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

(11) EP 1 736 656 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
27.12.2006 Bulletin 2006/52

(51) Int Cl.:
F02D 41/34 *(2006.01)* ***F02D 35/02*** *(2006.01)*
G01L 23/30 *(2006.01)*

(21) Application number: **05105668.7**

(22) Date of filing: **24.06.2005**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR LV MK YU

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(54) Method for determining and regulating the crank angle position of a crankshaft of a four-stroke internal combustion engine

(57) The present invention relates to a method for determining and regulating the crank angle position of a crankshaft of a four-stroke internal combustion engine with at least one cylinder which is controlled by an engine control unit (ECU), comprising the following steps

■ ascertaining the crank angle of the crankshaft by means of a crankshaft sensor, which scans the crankshaft, in particular a toothed wheel attached to the crankshaft,
■ determining the present phase of the respective operation cycle of said at least one cylinder by using at least one second sensor in order to distinguish between gas inlet and expansion stroke or gas outlet and compression stroke, and
■ synchronising the engine if necessary.

It is the objective of the present invention to provide a method of the above mentioned kind which does not require fuelling the engine during the synchronization procedure.

With respect to the objective a method is provided comprising the following steps:
■ using at least one pressure sensor as said at least one second sensor which is capable of detecting directly or indirectly a change of the in-cylinder pressure, in particular a rise of the in-cylinder pressure,
■ measuring at least once the output signal $p_{Sensor,A}$ of said at least one pressure sensor in a first crank angle domain comprising the top dead centre (TDC),
■ measuring at least once the output signal $p_{Sensor,B}$ of the at least one pressure sensor in a second crank angle domain spaced apart from said first crank angle domain ,
■ calculating the expression p = pSensor,A - $P_{Sensor,B}$,
■ comparing p with a predetermined threshold $P_{threshold}$,
■ synchronizing the engine by shifting the output signal of the ECU for injection and/or ignition by 360°CA forwards or backwards, if

$p \leq p_{threshold}$

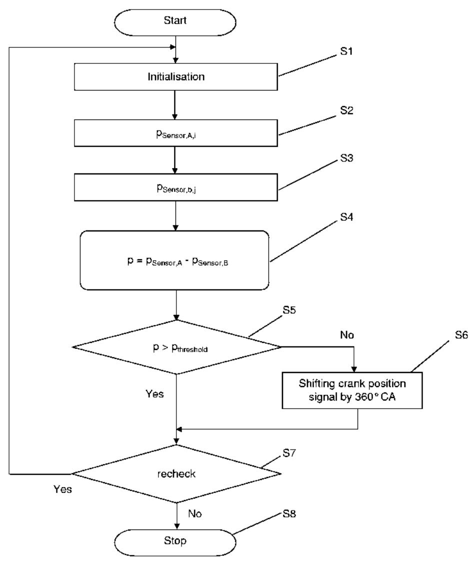

Fig. 2

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Description

[0001] The present invention relates to a method for determining and regulating the crank angle position of a crankshaft of a four-stroke internal combustion engine with at least one cylinder which is controlled by an engine control unit (ECU), comprising the following steps:

- ascertaining the crank angle of the crankshaft by means of a crankshaft sensor, which scans the crankshaft, in particular a toothed wheel attached to the crankshaft, and
- determining the present phase of the respective operation cycle of said at least one cylinder by using at least one second sensor in order to distinguish between gas inlet and expansion stroke or gas outlet and compression stroke.

[0002] In general a combustion cycle, i.e., operation cycle of a modern internal combustion engine comprises four strokes, namely gas inlet, compression, expansion and gas outlet, so that the engine operates in a so-called four-stroke combustion mode. In this mode the crankshaft rotates twice during one combustion cycle or in other words, one cycle amounts to 720° CA (crank angle). The combination of gas outlet and gas inlet forms together the gas exchange phase, whereas the two strokes compression together with subsequent expansion form the combustion phase.

[0003] For engine operation it is necessary to provide the engine control unit (ECU) with information about the crankshaft position in order to determine the injection timing and/or spark ignition timing. Usually the crank angle of the crankshaft is ascertained by means of a so-called crankshaft sensor, which scans the crankshaft, or a transductor disk with a characteristic surface that is connected to the crankshaft, for example a toothed wheel attached to the crankshaft.

[0004] But it is not sufficient to detect the crank angle position, because - as mentioned above - the crankshaft passes every crank angle position twice during one cycle, so that the engine control unit (ECU) further has to be provided with more detailed information, i.e., if the respective cylinder operates in the gas exchange phase or if the cylinder operates within the compression/expansion strokes, i.e., within the combustion phase. Otherwise the phase relationship could be wrong resulting in the undesired operation error that injection and/or ignition occurs within the gas exchange phase.

[0005] For this it is necessary to equip the engine with additional means for determining the absolute crankshaft position within an operation cycle. According to the state of the art a second sensor is used for this purpose.

[0006] One possibility for such a second sensor is a so-called camshaft sensor. Said camshaft sensor scans a transductor disk with a characteristic surface that is connected to the camshaft, for example a toothed wheel attached to the camshaft. In contrary to the crankshaft movement a camshaft revolution takes 720° CA (crank angle), so that the camshaft rotates with half engine speed.

[0007] By using a camshaft sensor it is possible to determine the angle position of the camshaft and by this it is possible to derive the required absolute crankshaft position, i.e., the crank angle, which ranges between 0 and 360° CA, and the phase, i.e., if the engine operates in the gas exchange phase or in the combustion phase. If the phase is incorrect a transposition of 360° CA takes place. The engine control unit (ECU) shifts the output signal for injection and/or ignition 360° CA forwards or backwards in order to synchronize the engine operation, i. e., to synchronise the crank angle position with injection timing and/or ignition timing. Although the absolute crank angle position of the crankshaft actually could be determined by sole usage of a camshaft sensor, a crankshaft sensor is used in addition because due to the higher number of revolutions the resolution is considerably higher.

[0008] An alternative sensor to the camshaft sensor is disclosed in the European patent EP 1 129 280 B1. According to the method described in EP 1 129 280 B1 used for detecting and influencing the phase position of an internal combustion engine a fuel rail sensor is used as second sensor.

[0009] The suggested method uses the effect that in a direct injection engine the fuel rail pressure is influenced by the in-cylinder pressure, because gas from the combustion chamber is forced back into the injection nozzles and the fuel rail during the injection when the nozzles are opened. The in-cylinder pressure influences the fuel rail pressure while fuel injection duration.

[0010] If the phase relationship is incorrect by 360° CA the engine control unit (ECU) - for example - delivers the injection command during the expansion stroke and not during the gas inlet as usual. The increased in-cylinder pressure leads to a pressure increase in the fuel rail resulting from the blowback caused by the in-cylinder counter pressure which forces gas into the injection valves and the fuel rail. The fuel pressure increase is detected by the fuel rail sensor and used by the engine control unit (ECU) for synchronization. If the phase relationship is incorrect by 360° CA the synchronization is realized by shifting the injection timing and/or ignition timing 360° CA forwards or backwards.

[0011] By using a fuel sensor the above described and well known camshaft sensor becomes obsolete, so that the costs for the engine management system can be lowered. But due to the fact that a fuel rail sensor is used, the described method requires to fuel the engine during synchronization, i.e., the method suggested in EP 1 129 280 B1 requires to open the injection nozzles to connect the fuel rail with the combustion chamber and to give the in-cylinder pressure the opportunity to influence fuel rail pressure during fuel injection.

[0012] The possible misfire of the engine due to an incorrect phase may result in an undesired exhaust emission increase, in particular unburned hydrocarbons, and furthermore a noise penalty.

[0013] Another method which enables to eliminate the camshaft sensor is disclosed in US 5,067,462. According to the method described in US 5,067,462 the output of an ionization current detector for detecting the ionization current across a spark is used as second sensor. For a short period after the start of the engine, the group of cylinders in the gas exchange phase and the group of cylinders in the compression stroke are ignited simultaneously. During this short period, the cylinders in the compression stroke are discriminated from the group of cylinders in the gas exchange phase, on the basis of the output of the ionization current detector, and the number of successive discriminations of the cylinders in the compression stroke is counted. When the counts reaches a predetermined value only the cylinder in the compression stroke is supplied with the ignition current thereafter.

[0014] The application of this method is restricted to spark-ignited engines because the synchronization based on a signal of an ionization current detector which detects the ionization current across the spark. Another disadvantage could be seen in the requirement of fuelling and sparking the engine during synchronization resulting in undesired misfiring if the phase is incorrect by 360° CA. As mentioned above already misfiring leads to an increase in exhaust and noise emissions.

[0015] With respect to this it is an objective of the present invention to provide a method for determining and regulating the crank angle position of a crankshaft of a four-stroke internal combustion engine according to the preamble of claim 1, which overcomes the problems known from the state of the art, making a camshaft sensor obsolete and in particular does not require fuelling the engine during the synchronization procedure.

[0016] According to the present invention and with respect to the objective to be solved, a method is provided for determining and regulating the crank angle position of a crankshaft of a four-stroke internal combustion engine with at least one cylinder which is controlled by an engine control unit (ECU), comprising the following steps:

- ascertaining the crank angle of the crankshaft by means of a crankshaft sensor, which scans the crankshaft, in particular a toothed wheel attached to the crankshaft, and
- determining the present phase of the respective operation cycle of said at least one cylinder by using at least one second sensor in order to distinguish between gas inlet and expansion stroke or gas outlet and compression stroke, i.e., between gas exchange phase and combustion phase,

and which is characterized in that

- using at least one pressure sensor as said at least one second sensor which is capable of detecting directly or indirectly a change of the in-cylinder pressure of said at least one cylinder, in particular a rise of the in-cylinder pressure,
- measuring at least once the output signal $p_{Sensor,A}$ of said at least one pressure sensor in a first crank angle domain comprising the top dead centre (TDC),
- measuring at least once the output signal $p_{Sensor,B}$ of the at least one pressure sensor in a second crank angle domain spaced apart from said first crank angle domain
- calculating the expression $p = p_{Sensor,A} - p_{Sensor,B}$,
- comparing p with a predetermined threshold $p_{threshold}$,
- synchronizing the engine by shifting the output signal of the ECU for injection and/or ignition by 360° CA forwards or backwards, i.e., shifting the crank position signal by 360°CA, if

$p \leq p_{threshold}$

[0017] The present invention, i.e., the inventive method neither is restricted to spark-ignited engines nor to diesel engines and could also be used for modern hybrid combustion processes.

[0018] In contrast to the conventional methods described in US 5,067,462 and in EP 1 129 280 B1 the inventive method does not require to fuel and/or spark the engine during synchronization.

[0019] By using at least one pressure sensor as second sensor in order to distinguish between gas inlet and expansion stroke or gas outlet and compression stroke undesired exhaust emissions caused by misfiring are prevented, in particular the emission of unburned hydrocarbons. Furthermore the noise behaviour is improved.

[0020] The pressure change in the combustion chamber caused by the piston movement of the respective engine cylinder is sufficient to determine the present phase, i.e., the present stroke of the operation cycle under consideration. The obsolete fuelling results in a considerable advantage with respect to exhaust and noise emissions in comparison to the conventional methods, in particular during a cold start procedure while the cold engine is cranked — for example - by a starter motor or the like, because the emissions of unburned hydrocarbons have to be considered as the most relevant emissions during cold start procedure.

[0021] As mentioned above one operation cycle covers 720° CA , so that the crankshaft passes every crank angle position twice during one cycle. Consequently one cycle comprises the top dead centre position twice, i.e., the piston of the at least one cylinder reaches the top dead centre twice, once during the gas exchange phase and for a second time during the combustion phase. Because of this it is preferred to measure the output signal $p_{Sensor,A}$ near the top dead centre (TDC) which is assumed to be the TDC within the combustion phase.

[0022] Preferred embodiments of the invention are specified in the dependent claims and are described in the following.

[0023] A preferred embodiment of the method is characterized in that

- said output signal $p_{Sensor,A,i}$ of said at least one pressure sensor is measured n_A times in said first crank angle domain with $n_A \geq 2$,
- said at least two output signals $p_{Sensor,A,i}$ are averaged for further processing.

[0024] The measurement of more than one pressure signal $p_{Sensor,A,i}$ and the subsequent averaging of these signal values is carried out with the purpose to achieve a higher accuracy in the sensor output signal by rejecting the noise on the measured signals.

[0025] Due to the same reason a preferred embodiment of the method is characterized in that

- said output signal $p_{Sensor,B,j}$ of said at least one pressure sensor is measured n_B times in said second crank angle domain with $n_B \geq 2$, and
- said at least two output signals $p_{Sensor,B,j}$ are averaged for further processing.

[0026] A preferred embodiment of the method is characterized in that said first crank angle domain and/or said second crank angle domain are/is predetermined in such a way, that said domain covers 60° CA or less, preferably said domain covers 40° CA or less.

[0027] A preferred embodiment of the method is characterized in that said first crank angle domain and/or said second crank angle domain are/is predetermined in such a way, that said domain covers 20° CA or less.

[0028] A small domain is preferred because the measurement of said at least one output signal $p_{Sensor,A}$ takes place more or less in the neighbourhood of the top dead centre (TDC), where the pressure gradient reaches the maximum during compression and expansion. If several signals are measured for generating an averaged signal value a wide domain results in a couple of values which differs strongly in their magnitude.

[0029] A preferred embodiment of the method is characterized in that said first crank angle domain and said second crank angle domain are spaced apart in such a way, that the separation distance $_{sep}$ between both domains is greater than 20° CA, i.e., $_{sep} > 20$ ° CA.

[0030] A preferred embodiment of the method is characterized in that said first crank angle domain and said second crank angle domain are spaced apart in such a way, that the separation distance $_{sep}$ between both domains is greater than 60° CA, i.e., $_{sep} > 60$ ° CA.

[0031] The chosen magnitude of said separation distance $_{sep}$ depends on the noise on said measured signals. It has to take into account that the output signals created for both domains are used for calculating the expression $p = p_{Sensor,A} - p_{Sensor,B}$. If the chosen separation distance $_{sep}$ is too small it may happen that there is no measurable, i.e., meaningful difference p due to signal noise. In this case no reliable data is available to decide if the engine is in phase or has to be synchronized by shifting the output signal of the ECU for injection and/or ignition 360° CA forwards or backwards.

[0032] The magnitude of the separation distance $_{sep}$ in question also depends on the specific sensor used for measuring. An example for a pressure sensor which is capable of detecting indirectly a change of the in-cylinder pressure is a structure-borne noise sensor which is well known. According to the state of the art such a sensor is often applied for acoustic investigations evaluating the noise, vibration and harshness behaviour of an engine. A structure-borne noise sensor can also be used as knock sensor for a gasoline engine. If such a sensor is already arranged at the engine for other purposes the inventive method could make use of this sensor, so that is is not necessary to provide an additional sensor. This measure helps to lower the total costs of the engine management system.

[0033] An example for a pressure sensor which is capable of detecting directly a change of the in-cylinder pressure is an in-cylinder pressure sensor which is a common component in modern engine management systems. Such a sensor often uses a piezoelectric element from which the electric resistance depends on the exterior pressure affecting the element.

[0034] If the noise on the measured signals is low said separation distance $_{sep}$ can be chosen smaller.

[0035] A preferred embodiment of the method is characterized in that said first crank angle domain and said second crank angle domain are spaced apart in such a way, that the separation distance $_{sep}$ between both domains is smaller than 270° CA, i.e., $_{sep} < 270$° CA.

[0036] The separation distance $_{sep}$ should be capped, because if the separation distance $_{sep}$ is chosen too great on the one side it can happen that the second crank angle domain closes on the first crank angle domain on the other side. For instance, if $_{sep} = 360$° CA and the both domains cover 100° CA or more, the second domain could reach deep into the compression stroke or expansion stroke in which the first domain is located.

[0037] A preferred embodiment of the method is characterized in that said threshold $p_{threshold}$ is predetermined with $p_{threshold} > 5$ bar, preferably with $p_{threshold} > 10$ bar. In general the magnitude of the threshold depends on the chosen separation distance $_{sep}$ and the location of both domains. The threshold has to be as high as required for rejecting the present signal noise.

[0038] One embodiment of the present invention will be described below with reference to the Figures 1a, 1b and 2:

Figure 1a shows schematically a pressure sensor output against crank angle (°CA) for the case where the crankshaft position signal is out-of-phase,

Figure 1b shows schematically a pressure sensor output against crank angle (°CA) for the case where the crankshaft position signal is in-phase, and

Figure 2 shows the flow diagram of an embodiment according to the invention.

[0039] Figure 1a illustrates schematically a pressure sensor output signal against crank angle (°CA) for the case where the crankshaft position signal is out-of-phase. As can be seen the top dead centre assumed to be the top dead centre within the combustion phase comprising compression and expansion stroke is in fact the top dead centre of the gas exchange phase. The crank position signal needs to be shifted by 360° CA.

[0040] In the following the application of the inventive method will be demonstrated on the basis of an out-of-phase situation.

[0041] A pressure sensor is used which is capable of detecting directly or indirectly a change of the pressure in the combustion chamber. By means of said sensor the output signal $p_{Sensor,A}$ in a first crank angle domain comprising the assumed top dead centre (TDC) is measured and stored. It is preferred to measure said output signal $p_{Sensor,A,i}$ two times or more often, i.e., n_A times with $n_A \geq 2$. The at least two output signals $p_{Sensor,A,i}$ are averaged for further processing in order to reject the signal noise and receive a more meaningful signal value.

[0042] In a further step the output signal $p_{Sensor,B,j}$ is measured also in a second crank angle domain spaced apart from the first crank angle domain and stored. According to the embodiment shown in Figure 1 a both crank angle domains , cover 90°CA whereas the separation distance $_{sep}$ between both domains is set to 90° CA, i.e., $_{sep}$ = 90 ° CA.

[0043] The sensor output signals $p_{Sensor,A}$ and $p_{Sensor,B}$ are used to calculate the expression:

$$p = p_{Sensor,A} - p_{Sensor,B}$$

which is compared with a predetermined threshold $p_{threshold}$. Obviously the engine has to be synchronized because p is negative and the following in equation is fulfilled:

$$p \leq p_{threshold}$$

[0044] Synchronization is realized by shifting the output signal of the ECU for injection and/or ignition 360° CA forwards or backwards, i.e., the crank angle position signal needs to be shifted by 360 °CA.

[0045] Figure 1b illustrates schematically a pressure sensor output signal against crank angle (°CA) for the case where the crankshaft position signal is in-phase. As can be seen the assumption of the top dead centre within the combustion phase is right. The crank position signal does not need to be shifted, because the crank position signal is in-phase with the pressure signal. Concerning the application of the inventive method in detail it is referred to Figure 1 a.

[0046] As can be seen $p > p_{threshold}$ if the threshold is chosen correctly, i.e., not to high. It is not necessary to synchronise the engine by shifting the crank position signal.

[0047] Figure 2 shows the flow diagram of an embodiment according to the invention.

[0048] In a first step S1 initialisation takes place. For example n_A and n_B are set to 10, i.e., the output signals $p_{Sensor,A,i}$ and $p_{Sensor,B,j}$ are measured ten times in both crank angle domains , and averaged for further processing (S2 and S3).

[0049] Both signal values $p_{Sensor,A}$ and $p_{Sensor,B}$ are used within a fourth step S4 to calculate the expression:

$$p = p_{Sensor,A} - p_{Sensor,B}$$

[0050] The result p is compared with a predetermined threshold $p_{threshold}$ in a fifth step S5.

[0051] If

$$p > p_{threshold}$$

the pressure signal and the crank position signal are in-phase and within step S7 is has to decided if the result has to be verified. Otherwise if

$$p \leq p_{threshold}$$

the crank position signal needs to be shifted by 360° CA for synchronizing the engine (S6). Afterwards within step S7 is has to decided if the result has to be verified.

[0052] If no verification is carried out the algorithm is terminated in step S8.

Reference signs

[0053]

CA	first crank angle domain second crank angle domain crank angle
ECU	engine control unit
i	number of the specific measurement in the first domain

j	number of the specific measurement in the second domain
nA	total number of measurements in the first crank angle domain
nB	total number of measurements in the second crank angle domain
sep	separation distance between both domains
$p_{Sensor,A}$ domain	output signal of the at least one second sensor within the first
$p_{Sensor,B}$ domain	output signal of the at least one second sensor within the first
$p_{threshold}$	threshold
TDC	top dead centre

Claims

1. A method for determining and regulating the crank angle position of a crankshaft of a four-stroke internal combustion engine with at least one cylinder which is controlled by an engine control unit (ECU), comprising the following steps:

   ■ ascertaining the crank angle of the crankshaft by means of a crankshaft sensor, which scans the crankshaft, in particular a toothed wheel attached to the crankshaft, and
   ■ determining the present phase of the respective operation cycle of said at least one cylinder by using at least one second sensor in order to distinguish between gas inlet and expansion stroke or gas outlet and compression stroke,

   characterized in that

   ■ using at least one pressure sensor as said at least one second sensor which is capable of detecting directly or indirectly a change of the in-cylinder pressure, in particular a rise of the in-cylinder pressure,
   ■ measuring at least once the output signal $p_{Sensor,A}$ of said at least one pressure sensor in a first crank angle domain comprising the top dead centre (TDC),
   ■ measuring at least once the output signal $p_{Sensor,B}$ of the at least one pressure sensor in a second crank angle domain spaced apart from said first crank angle domain
   ■ calculating the expression $p = p_{Sensor,A} - p_{Sensor,B}$,
   ■ comparing p with a predetermined threshold $p_{threshold}$,
   ■ synchronizing the engine by shifting the output signal of the ECU for injection and/or ignition by 360° CA forwards or backwards, if

$$p \leq p_{threshold}$$

2. A method according to claim 1, **characterized in that**

   ■ said output signal $p_{Sensor,A,i}$ of said at least one pressure sensor is measured n_A times in said first crank angle domain with $n_A \geq 2$,
   ■ said at least two output signals $p_{Sensor,A,i}$ are averaged for further processing.

3. A method according to claim 1 or 2, **characterized in that**

   ■ said output signal $p_{Sensor,B,j}$ of said at least one pressure sensor is measured n_B times in said second crank angle domain with $n_B \geq 2$, and
   ■ said at least two output signals $p_{Sensor,B,j}$ are averaged for further processing.

4. A method according to any of the preceding claims, **characterized in that** said first crank angle domain and/or said second crank angle domain are/is predetermined in such a way, that said domain covers 60° CA or less.

5. A method according to any of the preceding claims, **characterized in that** said first crank angle domain and/or said second crank angle domain are/is predetermined in such a way, that said domain covers 40° CA or less.

6. A method according to any of the preceding claims, **characterized in that** said first crank angle domain and/or said second crank angle domain are/is predetermined in such a way, that said domain covers 20° CA or less.

7. A method according to any of the preceding claims, **characterized in that** said first crank angle domain and said second crank angle domain are spaced apart in such a way, that the separation distance $_{sep}$ between both domains is greater than 20° CA, i.e., $_{sep} > 20°$ CA.

8. A method according to any of the preceding claims, **characterized in that** said first crank angle domain and said second crank angle domain are spaced apart in such a way, that the separation distance $_{sep}$ between both domains is greater than 60° CA, i.e., $_{sep} > 60°$ CA.

9. A method according to any of the preceding claims, **characterized in that** said first crank angle domain and said second crank angle domain are spaced apart in such a way, that the separation distance $_{sep}$

between both domains is smaller than 270° CA, i.e., $_{sep}$ < 270° CA.

10. A method according to any of the preceding claims, **characterized in that** said threshold $p_{threshold}$ is predetermined with $p_{threshold} > 5$ bar, preferably with $p_{threshold} > 10$ bar.

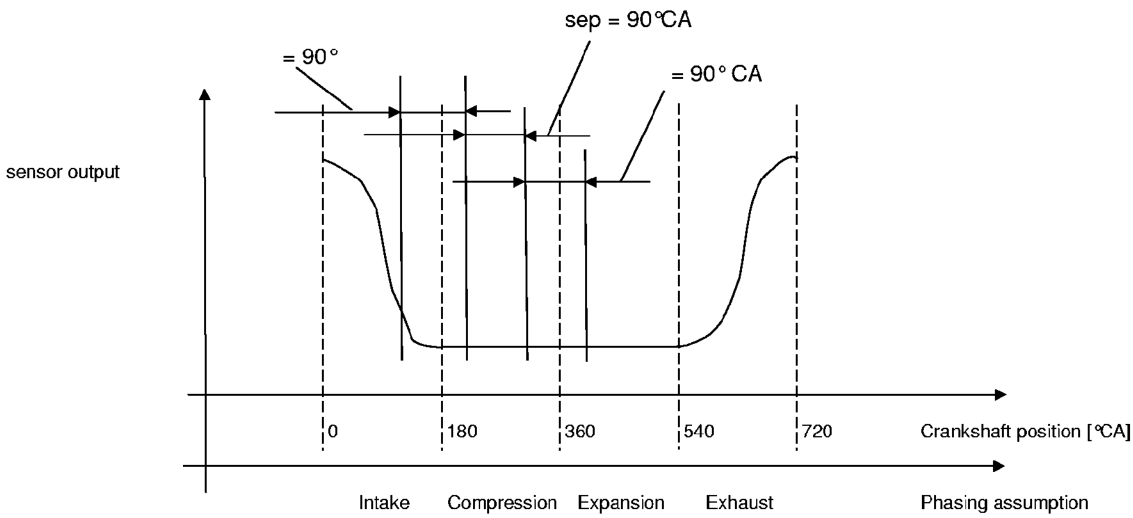
sep = 90°CA
= 90°
= 90° CA
sensor output
0
180
360
540
720
Crankshaft position [°CA]
Intake
Compression
Expansion
Exhaust
Phasing assumption

Fig. 1a

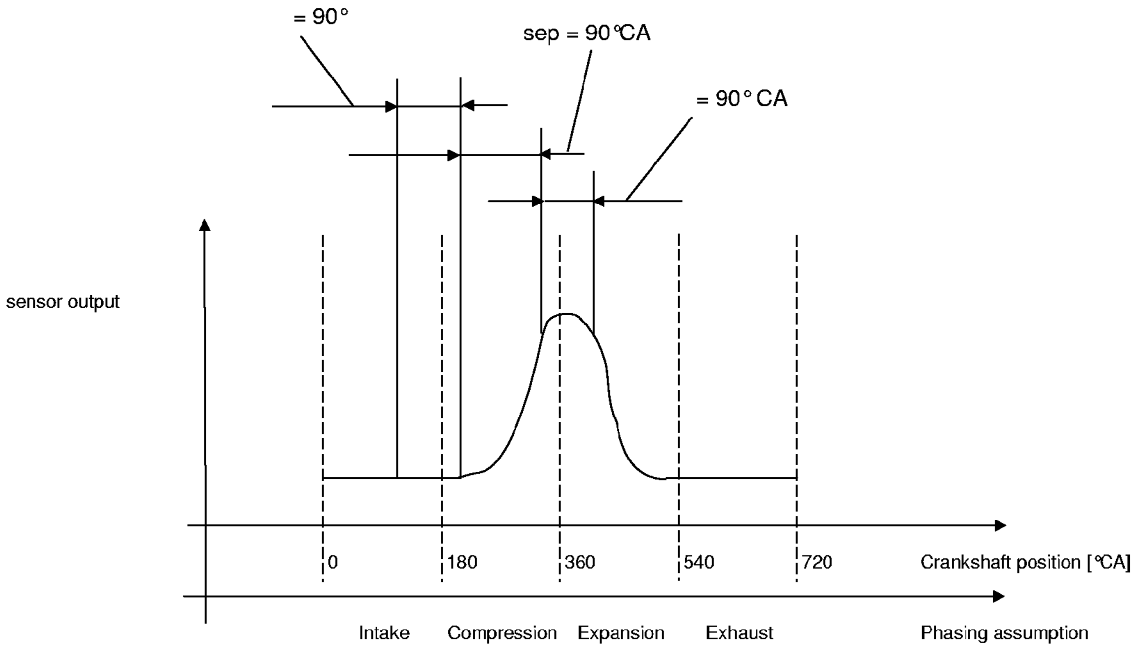
= 90°
sep = 90°CA
= 90° CA
sensor output
0
180
360
540
720
Crankshaft position [°CA]
Intake
Compression
Expansion
Exhaust
Phasing assumption

Fig. 1b

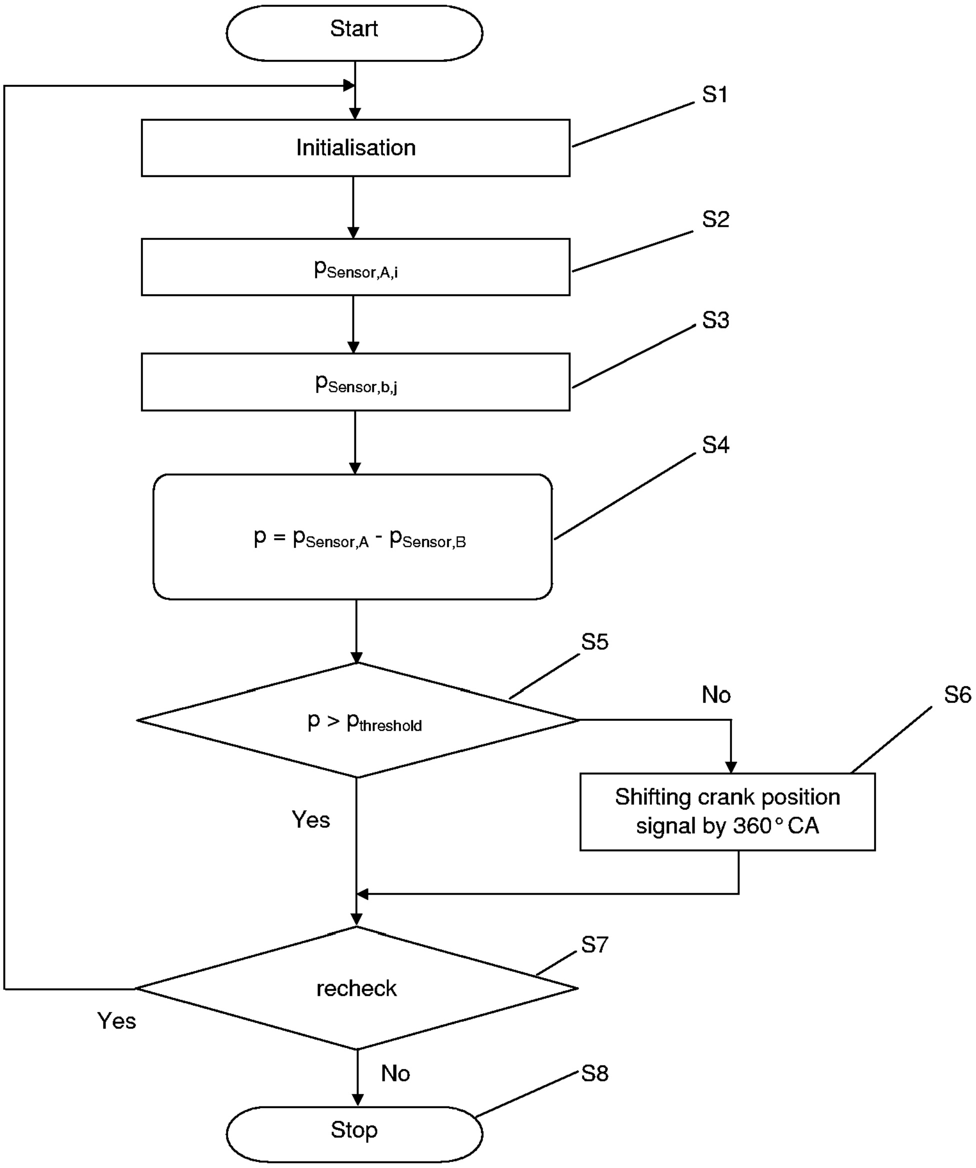
Start
S1
Initialisation
S2
$p_{Sensor,A,i}$
S3
$p_{Sensor,b,j}$
S4
$p = p_{Sensor,A} - p_{Sensor,B}$
S5
$p > p_{threshold}$
No
S6
Shifting crank position signal by 360° CA
Yes
S7
recheck
Yes
No
S8
Stop

Fig. 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 05 10 5668

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	US 5 623 412 A (MASSON ET AL) 22 April 1997 (1997-04-22) * abstract * * column 8, line 8 - line 33 * * figures 6-9 *	1-10	F02D41/34 F02D35/02 G01L23/30
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	18 November 2005	Libeaut, L

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CATEGORY OF CITED DOCUMENTS

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