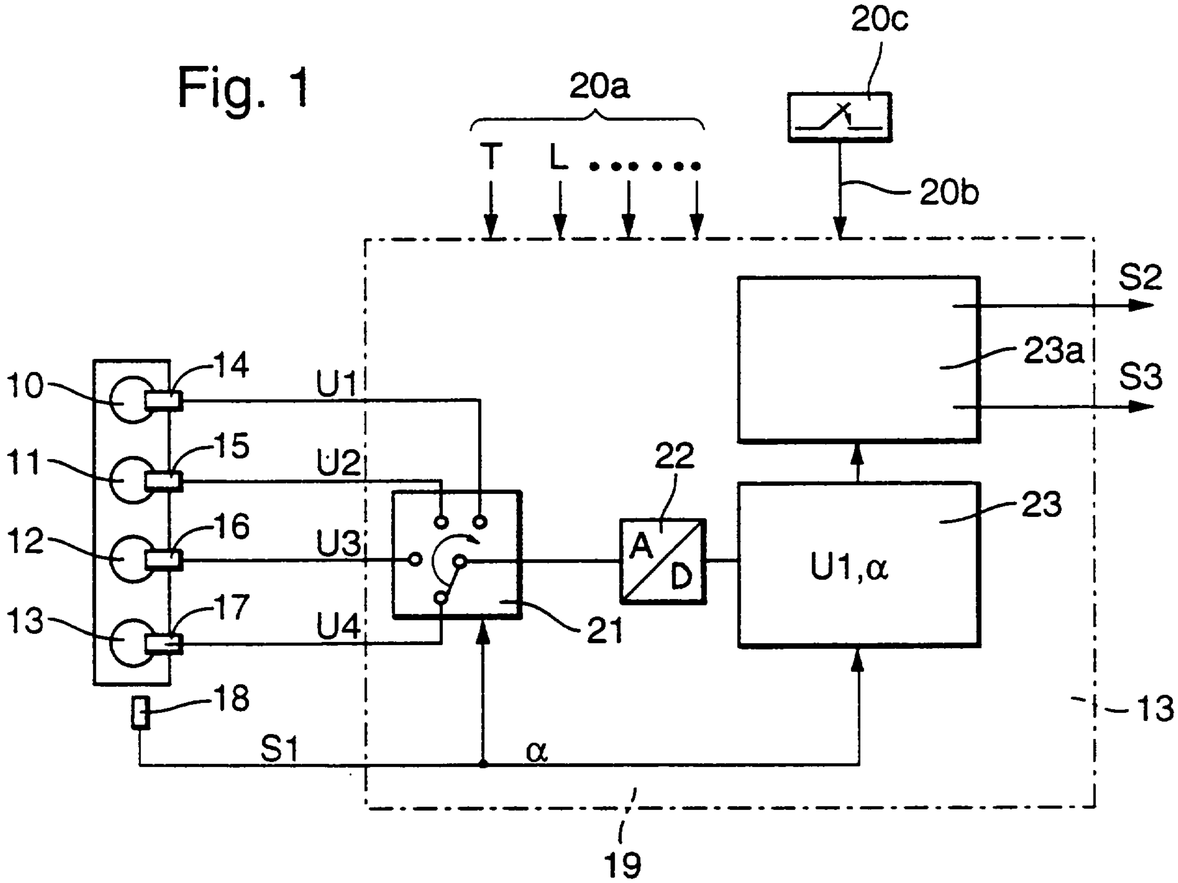

20c
20a
T
L
20b
S2
23a
S3
10
14
U1
11
15
U2
22
23
12
16
U3
A
D
U1,α
13
17
U4
21
18
13
S1
α
19

Fig. 2

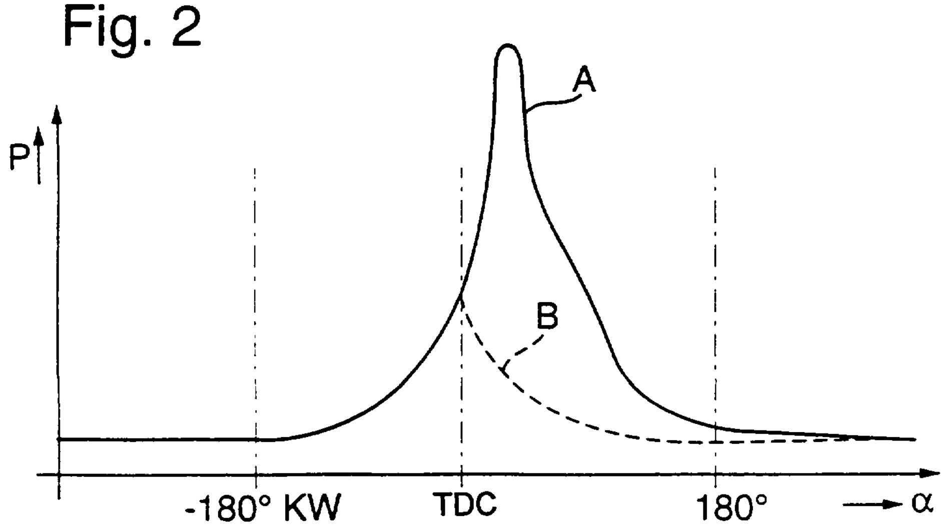

A
P
B
-180° KW
TDC
180°
α

Fig. 3

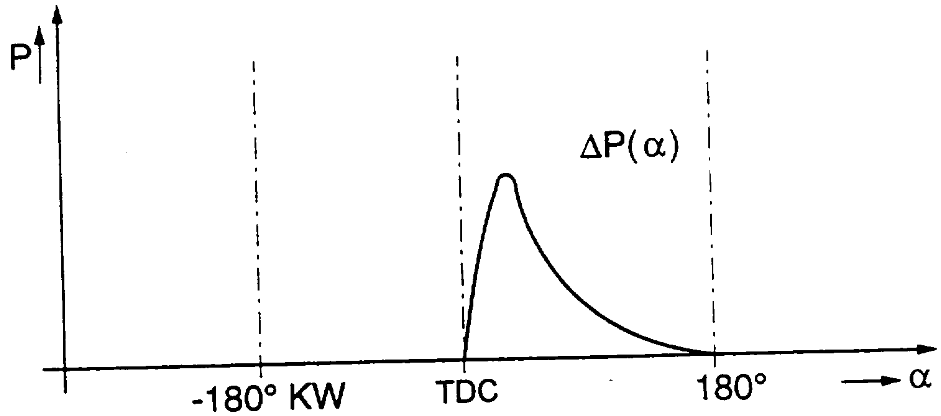


Fig. 4a

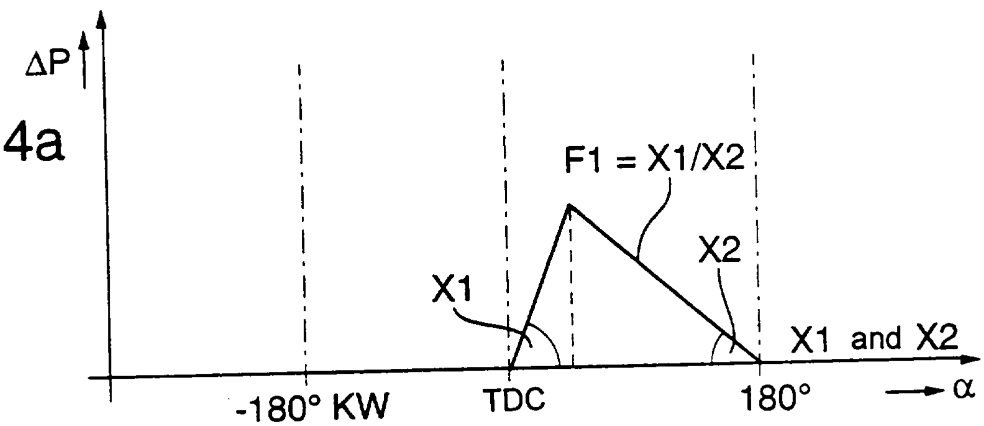


Fig. 4b

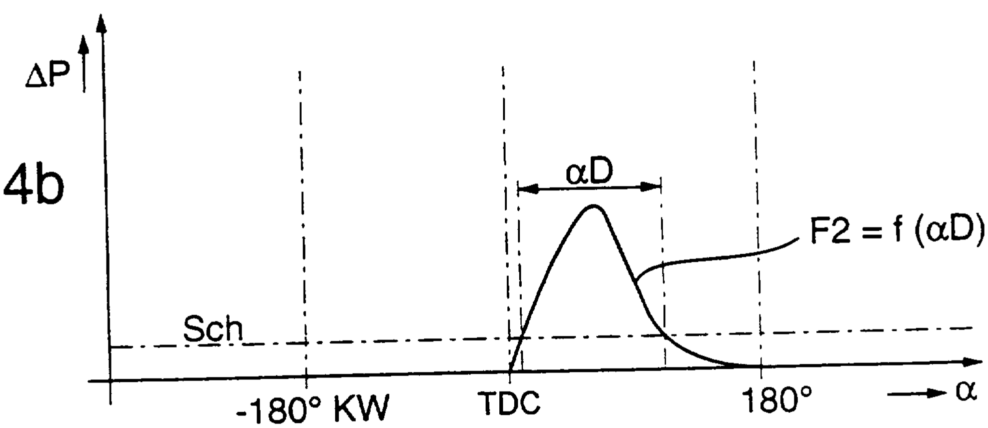


Fig. 4c

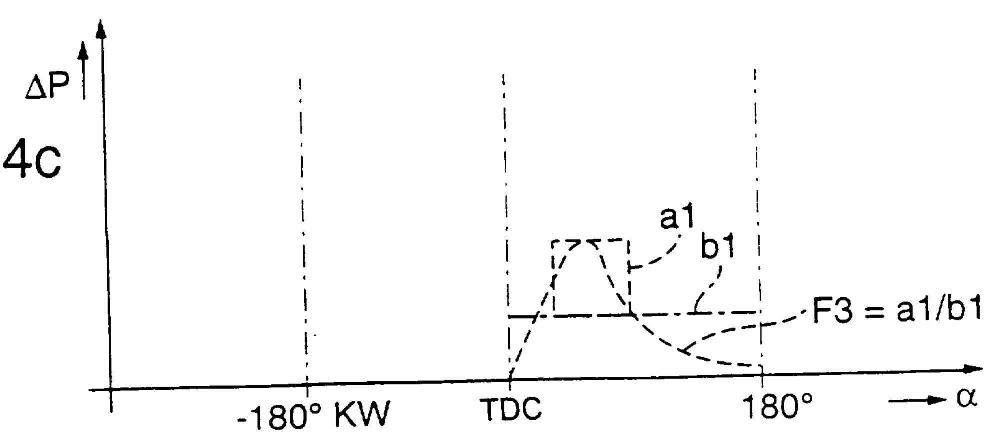


Fig. 5a

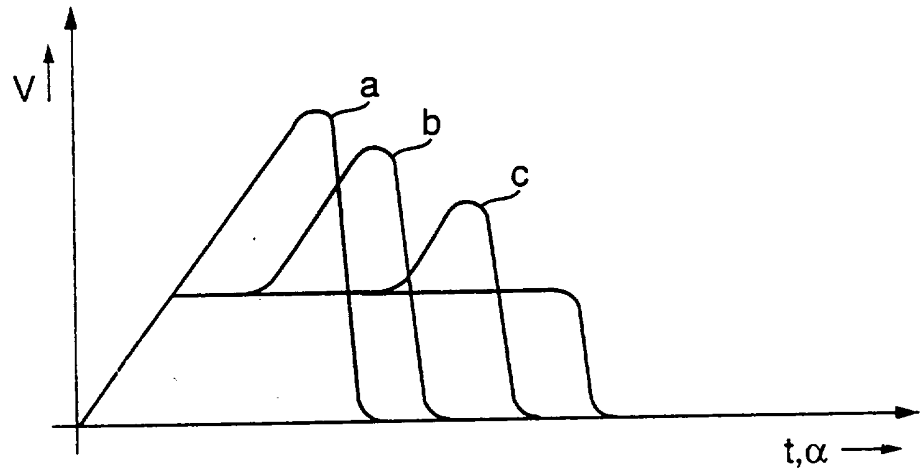
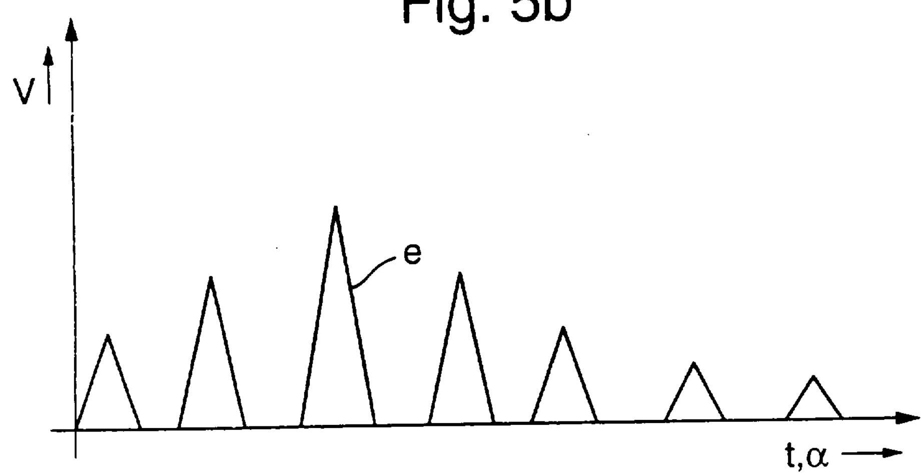


Fig. 5b



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METHOD OF DETERMINING A COMBUSTION-DEPENDENT MAGNITUDE IN AN INTERNAL COMBUSTION ENGINE

The present invention relates to a method of determining a combustion-dependent magnitude, especially a form factor for energy conversion, in an internal combustion engine, for example a diesel engine.

It is known to ascertain the course of the cylinder or combustion chamber pressure in at least one cylinder of an internal combustion engine with the aid of suitable pressure sensors and to derive, from an obtained pressure course, information concerning the combustion sequence in dependence on crankshaft angle. Drive control signals for control of ignition and/or injection are computed from this information. Usually, a combustion chamber pressure sensor is associated with each cylinder of the engine and a crankshaft angle sensor is used to provide an output signal representative of the crankshaft angular setting. The combustion chamber pressure course and the output signal of the crankshaft angle sensor are evaluated together by a control system of the engine. The evaluation of the pressure course in the context of engine regulation is described in, for example, DE-OS 43 41 796.

In this known equipment, the combustion in each cylinder of the engine is analysed from the combustion chamber pressure in dependence on crankshaft angle, wherein the measured combustion chamber pressure course is compared with an imaged pressure course. This imaged pressure course is obtained in that the pressure course measured between 0° crankshaft angle and top dead centre is continued symmetrically beyond top dead centre. Such a pressure course would arise in an ideal engine insofar as no combustion takes place and the engine would accordingly be in towed operation. Significant information concerning the combustion process can be obtained from the difference between the measured combustion chamber pressure course and the pressure course in towed operation. For example, the position of combustion is ascertained from the difference integral in the known equipment. The ascertained position of combustion is subsequently taken into consideration as actual value for regulation of the engine operation.

According to the present invention there is provided a method for ascertaining a combustion-dependent magnitude in an internal combustion engine with at least one cylinder pressure sensor which supplies a pressure-dependent signal, which is set into relation with a signal delivered by a crankshaft angle sensor, for the production of a pressure course dependent on crankshaft angle, characterised in that at least one form factor for the energy conversion is formed in dependence on the pressure course dependent on crankshaft angle.

Preferably, the pressure course is compared with a combustion chamber pressure course valid in towed operation for ascertaining a difference pressure course and the form factor or factors replicates or replicate a difference pressure integral. The integral can be formed between presettable crankshaft angles. Expediently, the indexed work is ascertained and form factors are determined therefrom. It is also possible that a form factor is formed with the use of geometric functions, in particular with the use of at least two triangles or two quadrilaterals, the size of which is so chosen that their area approximately corresponds with the combustion chamber difference pressure integral. A form factor can also be formed from a range or a duration in which the combustion chamber difference pressure lies above a presettable threshold. In yet another example, a form factor is formed subject to consideration of the mathematical description of the combustion chamber difference pressure course through approximation by a polynomial of n^{th} degree and the individual factors of the polynomial are converted into a form factor.

The invention also embraces an injection system for an internal combustion engine, in which regulation of the injection takes place subject to consideration of the form factors ascertained by the afore-described method according to the invention, wherein the regulation is carried out in such a manner that the form factors are regulated towards by comparison with the actual form factors. For preference, at least one multistage or steplessly adjustable injection valve is used, which makes injection processes possible by which desired form factors can be produced.

A method exemplifying the invention, for the ascertaining of a form factor for energy conversion in an engine with at least one cylinder pressure sensor, may have the advantage that the evaluation of a specific factor suffices for the analysis of combustion, this factor being denoted as a form factor of the energy conversion. The form factor is in advantageous manner replicated by a difference pressure integral which serves as measure for the energy conversion. The form factor corresponds merely with a numerical value for an area which is adapted to the difference pressure integral and the form factor can be represented in advantageous manner with the aid of simple geometric relationships. For example, the form factor can be formed from two triangular surfaces or two quadrilateral surfaces. However, the form factor can also be formed according to other criteria, for example as numerical value which indicates how long the difference pressure signal lies above a threshold value.

An optimum injection regulation can be achieved if a multistage or a stepless injection valve is used by which desired form factors can be produced. Consequently, it is possible to achieve an engine regulation which can be optimised in respect of consumption, noise development and emission of noxious exhaust substances. Furthermore, it is possible to operate the engine in a manner in which a high torque is producible in case of need. In advantageous manner, the method is used with a diesel engine having direction injection.

Examples of the method of the present invention will now be more particularly described with reference to the accompanying drawings, in which:

Fig. 1 is a schematic block diagram of signal processing means, for performance of a method exemplifying the invention, in an internal combustion engine;

Fig. 2 is a diagram showing the relationship between combustion chamber pressure in the engine and engine crankshaft angle with and without combustion;

Fig. 3 is a diagram showing a pressure difference course as a function of crankshaft angle;

Figs. 4a, 4b and 4c are diagrams showing different form factors formed by the method; and

Figs. 5a and 5b are diagrams showing possible courses for the volume of injected fuel as a function of time or crankshaft angle.

Referring now to the drawings there is shown in Fig. 1 signal processing means associated with an internal combustion engine having at least one combustion chamber pressure sensor. Individual cylinder pressure sensors 14, 15, 16 and 17, which deliver pressure-proportional output voltages U1, U2, U3 and U4, are arranged in the combustion chambers of the cylinders 10, 11, 12 and 13. Also present is a crankshaft angle sensor 18, which delivers an output signal S1 indicative of engine crankshaft angle α.

The output voltages of the pressure sensors 14, 15, 16 and 17 and the output signal S1 of the angle sensor 18 are fed to a control device 19, which processes these signals, of the engine. Further signals, for example temperature T, load L, etc., can be fed to the control device 19 by way of inputs 20a and are likewise processed further in the control device 19. A signal, which represents the setting of an accelerator pedal of a vehicle fitted with the engine, is fed to the control device 19 by way of an input 20b. This signal is ascertained with the aid of a pedal setting transmitter 20c, for example a potentiometer. The pedal setting signal represents the engine torque or acceleration desired by the vehicle driver and is thereby a measure of fuel quantity to be injected.

The control device 19 comprises a multiplexer 21, by way of which the output voltages of the pressure sensors 14, 15, 16 and 17 can be fed selectively to an analog-to-digital converter 22. The switching-over of the multiplexer 21 takes place in dependence on crankshaft angle and is triggered by appropriate drive control actions of the control device 19. If a multichannel analog-to-digital converter is used, the multiplexer 21 can be dispensed with. Evaluation of the signals takes place in a microprocessor 23 of the control device 19, which in dependence on ascertained magnitudes delivers control signals S2 and S3 by way of an output unit 23a to different components of the engine, for example injection signals to an injection system.

The exact ascertaining of the torque or the injected fuel quantity takes place in the microprocessor 23 of the control device 19. For this purpose, the pressure-proportional electrical voltage signal, for example U1, is initially synchronised with the crank angle α. Accordingly, pressure values, for example $P1(\alpha)$, which are referred to crankshaft angle and which are compared with pressure values to be expected in towed operation, are available to the microprocessor 23.

These pressure values, which occur in towed operation, are ascertained according to a presettable method, for example the measured combustion chamber pressure is used up to top dead centre (TDC) and, beyond TDC, the combustion chamber pressure imaged at

TDC. However, other methods can also be used for ascertaining the pressure course in towed operation.

In Fig. 2, the upper curve A shows combustion chamber pressure course $P(\alpha)$ as a function of combustion chamber pressure P (with combustion) and crankshaft angle α. The lower curve B shows the combustion chamber pressure course without combustion, in which case the pressure course beyond TDC was obtained by imaging, as already mentioned.

The difference pressure course $\Delta P(\alpha)$, thus the difference between the two curves A and B entered in Fig. 2, is illustrated as a function of crankshaft angle in Fig. 3. This difference pressure course is taken into consideration for the ascertaining of form factors.

Subject to consideration of the ascertainable difference pressure course according to Fig. 3, a form factor can be obtained from the energy conversion or the combustion chamber pressure course with the processing means according to Figure 1. This form factor makes it possible to provide very accurate regulation of injection, for example in the case of engines, especially diesel engines, with fuel injection directly into the cylinders. In the case of systems with preliminary injection for reduction of noise and noxious exhaust substances, a feedback can be obtained as to how successful the preliminary injection was with respect to a desired shape of the combustion chamber pressure course. Since it is known in principle how an optimum energy conversion combustion chamber difference pressure course should look, the actual difference pressure course can be ascertained by the processing means and compared with desired courses, wherein the injection signals must be varied in the case of, for example, a deviation. For ascertaining the actual form factor, the combustion chamber difference pressure course is evaluated as follows. All pressure differences are computed in a certain crankshaft angle interval or over the entire combustion cycle between minus 360° and 360° crankshaft angle (KW). For this computation, the combustion chamber pressure obtained for towed operation is deducted from the measured combustion chamber pressure. The resulting difference pressure course is evaluated with respect to appropriate properties. For example, the maximum slope can be determined by formation of the first derivative and the duration of the combustion can also be ascertained, for example from the spacing of the 0 positions. In addition, the dwell duration above a certain threshold can be evaluated or the maximum pressure or similar geometric magnitudes. These weightings ultimately always lead to a number, the so-called form factor. Some examples for ascertaining a form factor are illustrated in Figs. 4a, 4b and 4c. In Fig. 4a, a form factor F1 is computed from two triangular areas with the ratio of two slopes X1 and X2. The form factor can be represented as, for example, F1 = X1/X2. In Fig. 4b, an example is indicated for a form factor F2, which is determined from the period during which the difference pressure lies above a threshold Sch. This duration is denoted by αD. A form factor F2 formed in this manner can be represented as $F2 = f(\alpha D)$.

In Fig. 4c, an example is illustrated for a form factor F3 derived from two quadrilateral areas, wherein one of the areas is a square with an edge length a1 and the other is a rectangle with edge lengths a1 and b1. The associated form factor can be represented as F3 = a1/b1.

The indicated form factors represent dimensionless numbers which can be used for a form factor regulation of the combustion chamber pressure course of the engine.

If the difference pressure course is described with the aid of a mathematical approximation, for example by approximation with a polynomial of n^{th} order, it then results for the combustion chamber difference pressure course that:

$$Pd = f0 + f1X\alpha + f2X\alpha^2 + f3X\alpha^3 + ... + fn\alpha^n.$$

The individual factors of this polynomial f0 to fn are then converted into a form factor.

If the method according to the invention is used for ascertaining form factors in connection with an engine with special injection valves, the injection can be further optimised. In an engine with injection valves which are multistage or steplessly settable, different kinds of form factors can be produced for the energy conversion or combustion chamber difference pressure course. Ideal injection valves would be those by which - within a time unit - desired courses of the injection fuel volume as a function of time or crankshaft angle can be produced. Such fuel volume courses are illustrated in Fig. 5a. Regulation towards a desired form factor by pulsed operation of an injection valve or valves is also possible. Fig. 5b shows an associated fuel volume course. By the use of an injection valve of that kind and at least one combustion chamber pressure sensor or cylinder pressure sensor, noise development and development of noxious exhaust substances can be set to minimum values.

In an application phase, the desired optimisations in respect of noise development, NOx emission, soot emission, torque and so forth, target form factors can be defined, which are filed in an operating characteristic field dependent on rotational speed and torque, wherein this torque, corresponding to the wish of the driver of a vehicle fitted with the engine, is ascertained from the vehicle accelerator pedal setting. These form factors are then regulated towards by comparison with the actual form factors. The regulation is performed, for example, within the engine control system.

If a combustion chamber pressure sensor is provided at each cylinder of the engine, the form factor determination and thus the regulation of combustion can be performed individually for each cylinder. The output signals of the pressure sensors can be utilised for other purposes, for example for recognition of knocking, recognition of misfiring, estimation of rotational speed and so forth, wherein, if so desired, other sensors can be replaced or at least plausibility checks are possible by comparisons.

CLAIMS

1. A method of determining a combustion-dependent magnitude in an internal combustion engine, comprising the steps of measuring combustion chamber pressure in a cylinder of the engine and crankshaft angular setting, correlating measured values of the pressure and setting to obtain a pressure course dependent on crankshaft angle, and forming at least one form factor for energy conversion in the combustion chamber of that cylinder in dependence on the pressure course.

2. A method as claimed in claim 1, wherein the step of forming comprises comparing the pressure course with a combustion chamber pressure course applicable to towed operation of the engine.

3. A method as claimed in claim 2, wherein the step of forming comprises forming an integral of the difference between the compared courses.

4. A method as claimed in claim 3, wherein the or each factor is formed to replicate the integral.

5. A method as claimed in claim 3, wherein the integral is formed between predetermined angular settings of the crankshaft.

6. A method as claimed in claim 1, wherein the step of forming comprises ascertaining indexed work respective to the cylinder and determining the or each factor in dependence on the indexed work.

7. A method as claimed in claim 3, wherein the or each factor is formed with the use of geometric functions.

8. A method as claimed in claim 7, wherein the functions comprise at least two triangles or quadrilaterals having an area approximately corresponding with the integral.

9. A method as claimed in claim 2, wherein the or at least one factor is formed from a range or duration during which the difference between the compared pressures lies above a predetermined threshold.

10. A method as claimed in claim 2, wherein the at least one form factor is formed by mathematically describing the course of the difference between the compared pressures through approximation by a polynomial of n^{th} degree and converting the individual factors of the polynomial into the form factor.

11. A method as claimed in claim 1 and substantially as hereinbefore described with reference to the accompanying drawings.

12. A method of regulating fuel injection in an internal combustion engine, comprising the steps of determining form factors by a method as claimed in any one of the preceding claims, and carrying out the regulation in dependence on the result of comparison of the determined form factors with actual form factors.

13. A method as claimed in claim 12, wherein the step of carrying out the regulation is performed with use of a multistage or steplessly adjustable injector enabling injection procedures by which desired form factors can be produced.

14. Regulating means for an internal combustion engine, comprising means for measuring combustion chamber pressure in a cylinder of the engine and crankshaft angular setting, correlating measured values of the pressure and setting to obtain a pressure course dependent on crankshaft angle, and forming at least one form factor for energy conversion in the combustion chamber of that cylinder in dependence on the pressure course, and means for regulating fuel injection in the engine in dependence on the result of comparison of the determined form factor or factors with an actual form factor or actual form factors.

15. Regulating means as claimed in claim 14, wherein the regulation is performed with use of a multistage or steplessly adjustable injector enabling injection procedures by which desired form factors can be produced.

Application No:	GB 9823893.4	**Examiner:**	Steven Davies
Claims searched:	1-15	**Date of search:**	29 January 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): F1B-BCDC ; G1N-NAAJCR

Int Cl (Ed.6): F02D-41/40 ; F02P-5/15,5/153

Other: Online databases: WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X,P	EP 0859149 A2	(MANNESMANN) e.g. Fig.2	1,12,14,15
X	EP 0115807 A2	(NISSAN) e.g. page 18, line 10 to page 19, line 6	1-3, 12,14,15
X	US 5156126	(OHKUBO et al) the whole document	1,12,14,15
X	US 4928653	(OHKUBO et al) e.g. column 5, line 32 to column 9, line 10	1,12,14,15

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
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E Patent document published on or after, but with priority date earlier than, the filing date of this application.