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(72) Inventors:  

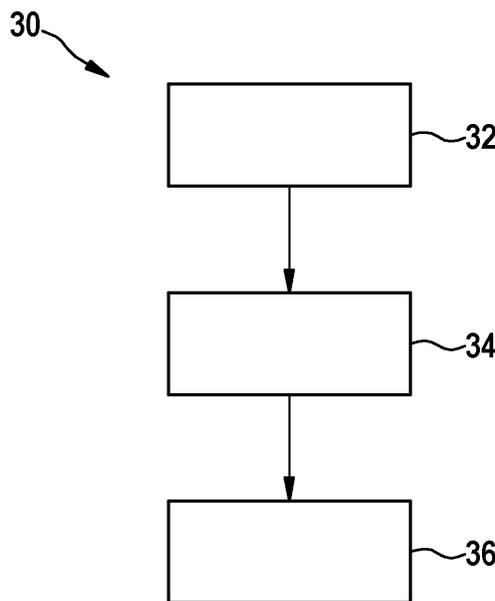
- **Paul, Joachim**  
**70026 Modugno (IT)**
- **Wenzel, Sebastian-Paul**  
**70127 Santo (IT)**
- **Saracino, Roberto**  
**73026 Melendueno (LE) (IT)**

(71) Applicant: **ROBERT BOSCH GMBH**  
**70442 Stuttgart (DE)**

(54) **Method of operating a combustion engine**

(57) A method of operating a combustion engine is specified. The combustion engine comprises a cylinder, a piston, an injection valve and a pressure sensor, wherein the cylinder and the piston delimit a combustion chamber, and wherein the method comprises injecting fuel with the injection valve into the combustion chamber in a load condition of the combustion engine and measuring a pressure signal in the combustion chamber with the pressure sensor. It is determined (32) during the load condition a value of an integral net heat release of the load condition corresponding to an actual angle of the com-

bustion engine and depending on the pressure signal. It is retrieved (34) during the load condition a value of an integral net heat release of an overrun condition of the combustion engine corresponding to the actual angle. And it is determined (36) during the load condition a value of an integral gross heat release of the load condition corresponding to the actual angle depending on the value of the integral net heat release of the overrun condition and the value of the integral net heat release in the load condition.



**Fig. 3**

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**Description**

## Prior Art

- 5 **[0001]** The invention relates to a method of operating a combustion engine. The invention relates to a control unit for operating a combustion engine and to a combustion engine comprising such a control unit.
- [0002]** E.g. US 2010/0121555 A1 discloses a combustion engine comprising a pressure sensor for measuring a pressure signal in a combustion chamber of the combustion engine. Furthermore, the combustion engine comprises an injection valve for injecting fuel into the combustion chamber. Based on the measured pressure signal, a point of injection is determined and the used for influencing the amount of fuel injected into the combustion chamber.
- 10 **[0003]** It is an object of the invention to improve the prior art systems.

## Disclosure of the invention

- 15 **[0004]** The invention solves this object by a method according to claim 1.
- [0005]** The presented method is able to determine an integral gross heat release of a load condition of a combustion engine which inter alia accounts for heat losses through cylinder walls. Moreover the integral gross heat release of the load condition is provided in real time. This enables a further processing of the integral gross heat release of the load condition and therefore a more precise observation and control of the actual combustion process in real time terms.
- 20 **[0006]** In an advantageous embodiment of the method values of an integral net heat release of an overrun condition are updated during the overrun condition taking advantageously into account a change of the combustion characteristics due to normal deterioration of the combustion engine.
- [0007]** The drawings show in:
- 25 Figure 1 a schematic block diagram of an embodiment of a combustion engine;
- Figure 2 a diagram exemplifying the progress of some characteristic values over a crank angle; and
- Figure 3 a schematic block diagram.
- 30 **[0008]** Figure 1 shows a schematic block diagram of an embodiment of a combustion engine according to the invention,
- [0009]** In figure 1, one cylinder 10 of a number of cylinders of an internal combustion engine is shown. The combustion engine may be a diesel engine or a gasoline engine and may have e.g. four or six cylinders.
- [0010]** In the cylinder 10, a piston 11 is movable in an up- and down direction as shown by arrow 12. The piston 11 is coupled by a connecting rod or the like to a crank shaft 13 so that the up- and down movement of the piston 11 is converted into a rotation of the crank shaft 13 as shown by arrow 14. Parallel to the up- and down direction according to arrow 12 it is left out a crevice region 15 between the piston 11 and the cylinder 10.
- 35 **[0011]** The cylinder 10 and the piston 11 delimit a combustion chamber 16. An injection valve 17 is allocated to the cylinder 10 such that fuel may be injected into the combustion chamber 16 by the injection valve 17. Furthermore, a pressure sensor 18 is allocated to the cylinder 10 such that the pressure in the combustion chamber 16 may be measured by the pressure sensor 18.
- 40 **[0012]** The combustion engine is in a load condition when fuel is being injected into the combustion chamber 16 by the injection valve 17 and the fuel being combusted resulting in a mechanical excitation of the crank shaft 13. The combustion engine is in an overrun condition when there is no mechanical excitation of the crank shaft 13 by fuel combustion but a mechanical excitation of the piston 11 by a movement of the crank shaft 13. Therefore in the overrun condition there is substantially no fuel injection into the combustion chamber 16. For example the overrun mode is present when the vehicle is driven downhill with a gear engaged. Of course the load condition and the overrun condition may not only be related to the combustion engine as a whole but also to a specific cylinder 10.
- 45 **[0013]** The combustion engine may comprise further sensors, e.g. a sensor assigned to the crank shaft 13 for measuring a rotational speed  $N$  and/or a crank angle  $\vartheta$  of the crank shaft 13, and so on. Furthermore, the combustion engine may comprise known functions, e.g. an exhaust gas recirculation, a turbo charger, a fuel tank ventilation and the like, with additional sensors.
- 50 **[0014]** A control unit 20, in particular a computer with a computer program, is assigned to the combustion engine. The control unit 20 generates an injection signal  $TI$  which is forwarded to the injection valve 17 for driving the injection valve 17 into a state in which fuel is injected by the injection valve 17. The pressure sensor 18 generates a pressure signal  $P$  which corresponds to the pressure measured in the combustion chamber 16 and which is input to the control unit 20. Furthermore, a number of other signals  $IN$ ,  $OUT$  are input to the control unit 20 and/or are output from the control unit 20. E.g. the rotational speed  $N$  is forwarded to the control unit 20.
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[0015] In terms of mass and energy content the combustion chamber 16 is characterized by a model according following equations 1 and 2, wherein the first equation 1 is related to a time interval  $dt$  and the second equation 2 is related to the crank angle interval  $d\vartheta$ .

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$$\frac{dQ_{ch}}{dt} = \frac{dU_s}{dt} + \frac{dW}{dt} + \sum_i h_i \cdot \frac{dm_i}{dt} + \frac{dQ_{ht}}{dt} \quad (1)$$

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$$\frac{dQ_{ch}}{d\vartheta} = \frac{dU_s}{d\vartheta} + \frac{dW}{d\vartheta} + \sum_i h_i \cdot \frac{dm_i}{d\vartheta} + \frac{dQ_{ht}}{d\vartheta} \quad (2)$$

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[0016] The term  $dQ_{ch}$  represents the variation of the chemical energy released by combustion of a fuel mass injected by the injection valve 17 into the combustion chamber 16. The term  $dU_s$  represents the variation of the internal energy of the gas mass of the charge into the combustion chamber due to temperature variation. The term  $dW$  which is also depicted in figure 1 represents the variation of the mechanical work of the piston 11. The term  $h_i$  represents a specific enthalpy relating to the  $i$ -th mass flow across system boundaries  $m_i$ . The term  $dQ_{ht}$  which is also depicted in figure 1 represents the variation of the heat transfer to and from the walls of the cylinder 10.

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[0017] Moreover figure 1 depicts the term  $h_f \cdot dm_f$  which relates to the energy associated to the fuel mass  $m_f$  injected into the combustion chamber 16 incorporating the specific enthalpy  $h_f$ . The term  $h' \cdot dm_{cr}$  relates to the energy flowing into and out of the crevice region 15.

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[0018] According to figure 1 the mass flux term of equations 1 and 2 can be expressed by the following equation 3.

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$$\sum_i h_i \cdot dm_i = h' \cdot dm_{cr} - h_f \cdot dm_f \quad (3)$$

[0019] To specify the model according to equation 1, 2 and 3 in more detail the following assumptions according to the equations 4 to 7 are made.

35

$$\left. \begin{array}{l} U_s = m \cdot u(T) \\ \left( \frac{du(T)}{dT} \right) = c_v \\ dm \approx 0 \end{array} \right\} \Rightarrow dU_s = m \cdot c_v \cdot dT + u(T) \cdot dm \approx m \cdot c_v \cdot dT \quad (4)$$

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$$\frac{dm_{cr}}{dt} \approx 0 \quad (5.1)$$

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$$h_f \approx 0 \quad (5.2)$$

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$$p \cdot V = m \cdot R \cdot T \quad (6)$$

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$$c_v = const_1 \quad with \quad \begin{cases} c_p = c_v + R \\ \frac{c_p}{c_v} = \gamma \end{cases} \quad (7)$$

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**[0020]** According to the equations 4 it is determined the variation  $dU_s$  of the sensible energy of the charge due to temperature variation  $dT$ , wherein the term  $m$  represents all the gas mass inside the combustion chamber 16, the term  $u(T)$  represents the energy depending on a temperature  $T$ , the term  $c_v$  represents a constant and the change of mass  $dm$  is considered negligible.

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**[0021]** According to equation 5.1 the mass flow in and out of the crevice region 15 during a specific time period is considered as negligible. Also the enthalpy  $h_f$  is considered as negligible according to equation 5.2. Equation 6 represents the ideal gas law with the pressure  $p$ , the volume  $V$ , the mass  $m$ , the gas constant  $R$  and the temperature  $T$ . Equations 7 define the constant values of  $c_v$  and  $c_p$ .

**[0022]** The following equation 7.1 can be written considering equation 3 and the assumptions of equations 5.1 and 5.2.

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$$\sum_i h_i \cdot dm_i = (h' \cdot dm_{cr} - h_f \cdot dm_f) \approx 0 \quad (7.1)$$

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**[0023]** According to the assumption of equation 7.1 the third summand on the right hand side of equations 1 and 2 is negligible.

**[0024]** According to the following equation 7.2 the mechanical work of the piston 11 equals the product of the instantaneous pressure and the in-cylinder volume variation.

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$$dW = p \cdot dV \quad (7.2)$$

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**[0025]** Considering the third assumption in equation 4,  $dm \approx 0$ , equation 6 can be differentiated to equation 7.4 by the step illustrated in equation 7.3 and equation 4 can be rewritten as equation 7.5 shows.

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$$p \cdot dV + V \cdot dp = m \cdot R \cdot dT \quad (7.3)$$

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$$dT = \frac{p \cdot dV + V \cdot dp}{m \cdot R} \quad (7.4)$$

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$$dU_s = m \cdot c_v \cdot dT = m \cdot c_v \cdot \frac{p \cdot dV + V \cdot dp}{m \cdot R} = \frac{c_v}{R} \cdot (p \cdot dV + V \cdot dp) \quad (7.5)$$

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 [0026] Considering the last equations 7.4 and 7.5 and the definitions in equation 7, the first two summands on the right hand side of equation 2 can be expressed in the following equation 7.6. From equation 7.6 the equation 8 can be derived.

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$$\begin{aligned} \frac{dU_s}{d\vartheta} + \frac{dW}{d\vartheta} &= \frac{c_v}{R} \cdot \left( p \cdot \frac{dV}{d\vartheta} + V \cdot \frac{dp}{d\vartheta} \right) + p \cdot \frac{dV}{d\vartheta} + p \cdot \frac{dV}{d\vartheta} = \\ &= \frac{c_p}{R} \cdot p \cdot \frac{dV}{d\vartheta} + \frac{c_v}{R} \cdot V \cdot \frac{dp}{d\vartheta} = \frac{\gamma}{\gamma-1} \cdot p \cdot \frac{dV}{d\vartheta} + \frac{1}{\gamma-1} \cdot V \cdot \frac{dp}{d\vartheta} \end{aligned} \quad (7.6)$$

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[0027] Considering the preceding assumptions the term  $\frac{dQ_{ch}}{d\vartheta}$  related to the variation of the chemical energy per variation of the crank angle  $\vartheta$  can be expressed by the following equation 8 which considers the measured in-cylinder pressure  $p$ , the volume of the combustion chamber  $V$  and the heat exchange with the walls of the cylinder 10.

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$$\frac{dQ_{ch}}{d\vartheta} = \frac{\gamma}{\gamma-1} \cdot p \cdot \frac{dV}{d\vartheta} + \frac{1}{\gamma-1} \cdot V \cdot \frac{dp}{d\vartheta} + \frac{dQ_{ht}}{d\vartheta} \quad (8)$$

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$$GHRR(\vartheta) = \frac{dQ_{ch}(\vartheta)}{d\vartheta} \quad (9.1)$$

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$$NHRR(\vartheta) = \frac{dQ_{ch}(\vartheta)}{d\vartheta} - \frac{dQ_{ht}(\vartheta)}{d\vartheta} = \frac{\gamma}{\gamma-1} \cdot p \cdot \frac{dV}{d\vartheta} + \frac{1}{\gamma-1} \cdot V \cdot \frac{dp}{d\vartheta} \quad (9.2)$$

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[0028] According to equation 9.1 the term  $\frac{dQ_{ch}(\vartheta)}{d\vartheta}$  represents the gross heat release rate GH RR including the heat exchange with the walls of the cylinder 10. According to equation 9.2 the net heat release rate NHRR does not include the heat exchange with the walls of the cylinder 10 resulting in the right hand side term considering equation 8.

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$$IGHR(\vartheta) = \int_{\vartheta_0}^{\vartheta} \frac{dQ_{ch}(\vartheta)}{d\vartheta} d\vartheta \quad (10.1)$$

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$$INHR(\vartheta) = \int_{\vartheta_0}^{\vartheta} \left[ \frac{dQ_{ch}(\vartheta)}{d\vartheta} - \frac{dQ_{ht}(\vartheta)}{d\vartheta} \right] d\vartheta = \int_{\vartheta_0}^{\vartheta} \left[ \frac{\gamma}{\gamma-1} \cdot p \cdot \frac{dV}{d\vartheta} + \frac{1}{\gamma-1} \cdot V \cdot \frac{dp}{d\vartheta} \right] d\vartheta \quad (10.2)$$

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**[0029]** The equation 10.1 represents the integrated gross heat release IGHR based on the gross heat release rate GHRR of equation 9.1. The equation 10.2 represents the integrated net heat release INHR base on the net heat release rate NHRR of equation 9.2.

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**[0030]** Regarding equation 10.2 the term  $\frac{dQ_{ht}(\vartheta)}{d\vartheta}$  strongly depends inter alia on the variation of gas temperature inside the combustion chamber 16, the temperature of the walls of the cylinder 10, the available surface for heat exchange and the mechanisms of heat transfer. A model to calculate  $\frac{dQ_{ht}(\vartheta)}{d\vartheta}$  would not provide the sufficient accuracy or

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would not be available in real time terms to calculate the respective values all due to the aforementioned complexity.

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**[0031]** Figure 2 shows a diagram exemplifying the progress of some characteristic values of the combustion engine over the crank angle  $\vartheta$ . The progress of the injection signal TI shows the release of a pilot injection into the combustion chamber 16 in the area PI and the release of a main injection into the combustion chamber 16 in the area MI. Therefore the progress of the signal TI shows the load condition of the combustion engine. It is marked the crank angle SOMIC which determines the start of the combustion of the main injection in the load condition of the combustion engine. Related to the progress of a net heat release rate  $NHRR_{load}$  in the load condition the crank angle SOMIC is located at a minimal turning point between two peaks, the first peak being related to the combustion of the pilot injection and the second peak related to the combustion of the main injection.

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**[0032]** Moreover figure 2 shows the progress of the pressure  $p_{load}$  in the load condition and the pressure  $p_{overrun}$  in the overrun condition. It is also shown the progress of an integrated gross heat release  $IGHR_{load}$  of the load condition, an integrated net heat release  $INHR_{load}$  of the load condition and an integrated heat release  $INHR_{overrun}$  in the overrun condition.

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**[0033]** In the overrun condition the assumptions according to equations 11.1 and 11.2 are made as no combustion takes place in the combustion chamber 16 and the term  $\frac{dQ_{ch}(\vartheta)}{d\vartheta}$  is considered negligible.

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$$GHRR(\vartheta)_{overrun} = \frac{dQ_{ch}(\vartheta)}{d\vartheta}_{overrun} \approx 0 \quad (11.1)$$

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$$NHRR(\vartheta)_{overrun} = \frac{dQ_{ch}(\vartheta)}{d\vartheta}_{overrun} - \frac{dQ_{ht}(\vartheta)}{d\vartheta}_{overrun} = - \frac{dQ_{ht}(\vartheta)}{d\vartheta}_{overrun} \quad (11.2)$$

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**[0034]** For the following the dynamics of the gas temperature in the combustion chamber, of wall temperature of the cylinder 10 and of the heat transfer mechanism are assumed to be the same in the load condition and in the overrun condition before the crank angle SOMIC. As the effects of gas temperature variation at an intake of the cylinder 10 are assumed to be not significant, it is assumed that the combusted pilot injections in the load condition do not lead to a significantly different gas mean temperature inside the combustion chamber 16 or a significantly different temperature of the walls of the cylinder 10 compared with the overrun condition. This assumption can be made as the pilot injections comprise only a small quantity of fuel and do burn only locally inside the combustion chamber 16.

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**[0035]** Therefore for crank angles  $\vartheta$  before the crank angle SOMIC equation 11.2 can be transformed to the following equation 12.

$$\frac{dQ_{ht}(\vartheta)}{d\vartheta}_{load} \approx \frac{dQ_{ht}(\vartheta)}{d\vartheta}_{overrun} = -NHRR(\vartheta)_{load} \quad (\vartheta < SOMIC) \quad (12)$$

**[0036]** The following equations 13.1 and 13.2 take into account the equation 12 and its assumptions.

$$GHRR(\vartheta)_{load} = NHRR(\vartheta)_{load} + \frac{dQ_{ht}(\vartheta)}{d\vartheta}_{load} = NHRR(\vartheta)_{load} - NHRR(\vartheta)_{overrun} \quad (13.1)$$

$$IGHR(\vartheta)_{load} = INHR(\vartheta)_{load} - INHR(\vartheta)_{overrun} = \int_{\vartheta_0}^{\vartheta} NHRR(\vartheta)_{load} d\vartheta - \int_{\vartheta_0}^{\vartheta} NHRR(\vartheta)_{overrun} d\vartheta \quad (13.2)$$

**[0037]** The relationship of  $IGHR_{load}$  can also be derived from figure 2 in a graphical manner. As  $IGHR_{load}$  remains up to the first increase at a nearly constant level around zero, the  $INHR_{load}$  can be subtracted from  $INHR_{overrun}$  or vice versa to obtain  $IGHR_{load}$ .

**[0038]** Of course the all of the aforementioned derivation of the equation 13.2 does not affect its possible application especially for values of  $IGHR_{load}$  after the crank angle  $SOMIC$ . Moreover the equation 13.2 is applicable to all kinds of combustion engines independently of what type of fuel is used to inject and combust inside the combustion engine.

**[0039]** Figure 3 shows a schematic block diagram 30 which comprises steps 32, 34 and 36 which are executed during the load condition of the combustion engine in order to determine the integrated gross heat release  $IGHR_{load}$ .

**[0040]** In step 32 it is determined a value of the integral net heat release  $INHR_{load}$  of the load condition corresponding to the actual angle  $\vartheta$  of the combustion engine and depending on the pressure signal  $p_{load}$ . The net heat release rate  $IHRR_{load}$  may be derived from the pressure signal  $p_{load}$ .

**[0041]** For example, the net heat release rate  $IHRR_{load}$  of the load condition and the net heat release rate  $IHRR_{overrun}$  of the overrun condition may be evaluated using a so-called "schnelles Heizgesetz (fast heating rule)"; reference is made e.g. to Pischinger, Kraßnig, Taucar, Sams, Thermodynamik der Verbrennungskraftmaschine, Wien, New York, Springer, 1989. According to this exemplary rule, the pressure within the combustion chamber, the volume of the combustion chamber and a so-called "kalorischer Wert (caloric value)" is used to calculate the net heat release rate  $IHRR_{load}$  in the load condition. The integral net heat release  $INHR_{load}$  of the load condition is the integrated net heat release rate  $NHRR_{load}$  in the load condition.

**[0042]** In step 34 a value of the integral net heat release  $INHR_{overrun}$  of the overrun condition of the combustion engine corresponding to the actual angle  $\vartheta$  is retrieved. For this purpose the values of the integral net heat release  $INHR_{overrun}$  of the overrun condition are provided while in the load condition by a respective memory means.

**[0043]** In a further embodiment the respective value of the integral net heat release  $INHR_{overrun}$  of the overrun condition corresponding to the angle  $\vartheta$  is determined for the combustion engine during the overrun condition and stored in the respective memory means. In an alternative embodiment the respective value of the integral net heat release  $INHR_{overrun}$  of the overrun condition corresponding to the angle  $\vartheta$  is determined during the overrun condition of a special application combustion machine in an application mode for a type of combustion engine. In an alternative embodiment the respective value of the integral net heat release  $INHR_{overrun}$  of the overrun condition corresponding to the angle  $\vartheta$  for a type of combustion engine is determined by a simulation of a type of combustion engine.

**[0044]** The values of the integral net heat release  $INHR_{overrun}$  of the overrun condition can be recorded additionally to the crank angle  $\vartheta$  over the rotational speed  $N$  of the combustion engine. That means that the integral net heat release  $INHR_{overrun}$  of the overrun condition is recorded in a map and depends on the crank angle  $\vartheta$  and the rotational speed of the combustion engine. For the sake memory capacity the values or curves of the integral net heat release  $INHR_{overrun}$  of the overrun condition may be recorded in steps of 250 to 500 rpm of the rotational speed  $N$ .

**[0045]** In a further embodiment of the method the integral net heat release  $INHR_{overrun}$  of the overrun condition is

updated when the combustion engine is in the overrun condition to take into account the normal deterioration of the combustion engine. This update method may be accomplished by retrieving the recorded value of the integral net heat release  $INHR_{overrun}$  of the overrun condition, combine the recorded value with the determined value of the integral net heat release  $INHR_{overrun}$  of the overrun condition and storing the result. This update method may be accomplished especially by multiplying the recorded value of the integral net heat release  $INHR_{overrun}$  with a first number and by multiplying a new value of the integral net heat release  $INHR_{overrun}$  with a second number, wherein the first number is greater than the second number and the sum of the first number and the second number equals one, and saving the sum of both products by overwriting the recorded value of the integral net heat release  $INHR_{overrun}$  of the overrun condition.

**[0046]** In step 36 a value of the integral gross heat release  $IGHR_{load}$  of the load condition corresponding to the actual angle  $\vartheta$  is determined depending on the retrieved value of the integral net heat release  $INHR_{overrun}$  of the overrun condition and the already determined value of the integral net heat release  $INHR_{load}$  of the load condition. More specifically the value of the integral gross heat release  $IGHR_{load}$  of the load condition corresponding to the actual angle  $\vartheta$  is determined by subtracting the value of the integral net heat release  $INHR_{overrun}$  of the overrun condition from the value of the integral net heat release ( $INHR_{load}$ ) of the load condition or vice versa.

### Claims

1. A method of operating a combustion engine, wherein the combustion engine comprises a cylinder (10), a piston (11), an injection valve (17) and a pressure sensor (18), wherein the cylinder (10) and the piston (11) delimit a combustion chamber (16), and wherein the method comprises injecting fuel with the injection valve (17) into the combustion chamber (16) in a load condition of the combustion engine and measuring a pressure signal ( $p_{load}$ ) in the combustion chamber (16) with the pressure sensor (18), **characterized by** the steps of: determining (32) during the load condition a value of an integral net heat release ( $INHR_{load}$ ) of the load condition corresponding to an actual angle ( $\vartheta$ ) of the combustion engine and depending on the pressure signal ( $p_{load}$ ), retrieving (34) during the load condition a value of an integral net heat release ( $INHR_{overrun}$ ) of an overrun condition of the combustion engine corresponding to the actual angle ( $\vartheta$ ), and determining (36) during the load condition a value of an integral gross heat release ( $IGHR_{load}$ ) of the load condition corresponding to the actual angle ( $\vartheta$ ) depending on the value of the integral net heat release ( $INHR_{overrun}$ ) of the overrun condition and the value of the integral net heat release ( $INHR_{load}$ ) of the load condition.
2. The method of claim 1 wherein the method comprises the step of determining (36) during the load condition the value of an integral gross heat release ( $IGHR_{load}$ ) of the load condition corresponding to the actual angle ( $\vartheta$ ) by subtracting the value of the integral net heat release ( $INHR_{overrun}$ ) of the overrun condition from the value of the integral net heat release ( $INHR_{load}$ ) of the load condition.
3. The method according to claim 1 or 2, wherein the values of the integral net heat release ( $INHR_{overrun}$ ) of the overrun condition over the angle ( $\vartheta$ ) are further recorded over a rotational speed ( $N$ ) of the combustion engine.
4. The method according to one of the preceding claims, wherein the method comprises the step: determining during the overrun condition the value of the integral net heat release ( $INHR_{overrun}$ ) of the overrun condition corresponding to the actual angle ( $\vartheta$ ) and storing the value of the integral net heat release ( $INHR_{overrun}$ ) of the overrun condition.
5. The method according to one of the preceding claims, wherein the method comprises the step: updating during the overrun condition the value of the integral net heat release ( $INHR_{overrun}$ ) of the overrun condition.
6. A control unit (20) for operating a combustion engine, wherein the control unit (20) is adapted to carry out the method steps of one of the claims 1 to 5.
7. The control unit (20) of claim 5 further comprising a computer and a computer program, wherein the computer program carries out the method steps of one of the claims 1 to 5.
8. A combustion engine comprising the control unit (20) of one of the claims 6 or 7.

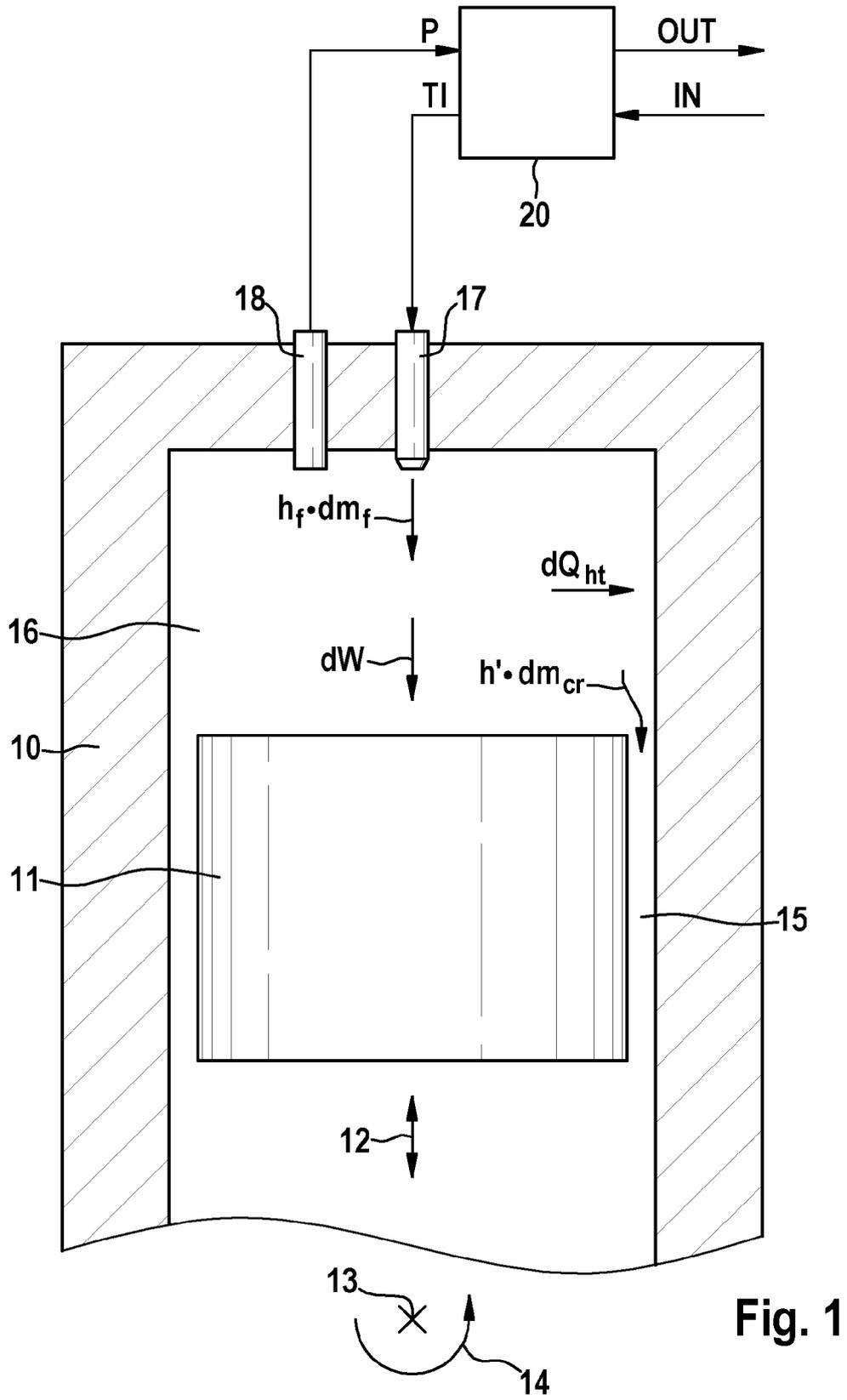


Fig. 1

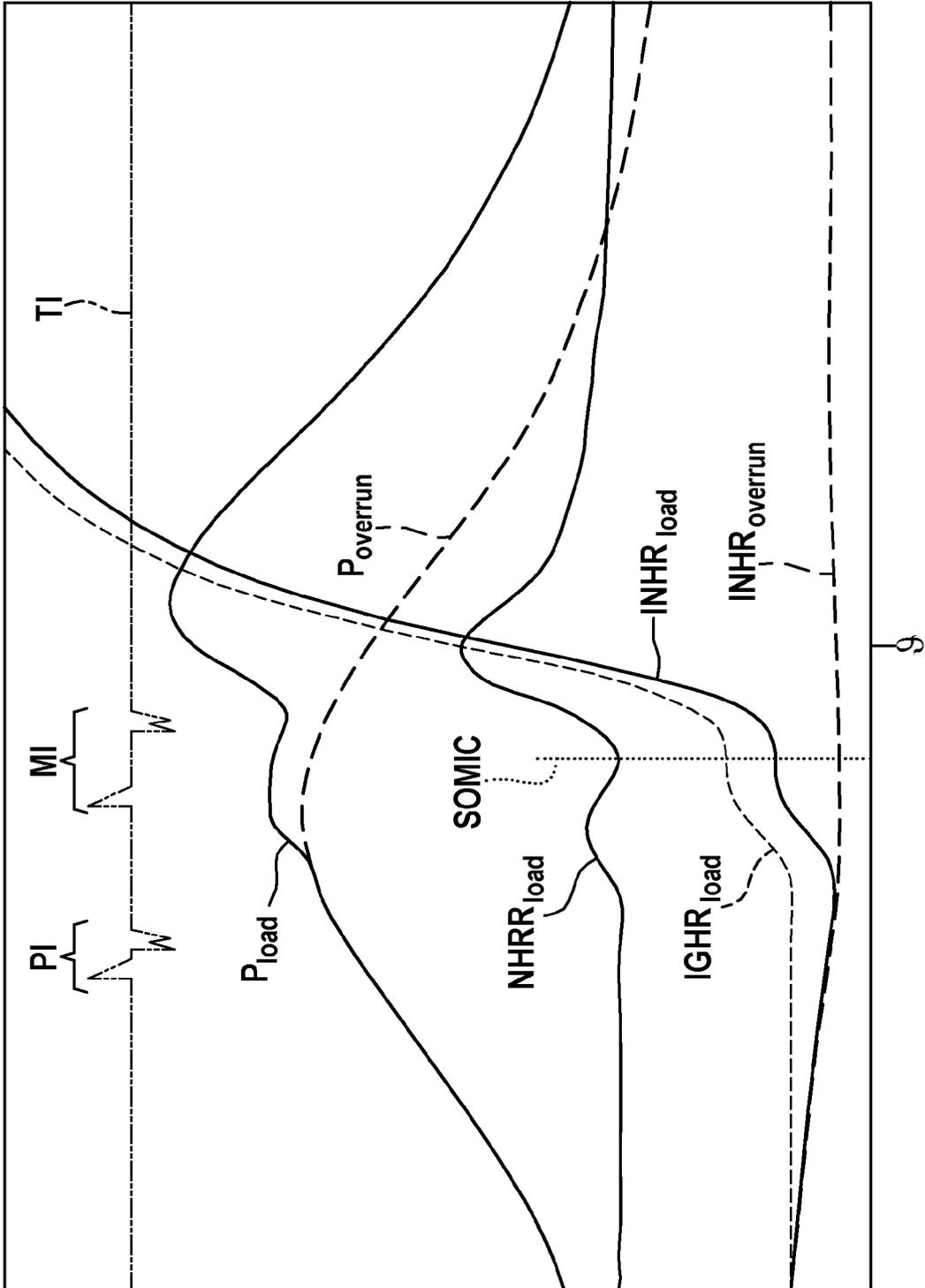
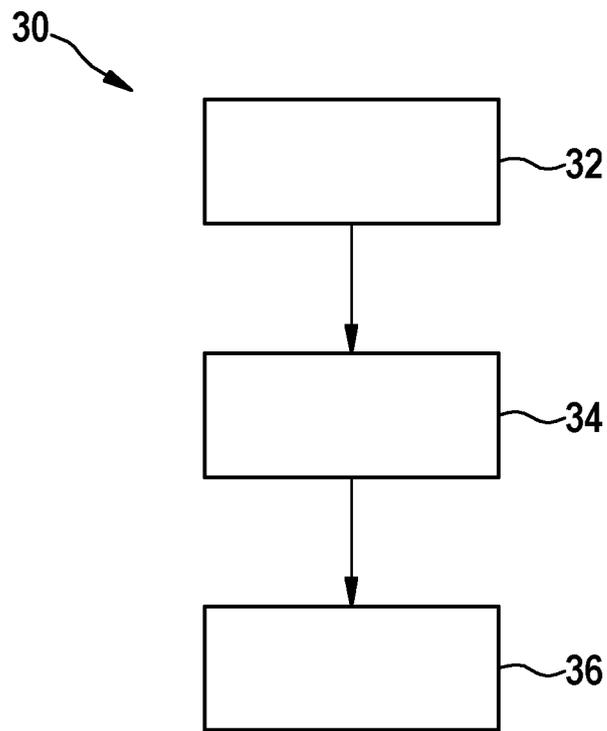


Fig. 2



**Fig. 3**



EUROPEAN SEARCH REPORT

Application Number  
EP 13 15 7358

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 1 936 156 A1 (DELPHI TECH INC [US]) 25 June 2008 (2008-06-25)	1,2,6-8	INV. F02D35/02
A	* abstract * * paragraph [0006] - paragraph [0008] * * paragraph [0033] - paragraph [0034] * * claims 1,11 * * figures 3-7 *	3-5	
A	----- DE 10 2006 001271 A1 (SIEMENS AG [DE]) 12 July 2007 (2007-07-12) * paragraph [0006] - paragraph [0011] * * paragraph [0041] - paragraph [0047] *	1-8	
A	----- US 2009/055074 A1 (ISHIGURO TETSUYA [JP] ET AL) 26 February 2009 (2009-02-26) * abstract * * paragraph [0004] * * paragraphs [0006] - [0008] * * paragraph [0042] - paragraph [0044] * * paragraph [0048] - paragraph [0052] *	1-8	
A	----- DE 10 2008 004221 A1 (BOSCH GMBH ROBERT [DE]) 16 July 2009 (2009-07-16) * paragraphs [0014], [0015], [0017] * * paragraphs [0019], [0038], [0041] *	1,6	TECHNICAL FIELDS SEARCHED (IPC) F02D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 12 July 2013	Examiner Wettemann, Mark
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	

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.

EP 13 15 7358

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