(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 593 825 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
26.09.2007 Bulletin 2007/39

(51) Int Cl.:
F02D 41/14 *(2006.01)* ***F02D 35/02*** *(2006.01)*
F02D 41/24 *(2006.01)* ***F02D 41/34*** *(2006.01)*

(21) Application number: **04101924.1**

(22) Date of filing: **05.05.2004**

(54) **Method to balance the cylinders of a combustion engine with sensors for each cylinder**

Vorrichtung zur Zylindernbalancierung einer Brennkraftmaschine mit einem Sensor für jeden Zylinder

Système pour équilibrer des cylindres dans un moteur à combustion interne avec un capteur par cylindre

(84) Designated Contracting States:
DE FR GB

(43) Date of publication of application:
09.11.2005 Bulletin 2005/45

(73) Proprietor: **Ford Global Technologies, LLC, A subsidary of Ford Motor Company**
Dearborn, MI 48126 (US)

(72) Inventors:
- **Moraal, Paul Eduard**
  6291 VP, Vaals (NL)
- **Sadai, Stephane**
  52064, Aachen (DE)
- **Bayliss, Warren**
  B98 0NY, Redditch (GB)
- **Vantine, Katie**
  52062, Aachen (DE)
- **Christen, Urs**
  52072, Aachen (DE)
- **Chevalier, Alain**
  4880, Aubel (BE)

(74) Representative: **Drömer, Hans-Carsten et al**
Ford-Werke Aktiengesellschaft,
Patentabteilung NH/DRP,
Henry-Ford-Strasse 1
50725 Köln (DE)

(56) References cited:
EP-A- 0 411 580
WO-A-20/04022951
US-A- 4 744 244

EP 1 593 825 B1

Description

[0001] The invention relates to a method and a system for balancing the cylinders of an internal combustion engine which are equipped with individual cylinder sensors.

[0002] In recent years, engines have become more and more refined in terms of vibrations and noise. Customers expect diesel engines to be on a par with gasoline engines. An important contribution to reducing vibrations and noise is achieved by balancing the operation of the individual cylinders of an engine. By removing imbalance, low frequency oscillations (rumble or beat) which are perceived by the driver as very annoying are avoided.

[0003] There are two possible approaches to cylinder balancing. Either the imbalance can be detected with only one sensor, e.g., the crank position sensor by measuring crank shaft acceleration in a crank angle window associated with each cylinder (cf. EP 1 020 629 A2), or with a separate sensor for each cylinder, e.g., with in-cylinder pressure sensors (cf. EP 1 061 246 A2).

[0004] The first approach with a single sensor offers the advantage that the sensor is the same for all cylinders and thus cannot introduce apparent imbalance due to a mis-calibration of some sensors. On the other hand, acceleration (or crank shaft torque) measurements are only feasible at engine operating points with low speed and low torque because at higher speed or torque (higher inertia seen by the e n-gine), the differences between the accelerations due to each cylinder become so small that they cannot be resolved anymore. This problem is exacerbated for e n-gines with more than four cylinders.

[0005] The second approach with cylinder-individual sensors works also at higher engine torque or speed because the method no longer relies on a small crank angle window. With sensors which provide information about the indicated torque produced by the individual cylinders or the fuel burned in them (with in-cylinder pressure sensors, this amounts to calculating indicated mean effective pressure or heat release, respectively, for each cylinder), the whole combustion cycle is available for assessing these values, independent of the number of cylinders per engine. However, there is no a priori guarantee that the sensors give correct readings. Drift in sensor gains or offsets may lead to apparent imbalance even when the engine as such is perfectly balanced.

[0006] The need to calibrate cylinder-individual sensors has been recognised and tried to achieve in the state of the art. According to an approach disclosed in the WO 2004/022951 A1, an internal combustion engine is operated in a state in which a comparatively precise cylinder balancing is possible, for example in a state of idling. The cylinder sensors are then calibrated based on the assumption that the engine is perfectly balanced. According to a method described in the EP 411 580 A1, each cylinder sensor is calibrated during an intake stroke of the corresponding cylinder with respect to a predetermined reference minimum of the cylinder pressure. In an approach described in the US 4 744 244, the occurrence of a non-combustion state is determined and the cylinder pressures measured at this time are then used to calculate correction factors for the cylinder-individual sensors.

[0007] Based on this situation it was an object of the present invention to provide means for a more reliable balancing of cylinders of an internal combustion engine with individual cylinder sensors.

[0008] This object is achieved by a method according to claim 1 and a system according to claim 8. Preferred embodiments are disclosed in the dependent claims.

[0009] The method for balancing the cylinders of an internal combustion engine which are equipped with individual cylinder sensors is characterized in that the properties of these cylinder sensors are balanced with respect to each other before they are used for balancing the cylinders. This sensor balancing has the advantage that variations from sensor to sensor are first compensated for before the sensor readings are used in order to balance the internal combustion engine. Thus balancing of the cylinders is not impaired by variations from sensor to sensor and the result is comparable to the balancing of cylinders with one single sensor. In contrast to such a single sensor, however, the individual sensors cover a much larger range of operating conditions of the internal combustion engine.

[0010] According to a preferred embodiment, the balancing of the properties of the cylinder sensors is achieved by adapting their individual gain and/or offset. The conversion of a measured quantity like in-cylinder pressure to a signal like voltage or current is normally achieved by a multiplying factor or gain and an additive term or offset. Thus there are usually two constants that are suited for the required adaptation between sensors.

[0011] According to the invention, the properties of the cylinder sensors are balanced by comparison with a single engine sensor which monitors all cylinders simultaneously. Such a single sensor, which may for example be a crank shaft sensor, obviously cannot show any inter-sensor variations, and therefore measures the processes in all cylinders in the same way. This makes the single engine sensor suited as a reference for the balancing of the individual cylinder sensors.

[0012] The use of a single engine sensor mentioned above is preferably done in the following way:

a) The engine sensor is first used to balance the internal combustion engine by known techniques. This balancing typically requires that certain operating conditions of the engine prevail, for example a low or intermediate speed range.

b) The thus balanced run of the internal combustion engine is then used in order to balance the properties of the individual cylinder sensors with respect to each other. This second step is preferably done in the same operating range of the engine as step a), because this guarantees that the engine is still balanced.

[0013] When balancing the properties of the sensors with respect to a pre-balanced engine, different quantities of the combustion process may be used as reference. One preferred quantity is the indicated mean effective pressure of the cylinders. The use of this quantity implies that the engine is primarily balanced with respect to the torque at the crankshaft. Another possible quantity is the heat release during combustion in the cylinders. This approach puts a stress on emission properties of the internal combustion engine.

[0014] According to a further development of the method, the balancing of the properties of the individual cylinder sensors is repeated if given criteria are fulfilled. The balancing may for instance be repeated if a threshold is reached for the traveled distance, the time and/or the number of operating cycles since the last balancing.

[0015] The invention further comprises a system according to claim 8 for balancing the cylinders of an internal combustion engine, the system comprising the following components:

a) At least one cylinder sensor in each of the cylinders for monitoring the combustion process.

b) An engine sensor which monitors all cylinders.

c) A control unit that is coupled to the sensors and adapted to balance the properties of the cylinder sensors with respect to each other.

[0016] The system is adapted to execute a method of the kind described above. Therefore, reference is made to the description above for more information on details, improvements and further developments of such a system.

[0017] The cylinder sensors of the system may particularly comprise pressure sensors for measuring the in-cylinder pressure.

[0018] According to a further development of the system, the engine sensor may be a crankshaft sensor.

[0019] In the following, the invention is described in more detail with respect to preferred embodiments thereof and the accompanying figure, which schematically shows the components of a system according to the present invention.

[0020] The figure depicts an internal combustion engine 1 with for example four cylinders 2. The cylinders 2 are connected to a crankshaft 7 and are supplied with fuel via a fueling system 4.

[0021] Each cylinder 2 is equipped with an individual cylinder sensor 3, which may for instance be a pressure sensor. All cylinder sensors 3 are connected to a control unit 5, for example a microcomputer or a module of the engine control unit. The control unit 5 is connected to the fueling system 4 for controlling the amount of fuel that is supplied to each individual cylinder 2. Moreover, the control unit 5 is connected to a crankshaft sensor 6 that monitors the rotation angle of the crank shaft 7. The purpose and the operation of this system is described in more detail below. Though this description will refer to a diesel engine 1, the ideas apply to any multi-cylinder engine without restrictions. Moreover, though reference is made to in-cylinder pressure sensors 3 for the cylinder individual sensors, the invention equally applies to other types of sensors, e.g., ionization sensors.

[0022] In order to balance an engine 1 with individual sensors 3 for each cylinder 2, it is not sufficient to just remove the imbalance from the sensor signals. The sensors 3 themselves need to be balanced first. This approach is a central aspect of the present invention.

[0023] Therefore, a procedure shall be provided which first ensures that the sensors 3 are balanced and then uses the cylinder-individual sensors 3 to balance the engine 1 in the whole operating range. The first step, balancing the sensors 3, can be achieved by comparing the sensor readings with that from a single sensor such as the crank position sensor 6 in an operating point where balancing with just one sensor 6 is applicable.

[0024] Cylinder pressure sensors 3 are commonly used in the development process of automotive engines. The potential for application in an engine management system has been recognized as early as the 1980s, but actual application has been hindered by the lack of a suitable pressure sensor to combine accuracy, durability, and low cost. Several suppliers are currently developing prototypes utilizing different physical principles. Most low cost sensor technologies will require regular recalibration of the sensor characteristics which translate a measured signal (voltage, current, etc.) to the actual pressure values.

[0025] The relation between the in-cylinder pressure, p, applied to the sensing element and the voltage trace, U, thus generated is assumed to be of the following form

$$U = S(p - p_0) + U_0 \quad (1)$$

where p_0 and U_0 denote a reference pressure and voltage, respectively, and S the sensor gain (in [V/bar]; also called sensitivity). In order to reconstruct the pressure p from the voltage signal U,

$$p = \frac{U - U_0}{S} + p_0 = \frac{U}{S} + \frac{U_{off}}{S}, \quad (2)$$

the sensor gain, S, and the sensor offset, $U_{off} = Sp_0 - U_0$, must be known. A method for the online identification of S may be based on the pressure being known at one crank angle (e.g., intake valve closure; index 1) and being calculated at another crank angle during compression (e.g., 30° before top dead center; index 2). By comparing measured voltages at these two locations with the known/computed pressures, the sensor gain can be estimated:

$$\hat{S} = \frac{U_2 - U_1}{(r_V / r_T - 1)(\alpha p_i)} \quad (3)$$

where $r_V = V_1/V_2$ and $r_T = T_1/T_2$ denote the cylinder volume and temperature ratios at the two locations, and α is a correcting factor (possibly engine speed dependent) which corrects the intake manifold pressure, p_i, to reflect the in-cylinder pressure, p_1, at the first crank angle position. The temperature ratio, r_T, can be fitted as a function of crank angle, while r_V is determined by the geometry of the engine 1.

[0026] Once the sensor $_g$ain is known, the sensor offset can be estimated from the known pressure, pi = αp_i:

$$\hat{U}_{off} = Sp_1 - U_1 \quad (4)$$

[0027] There are other methods to estimate U_{off} which do not rely on the sensor gain explicitly.

[0028] Several parameters can introduce small errors in the sensor gain estimation and thus lead to an imbalance in the sensed pressure signals of a multi-cylinder engine 1. The ratio r_V is calculated for perfect geometry, but due to manufacturing tolerances or depositions in the cylinders 2, this ratio may slightly vary for the individual cylinders. Heat transfer and blowby, which both influence the fits for r_T and α but are not taken into account explicitly, may differ. The breathing characteristics of the individual cylinders are in general different, which cannot be captured with a single α for the engine 1. Moreover, the individual cylinders usually see different levels of exhaust gas recirculation (EGR dispersion) which again can lead to a small imbalance in the sensor gain estimation. All these parameters influence the sensor offset estimation as well.

[0029] Cylinder balancing with first balancing cylinder-individual sensors 3 can be carried out with the following steps.

STEP 1: Balance the engine 1 with respect to timing. This can be done, to name just two possibilities, by determining the start of combustion (cf. EP 01130557.0) or the peak pressure location from the pressure signals and adjusting the start of injection until the signals match for all cylinders. This timing (or phasing) information can be obtained without the sensors being balanced because the magnitude of the pressure reading is not important. This first step is not absolutely necessary for the following steps but it may improve the result.

STEP 2: Balance the engine 1 at an engine operating condition at which balancing with a single sensor 6 on the crankshaft is possible.

STEP 3: Balance the sensors 3 in each cylinder 2 at the same operating region as employed in STEP 2. This is achieved by adjusting correction terms for each estimated sensor gain or sensor offset.

STEP 4: Store the correction terms identified in STEP 3.

[0030] These correction terms can now be applied in the whole engine operating range. The procedure has to be repeated periodically in order to compensate for newly introduced imbalance due to aging of the fuel injection equipment and the engine 1.

[0031] In the following, the individual steps cited above are explained in more detail:

STEP 1: Balancing with respect to timing

[0032] Timing information can be extracted from the pressure signal without having a perfect calibration of the sensor 3. This information which describes the location of the combustion relative to crank position could be start of combustion (for instance obtained with the method described in EP 1321655) or peak pressure location; the symbol $\bar{\theta}_i$ shall denote that location for the i-th cylinder.

[0033] The deviation, d_i, for the i-th cylinder from the mean value over n_{cyl} cylinders is calculated as

$$d_i = \bar{\theta}_i - \frac{1}{n_{cyl}} \sum_{k=1}^{n_{cyl}} \bar{\theta}_k \quad . \tag{5}$$

[0034] With an integrating controller, d_i can be used to correct for the imbalance by adjusting start of injection, SOI.

$$\begin{aligned} u_i &= k_I \cdot d_i \\ \mathrm{SOI}_i &= \mathrm{SOI}_{overall} + u_i \end{aligned} \tag{6}$$

where k_I is the integrator gain, $\mathrm{SOI}_{overall}$ is the value coming from the timing strategy and is intended to be applied to all the cylinders, and SOI_i is the corrected value for the i-th cylinder 2.

[0035] In order to improve the precision of this balancing with respect to timing, the number of injections per combustion event could be limited to just one (main injection).

[0036] If start of combustion is controlled directly (rather than start of injection), the cylinders are balanced automatically if the cylinder-individual values are used for control.

STEP 2: Balancing the engine 1 with a single sensor 6

[0037] The usual way to measure an imbalance with a single sensor 6 is to measure engine speed in a small angular window shortly before the combustion in the next cylinder occurs. Engine speed is actually determined by measuring the time it takes for a certain number of flywheel teeth to pass the sensor 6 which detects the edges (e.g., a hall sensor).

[0038] If δt_i is the time measured for the sector associated with the i-th cylinder and $\delta\theta$ is the size of the sector, the engine speed (in rpm) associated with this i-th cylinder is given as

$$N_i = \frac{\delta\theta}{360}\frac{60}{\delta t_i} \quad (7)$$

[0039] As in (5), an imbalance index can be calculated

$$D_i = \left(N_i - \frac{1}{n_{cyl}}\sum_{k=1}^{n_{cyl}} N_k\right)\frac{1}{D_{max}} \quad (8)$$

where D_{max} is used to scale the imbalance index to values between -1 and 1.

[0040] The imbalance index (8) can be used to balance the engine 1 by correcting the main fuel quantity, fq, with, for instance, an I controller.

$$\begin{aligned} u_i &= k_I \cdot D_i \\ \mathrm{fq}_i &= \mathrm{fq}_{\mathrm{overall}} + u_i \end{aligned} \quad (9)$$

where k_1 is negative such that a positive D_i leads to a reduction in fuel.

[0041] This algorithm is just to explain the principle; any other balancing method based on a single sensor 6 could be employed instead (e. g. EP 10 61 246 A2).

STEP 3: Balancing the cylinder-individual sensors 3

[0042] As soon as the imbalance indices D_i calculated in the previous step are below a certain threshold, balancing of the individual sensors 3 can start. Depending on whether the torque acting on the crank shaft 7 or the total amount of fuel burned in each cylinder 2 should be balanced, either the indicated mean effective pressure (IMEP) or the heat release should be calculated as the cylinder-individual balancing criterion.

[0043] IMEP (in bar) is calculated as the integral of pressure times change in cylinder volume over the whole combustion cycle:

$$\mathrm{IMEP} = \frac{1}{V_d}\int_0^{720} p(\theta)\frac{d}{d\theta}V(\theta)d\theta \quad (10)$$

where θ is the crank angle and V_d the engine displacement. When utilizing the voltage signal instead of the pressure, the sensor gain can be taken out of the integral, and the offset, U_{off}, disappears.

$$\mathrm{IMEP} = \frac{1}{V_d S}\int_0^{720} U(\theta)\frac{d}{d\theta}V(\theta)d\theta + \underbrace{\frac{1}{V_d S}\int_0^{720} U_{off}(\theta)\frac{d}{d\theta}V(\theta)d\theta}_{0} \quad (11)$$

[0044] This is also true if IMEP is calculated over the compression and exhaust strokes only (net IMEP instead of gross IMEP). For practical purposes, the integral is approximated with a summation since the pressure signal is sampled.

$$\mathrm{IMEP}_i = \frac{1}{V_d S} \sum_{\substack{k \text{ in} \\ \text{compression and expansion}}} U_i(k) dV(k) \quad (12)$$

[0045] The index i indicates that this is done for each cylinder 2 individually.

[0046] Since U_{off} is eliminated in (11) and (12), there is no need for balancing U_{Off} when the IMEP is used as balancing criterion.

[0047] Alternatively, heat release (in J) can be calculated as an integral involving pressure and cylinder volume from start of combustion (SOC) to end of combustion (EOC) (with heat transfer through the walls being neglected, this is the net heat release):

$$\mathrm{HR} = \frac{c}{\gamma - 1} \int_{\mathrm{SOC}}^{\mathrm{EOC}} \left(\gamma p(\theta) \frac{d}{d\theta} V(\theta) + V(\theta) \frac{d}{d\theta} p(\theta) \right) d\theta \quad (13)$$

where γ is the mean ratio of specific heats and c a constant to convert pressure from bar to Pa. When using voltages, the sensor gain can again be isolated, but the sensor offset does not disappear.

$$\mathrm{HR} = \frac{c}{\gamma - 1} \frac{1}{S} \int_{\mathrm{SOC}}^{\mathrm{EOC}} \left(\gamma (U(\theta) + U_{off}) \frac{d}{d\theta} V(\theta) + V(\theta) \frac{d}{d\theta} U(\theta) \right) d\theta \quad (14)$$

[0048] However, in the crank angle range used for the heat release calculation, U_{Off} is much smaller than U such that the small errors in U_{Off} can be neglected for balancing the sensors with the sensor gain. (Remarks: 1. If U_{Off} was large, the resolution of the pressure measurement would be compromised because most of the input range would be used to cope with the constant U_{Off}. Hence, the sensor will be designed in such a way that U_{Off} is relatively small. Moreover, if SOC and EOC are chosen symmetric with respect to top dead center, the term with U_{Off} vanishes altogether. 2. If the sensor gain is assumed to be known and fixed, then U_{Off} is used to balance the sensor; see below.) Again, the integral is converted to a summation for the actual implementation.

$$\mathrm{HR}_i = \frac{c}{\gamma - 1} \frac{1}{S} \sum_{k \text{ from SOC}}^{\mathrm{EOC}} \left(\gamma (U_i(k) + U_{off}) dV(k) + V(k) dU(k) \right) \quad (15)$$

[0049] As in the previous steps, a deviation can be calculated for either IMEP_i or HR_i.

$$s_i = \left(\mathrm{IMEP}_i - \frac{1}{n_{cyl}} \sum_{k=1}^{n_{cyl}} \mathrm{IMEP}_k \right) \frac{1}{s_{max}} \qquad (16)$$

or

$$s_i = \left(\mathrm{HR}_i - \frac{1}{n_{cyl}} \sum_{k=1}^{n_{cyl}} \mathrm{HR}_k \right) \frac{1}{s_{max}} \qquad (17)$$

where again the scaling S_{max} is used to get numbers between -1 and 1. The imbalance indices s_i are now used to adjust the sensor gain, calculated as described above, until the imbalance indices are sufficiently close to zero. This can again be achieved with an I controller:

$$\begin{aligned} \delta S_i &= k_I s_i \\ S &= \hat{S} + \delta S_i \end{aligned} \qquad (18)$$

where ^S is from (3). The integrator gain, k_I, is positive such that positive s_i lead to an increase in S and hence a decrease in IMEP_i or HR_i.

[0050] If the sensor gain is assumed to be fixed, nothing can (and needs to) be done if the balancing criterion is the IMEP. With heat release, the only parameter to adjust is the sensor offset, U_{Off}. If this can be used (it might be difficult because it is small), the approach can be similar as in (18):

$$\begin{aligned} \delta U_{off,i} &= k_I s_i \\ U_{off} &= \hat{U}_{off} + \delta U_{off,i} \end{aligned} \qquad (19)$$

where k_I is negative such that positive s_i cause U_{off} and hence IMEP_i or HR_i to decrease.

[0051] For the sensor balancing with (18) or (19), the engine 1 needs to stay in the operating range in which balancing with a single sensor 6 is possible. It does not need to be the same operating point (in terms of engine speed and load) for all the duration of the balancing, as long as the adaptations described with respect to STEP 1 and STEP 2 continue to be active.

STEP 4:

[0052] Once all the imbalance indices s_i calculated in the previous step are below a certain threshold, the corrections, δS_i (or $\delta U_{Off,i}$), for the sensor gain (or offset) can be stored and applied throughout the engine operating range. This is done by switching off the single sensor based balancing (9) and using the imbalance indices s_i to adjust fuel:

$$\begin{aligned} u_i &= k_I s_i \\ \mathrm{fq}_i &= \mathrm{fq}_{\mathrm{overall}} + u_i \end{aligned} \qquad (20)$$

where k_I is negative such that positive s_i lead to decreased fueling. In this way, the cylinders can be balanced in the whole engine operating range.

[0053] The whole balancing procedure is activated again if the distance, number of operating hours, or number of combustion cycles since the last sensor balancing exceeds a given threshold. Alternatively, single sensor based balancing may be used whenever the engine is operated under conditions where this is possible, and cylinder-individual sensor based balancing outside.

[0054] The I controllers ((6), (9), (18), (19), (20)) are preferably converted to discrete-time versions for the actual implementation. Moreover, they could be exchanged by more general controllers, such as PID or neural network based controllers for instance.

[0055] Different balancing criteria may be used than those introduced in the previous section. For the single sensor based balancing, it could be the crank shaft torque measured with a torque sensor, or it could be some exhaust gas property, e.g., the air-to-fuel ratio, measured with sufficient temporal resolution to detect differences between the cylinders. For balancing with cylinder-individual sensors 3, other pressure-derived quantities could be used, such as peak pressure or emissions estimates. Or the type of sensors 3 could be changed altogether, to ionization sensors for instance.

[0056] In summary, cylinder-individual sensors 3 need to be used in order to balance the cylinders of a multi-cylinder engine 1 in the whole engine operating range. However, these sensors 3 must be balanced themselves by adjusting their gains or offsets in order to avoid introducing imbalance in the engine operation due to imbalanced sensors 3. The cylinder-individual sensors 3 are balanced by balancing the engine 1 with a single sensor 6 in the operating region where this is possible and then adapting the sensor gains or offset to get balanced readings from the cylinder-individual sensors 3. Once this has been done, the engine 1 can be balanced in the whole operating range.

[0057] Two possibilities for balancing the engine 1 with in-cylinder pressure sensors 3 were described in detail. Either the indicated mean effective pressure (IMEP) is calculated for each cylinder 2 and balanced, or cylinder-individual heat release is used for balancing. The first option stresses the torque experienced by the crank shaft and thus is preferred to reduce vibrations. The second option is more linked to the amount of fuel burned in each cylinder 2, and thus tends to balance the emissions - assuming equal distribution of recirculated exhaust gas.

Notation

[0058]

Variable	Unit	Description
c	Pa/bar	constant to convert pressure from bar to Pa
d_i	°	imbalance index for timing (i^{th} cylinder)
D_i	-	(normalized) imbalance index for engine speed (i^{th} cylinder)
D_{max}	rpm	scaling
EOC	°	end of combustion
fq_i	mg/st	fuel quantity for i^{th} cylinder
$fq_{overall}$	mg/st	fuel quantity
k	-	index
k_I	1/s	integrator gain
IMEP	bar	indicated mean effective pressure
$IMEP_i$	bar	indicated mean effective pressure for the i^{th} cylinder
n_{cyl}	-	number of cylinders
N_i	rpm	local engine speed (i^{th} cylinder)
p	bar	in-cylinder pressure
p_0	bar	reference pressure
p_1, p_2	bar	pressure at two crank angle positions
p_i	bar	intake manifold pressure
r_T	-	ratio of in-cylinder temperatures at two crank angle positions
r_V	-	ratio of cylinder volumes at two crank angle positions
S	V/bar	sensor gain
$\hat{S}$	V/bar	estimated sensor gain
S_i	V/bar	sensor gain of the i^{th} cylinder
s_i	-	(normalized) imbalance index for IMEP or heat release (i^{th} cylinder)
s_{max}	bar or J	scaling

(continued)

Variable	Unit	Description
SOC	°	start of combustion
SOI_i	°	start of injection for i^{th} cylinder
$SOI_{overall}$	°	start of injection
T_1, T_2	K	in-cylinder temperatures at two crank angle positions
u_i		intermediate variable for I controllers
U	V	voltage signal from the in-cylinder pressure sensor
U_0	V	reference voltage
U_1, U_2	V	voltage from the pressure sensor at two crank angle positions
U_{off}	V	sensor offset
V	m^3	cylinder volume
V_1, V_2	m^3	cylinder volumes at two crank angle positions
V_d	m^3	engine displacement
α	-	correction factor
γ	-	ratio of specific heats
δS_i	V/bar	correction term for the sensor gain (i^{th} cylinder)
δt_i	s	time measured for the sector (i^{th} cylinder)
$\delta U_{off.i}$	V	correction term for the sensor offset (i^{th} cylinder)
$\delta\theta$	°	crank angle sector for measuring local engine speed
θ	°	crank angle
$\bar{\theta}_i$	°	timing information for the i^{th} cylinder

Claims

1. Method for balancing the cylinders (2) of an internal combustion engine (1) which are equipped with individual cylinder sensors (3), wherein the properties of the cylinder sensors (3) are balanced with respect to each other,
characterized in that
the properties of the cylinder sensors (3) are balanced by comparison with a single engine sensor (6) which monitors all cylinders (2).

2. Method according to claim 1,
characterized in that
the balancing of the properties of the sensors (3) is achieved by adapting their individual gain and/or offset.

3. Method according to claim 1 or 2,
characterized in that
the single engine sensor (6) which monitors all cylinders (2) is a crankshaft sensor.

4. Method according to one of claims 1 to 3,
characterized in that

   a) the engine sensor (6) is used to balance the internal combustion engine (1) first;
   b) the balanced run of the internal combustion engine (1) is then used to balance the properties of the cylinder sensors (3) with respect to each other.

5. Method according to claim 4,
characterized in that
the properties of the sensors (3) are balanced with respect to the indicated mean effective pressure of the cylinders (2).

6. Method according to claim 4,
characterized in that
the properties of the sensors (3) are balanced with respect to heat release during combustion in the cylinders (2).

7. Method according to one of claims 1 to 6,
characterized in that
the balancing of the properties of the sensors (3) is repeated if given criteria are fulfilled, preferably if a threshold for the distance, time and/or number of operating cycles is reached.

8. System for balancing the cylinders (2) of an internal combustion engine (1), comprising

a) at least one cylinder sensor (3) in each of the cylinders (2) for monitoring the combustion process;
b) an engine sensor (6) which monitors all cylinders (2);
c) a control unit (5) that is coupled to the cylinder sensors (3) and the engine sensor (6) and that is adapted to balance the properties of the cylinder sensors with respect to each other by comparison with the engine sensor (6).

9. System according to claim 8,
characterized in that
the cylinder sensors comprise a pressure sensor (3).

10. System according to claim 8 or 9,
characterized in that
the engine sensor is a crankshaft sensor (6).

Patentansprüche

1. Verfahren zum Abgleichen der Zylinder (2) eines Verbrennungsmotors (1), welche mit einzelnen Zylindersensoren (3) ausgerüstet sind, wobei die Eigenschaften der Zylindersensoren (3) miteinander abgeglichen werden,
dadurch gekennzeichnet, dass
die Eigenschaften der Zylindersensoren (3) durch Vergleich mit einem einzelnen Motorsensor (6) abgeglichen werden, welcher alle Zylinder (2) überwacht.

2. Verfahren gemäß Anspruch 1,
dadurch gekennzeichnet, dass
das Abgleichen der Eigenschaften der Sensoren (3) durch Anpassen ihres individuellen Zuwachses und/oder Versatzes erzielt wird.

3. Verfahren gemäß Anspruch 1 oder 2,
dadurch gekennzeichnet, dass
der einzelne Motorsensor (6), welcher alle Zylinder (2) überwacht, ein Kurbelwellensensor ist.

4. Verfahren gemäß einem der Ansprüche 1 bis 3,
dadurch gekennzeichnet, dass

a) der Motorsensor (6) verwendet wird, um den Verbrennungsmotor (1) zuerst abzustimmen;
b) der abgeglichen Lauf des Verbrennungsmotors (1) dann verwendet wird, um die Eigenschaften der Zylindersensoren (3) in Bezug auf einander abzugleichen.

5. Verfahren gemäß Anspruch 4,
dadurch gekennzeichnet, dass
die Eigenschaften der Sensoren (3) in Bezug auf den gekennzeichneten mittleren Wirkdruck der Zylinder (2) abgeglichen werden.

6. Verfahren gemäß Anspruch 4,
dadurch gekennzeichnet, dass
die Eigenschaften der Sensoren (3) in Bezug auf Wärmefreisetzung während der Verbrennung in den Zylindern (2) abgeglichen werden.

7. Verfahren gemäß einem der Ansprüche 1 bis 6,
dadurch gekennzeichnet, dass

das Abgleichen der Eigenschaften der Sensoren (3) wiederholt wird, wenn gegebene Kriterien erfüllt sind, vorzugsweise wenn ein Schwellenwert für den Abstand, die Zeit und/oder die Anzahl der Arbeitszyklen erreicht ist.

8. System zum Abgleichen der Zylinder (2) eines Verbrennungsmotors (1), umfassend

a) wenigstens einen Zylindersensor (3) in jedem der Zylinder (2) zum Überwachen des Verbrennungsprozesses;
b) einen Motorsensor (6), welcher alle Zylinder (2) überwacht;
c) eine Steuereinheit (5), welche mit den Zylindersensoren (3) und dem Motorsensor (6) gekoppelt ist und welche ausgelegt ist, um die Eigenschaften der Zylindersensoren in Bezug auf einander durch Vergleich mit dem Motorsensor (6) abzugleichen.

9. System gemäß Anspruch 8,
dadurch gekennzeichnet, dass
die Zylindersensoren einen Drucksensor (3) umfassen.

10. System gemäß Anspruch 8 oder 9,
dadurch gekennzeichnet, dass
der Motorsensor ein Kurbelwellensensor (6) ist.

Revendications

1. Procédé pour équilibrer les cylindres (2) d'un moteur à combustion interne (1) qui sont équipés de capteurs de cylindre individuels (3), dans lequel les propriétés des capteurs de cylindre (3) sont équilibrées les unes par rapport aux autres, **caractérisé en ce que** les propriétés des capteurs de cylindre (3) sont équilibrées par comparaison avec un seul capteur de moteur (6) qui surveille tous les cylindres (2).

2. Procédé selon la revendication 1, **caractérisé en ce que** l'équilibrage des propriétés des capteurs (3) est réalisé en adaptant leur gain et/ou leur décalage individuel.

3. Procédé selon la revendication 1 ou 2, **caractérisé en ce que** le seul capteur de moteur (6) qui surveille tous les cylindres (2) est un capteur de vilebrequin.

4. Procédé selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que**:

a) le capteur de moteur (6) est utilisé pour équilibrer d'abord le moteur à combustion interne (1);
b) la marche équilibrée du moteur à combustion interne (1) est alors utilisée pour équilibrer les propriétés des capteurs de cylindre (3) les unes par rapport aux autres.

5. Procédé selon la revendication 4, **caractérisé en ce que** les propriétés des capteurs (3) sont équilibrées par rapport à la pression effective moyenne indiquée des cylindres (2).

6. Procédé selon la revendication 4, **caractérisé en ce que** les propriétés des capteurs (3) sont équilibrées par rapport au dégagement de chaleur pendant la combustion dans les cylindres (2).

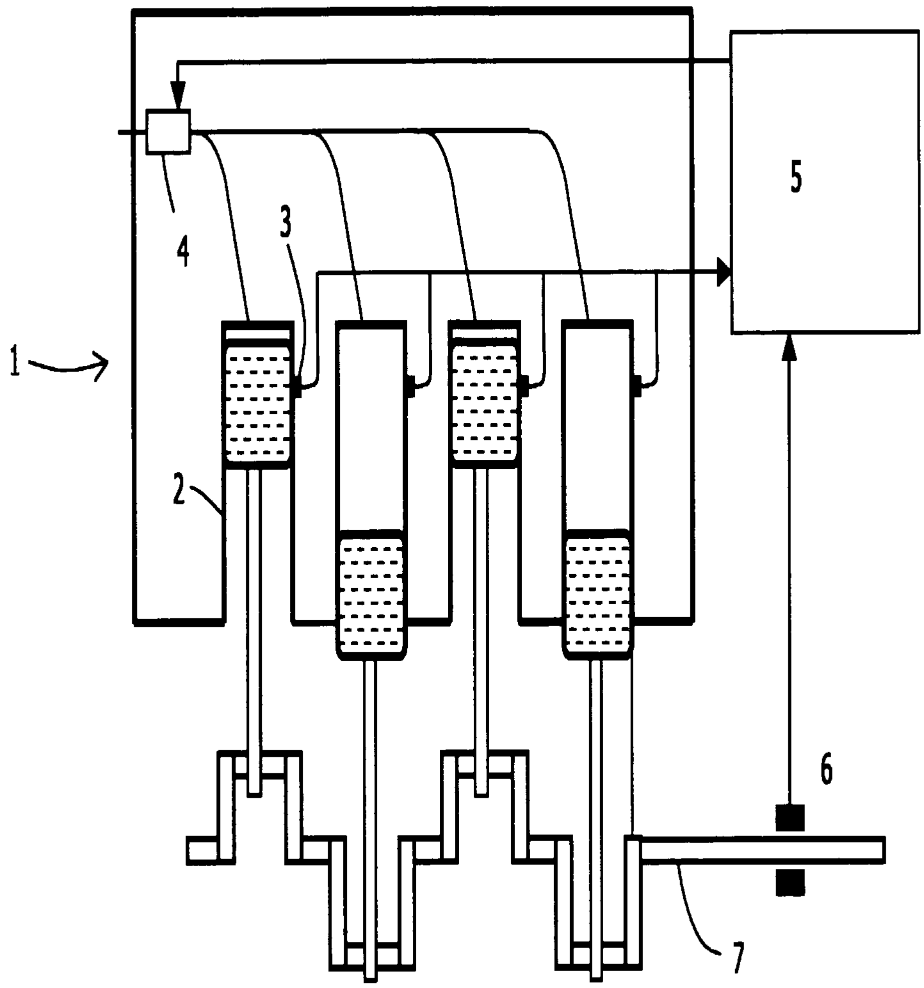
7. Procédé selon l'une quelconque des revendications 1 à 6, **caractérisé en ce que** l'équilibrage des propriétés des capteurs (3) est répété si des critères donnés sont remplis, de préférence si un seuil pour la distance, la durée et/ou le nombre de cycles opératoires est atteint.

8. Système pour équilibrer les cylindres (2) d'un moteur à combustion interne (1), comprenant:

a) au moins un capteur de cylindre (3) dans chacun des cylindres (2) pour surveiller le processus de combustion;
b) un capteur de moteur (6) qui surveille tous les cylindres (2); et
c) une unité de commande (5) qui est couplée aux capteurs de cylindre (3) et au capteur de moteur (6) et qui est adaptée pour équilibrer les propriétés des capteurs de cylindre les unes par rapport aux autres par comparaison avec le capteur de moteur (6).

9. Système selon la revendication 8, **caractérisé en ce que** les capteurs de cylindre comprennent un capteur de pression (3).

10. Système selon la revendication 8 ou 9, **caractérisé en ce que** le capteur de moteur est un capteur de vilebrequin (6).


1
2
3
4
5
6
7

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 1020629 A2 **[0003]**
- EP 1061246 A2 **[0003] [0041]**
- WO 2004022951 A1 **[0006]**
- EP 411580 A1 **[0006]**
- US 4744244 A **[0006]**
- EP 01130557 A **[0029]**
- EP 1321655 A **[0032]**