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(54) **Title**: METHOD AND DEVICE FOR DETERMINING IN-CYLINDER PRESSURE OF A COMBUSTION ENGINE

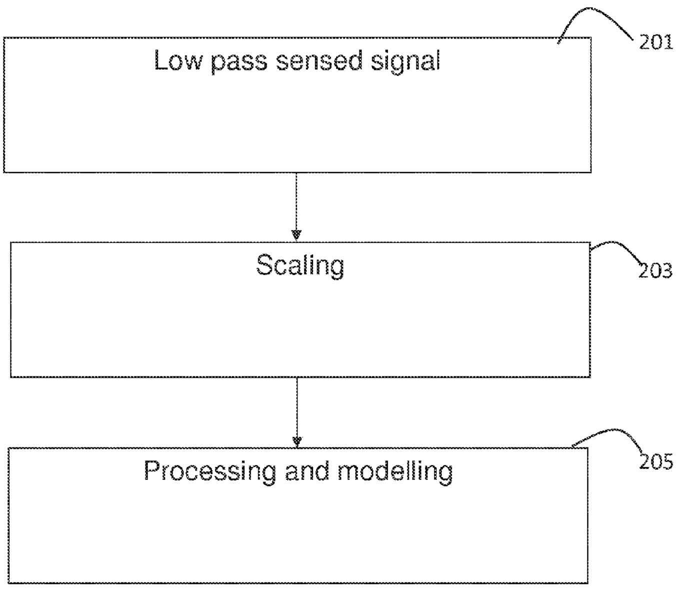

Fig. 2

(57) **Abstract**: Methods and devices for processing a signal generated by a sensor (7) adapted to sense pressure variations generated in a cylinder (61- 66) of a combustion engine (1) are described. The sensor is mounted on the combustion engine outside the cylinder. The sensor signal is low-pass filtered (201) forming at least a part of an in-cylinder pressure curve, and the in-cylinder pressure curve is scaled using a model of the compression in the cylinder forming a scaled pressure curve of the at least a part of the in-cylinder pressure curve.

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METHOD AND DEVICE FOR DETERMINING IN-CYLINDER PRESSURE OF A COMBUSTION ENGINE

FIELD OF THE INVENTION

The present invention relates to a method and a device for determination of in-cylinder pressure of a combustion engine.

BACKGROUND

There is a constant aspiration to achieve control of a combustion engine in such a manner that fuel used therein is burned in the engine’s cylinders, while generating a maximum amount of work output from the engine and a minimum amount of emissions of environmentally hazardous pollutants. It is of importance in such aspiration to have constant knowledge of the combustion engine’s operating conditions. One important source of information is the pressure in the cylinder(s) of the combustion engine.

Further, US 8396649 describes a method whereby some in-cylinder pressure data can be reconstructed using a vibration signal from a vibration sensor located outside the cylinder.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide methods and devices, which at least partly solve the above problems, and which are improved in at least some respect in relation to prior art methods and devices.

This object is achieved with the method and the devices as set out in the accompanying claims.

In accordance with one embodiment a method of processing a signal generated by a sensor adapted to sense pressure variations generated in a cylinder of a combustion engine is provided. The sensor is mounted on the engine outside the cylinder. The method comprise low-pass filtering the signal from the sensor forming at least a part of an in-cylinder pressure curve. The in-cylinder pressure curve is then scaled using a model of the compression in the cylinder forming a scaled pressure curve of the at least a part of the in-cylinder pressure curve. By first generating an in-cylinder pressure curve and then scale the thus acquired curve it is possible to generate an in-cylinder pressure curve that with a low amount of processing represents the in-cylinder pressure curve both in terms of its shape and also in terms of the absolute pressure values.

The in-cylinder pressure curve thus formed can represent the entire in-cylinder pressure curve of a complete working cycle of a cylinder or in some applications only a part thereof. The working cycle can be for a four stroke engine or a two-stroke engine.

In accordance with some embodiments the formed in-cylinder pressure curve is phase aligned.

In accordance with some embodiments a part or parts of the formed-in-cylinder pressure curve is replaced by pressure values determined from a model. The part or parts being replaced can correspond to parts of the in-cylinder curve that are determined to comprise noise above a predetermined threshold level.

In accordance with some embodiments the formed in-cylinder curve is smoothened to generate a curve that can be differentiated in each point of the in-cylinder curve.

In accordance with some embodiments the sensor senses signals on the long side of the engine. The sensor can sense signals on the long side of the engine with the lower temperature compared to the other long side of the engine. In accordance with another embodiment the sensor is located on the warm side of the engine. The signals can typically be a vibration signal or a displacement signal.

In accordance with some embodiments the compression model is an adiabatic compression model.

In accordance with some embodiments the sensor senses a vibration or a displacement in the engine.

The invention also relates to a device for performing the method as set out above, and to a motor vehicle comprising such a device.

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

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

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

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

BRIEF DESCRIPTION OF THE DRAWINGS

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

Fig. 1 is a schematic view illustrating a part of a combustion engine,

Fig. 2 is a flow chart illustrating some steps performed when processing a sensor signal,

Fig. 3 is a diagram of an electronic control device,

Fig. 4 shows a possible placement of a sensor element,

Fig. 5 illustrates a sensor signal, cylinder pressure and heat release for a compression cycle,

Fig. 6 is similar to Fig. 5 with averaged and filtered signal data,

Fig. 7 illustrates a magnitude spectrum of measured pressure and sensed signal

Figs. 8 and 9 illustrate a typical adiabatic compression curve,

Fig. 10 depicts a filtered and scaled sensor signal,

Fig. 11 depicts a signal modelled using pre-compression model,

Fig. 12 illustrates a smoothed curve,

Fig. 13 illustrates adding of a phase compensation to the signal,

Fig. 14 illustrates the use of a post-power model in the signal processing, and

Fig. 15 illustrates the final result using an advanced model.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 illustrates schematically a combustion engine 1, which engine is here arranged in an implied motor vehicle 2, for example a truck. The engine is equipped with a device 3, indicated with a dashed line, adapted to detect operating conditions in the engine, and such device has a schematically drawn device 4, which is adapted to detect pressure changes in the cylinder chambers 5 of the combustion engine's cylinders 61-66, of which there are six in this case, but of which there may be any number.

The device 4 has in this example one sensor element 7 per cylinder 61-66, and this is provided outside the associated cylinder chamber 5. The sensor elements are adapted to sense vibrations or displacements and in particular adapted to sense displacements or vibrations in the engine resulting from pressure variations in the cylinders thereof. The terms vibrations/ displacement are used herein to refer to any movement in the engine that can be sensed by the sensor element 7. The sensors can be piezo resistive or piezo electrical sensors, or other types of vibration or displacement sensing elements such as strain measurement device for example a strain gauge.

The device 3 also comprises a unit 9, which may consist of the vehicle's 2 electronic control device adapted to receive information about the detected movements from the sensor element(s) 7, and to compare such information, or information calculated based on such sensor information, with stored values, and to deliver measuring values for the state of the engine 1 and/or processes in the engine. Thus, information about the engine's operating conditions or divergences from these, which suitably provide the bases for control of various components in the combustion engine, such as for example fuel injection, may be obtained based on the sensor elements' 7 detection.

As has been realized pressure changes in the cylinder chamber 5, can be sensed by a sensor outside the cylinder chamber to produce high quality signals, which require a simple filtering or processing, to be used when forming an in-cylinder pressure curve or a part thereof.

Fig. 2 shows a flow chart illustrating an embodiment of a method for processing a signal generated by a sensor adapted to sense vibrations or displacements generated in a cylinder of a combustion engine. The sensor is mounted on the engine outside the cylinder. First, in a step 201, the signal from the sensor is low pass filtered to form at least a part of an in-cylinder pressure curve. Then, in a step 203, the in-cylinder pressure curve is scaled using a model of the compression in the cylinder to forming a scaled pressure curve of the at least a part of the in-cylinder pressure curve. In accordance with one exemplary embodiment the compression model used in step 203 is an adiabatic compression model. Additional processing and modelling steps can also be performed as is indicated by step 205. The order in which the steps 201 – 205 are performed can be different in different processing implementations for processing the vibration signal to form an in-cylinder pressure curve or a part thereof. Processing and modelling steps that can be performed will be exemplified in more detail below.

A computer program code for the implementation of a method according to the invention is suitably included in a computer program, loadable into the internal memory of a computer, such as the internal memory of an electronic control device of a combustion engine. Such a computer program is suitably provided via a computer program product, comprising a non-transitory data storage medium readable by an electronic control device, which data storage medium has the computer program stored thereon.

Said data storage medium is e.g. an optical data storage medium in the form of a CD-ROM, a DVD, etc., a magnetic data storage medium in the form of a hard disk drive, a diskette, a cassette, etc., or a Flash memory or a ROM, PROM, EPROM or EEPROM type memory.

Fig. 3 schematically illustrates an electronic control device 9 comprising execution means 17, such as a central processor unit (CPU), for the execution of computer software. The execution means 17 communicates with a memory 18, e.g. a RAM memory, via a data bus 19. The control device 9 also comprises a data storage medium 20, e.g. in the form of a Flash memory or a ROM, PROM, EPROM or EEPROM type memory. The execution means 17 communicates with the data storage means 20 via the data bus 19. A computer program comprising computer program code for the implementation of a method according to the invention is stored on the data storage medium 20.

Fig. 4 shows a possible sensor placement. The sensor element 7 is here placed on the engine. In particular the sensor element can be placed on a section on the cylinder head. The sensor elements/sensors 7 may be of a suitable type, e.g. piezo resistive or piezo electrical elements or optical sensors. The sensor element may be placed on the engine in an area adjacent to the outlet of the exhaust channel from a cylinder. For example, it may be placed on a surface on the engine next to the outlet, on the engine, of the exhaust channel from a cylinder. The surface where the sensor 7 is placed may be substantially vertical. The sensor may be arranged to detect vibrations or displacements, which are perpendicular to the movements of the piston. The sensor may also be arranged to detect vibrations or displacements, which are perpendicular both in relation to the piston's direction of movement and in relation to the engine's longitudinal direction. In one embodiment, the sensor is located on the engine's long side. The sensor may be arranged to detect vibrations or displacements in a direction, which is perpendicular in relation to the surface on which it is placed.

In another embodiment (not shown), the sensor element 7 may be placed in a corresponding manner as when placed on the engine at the outlet of the exhaust channel from a cylinder, but instead placed in a corresponding location on the engine, at the suction channel's inlet to a cylinder.

The signal detected by the sensor element 7 may be treated in various ways as will be exemplified below. The signal from the sensor senses vibrations are low-pass filtered to generate an in–cylinder pressure curve or at least a part thereof. The in-cylinder pressure curve can typically be a continuous curve. The thus formed pressure curve can be used to calculate different values at engine control. To enhance the accuracy of the in-cylinder pressure curve, the in-cylinder pressure curve can be processed further in one or more modelling steps and refinement steps.

Below some of such modelling steps and refinement steps are described by way of detailed implementation examples. The invention is not limited in any way to the embodiments described, but numerous possible modifications thereof can be envisaged. In particular steps can be omitted or steps from different embodiments can be combined or performed in other sequences than the ones described.

Signal Content Identification

An exemplary recurring appearance can be seen in Fig. 5 where the sensor signal (knock signal) is plotted together with the cylinder pressure. Data is in this example based on a run of 1200RPM at 100% load. Other setting are of course possible. The sensor data can in accordance with some embodiments be averaged. For example the data can be averaged over 10 cycles and Savitzky-Golay smoothed (optimized at Polynomial order 2 and frame size 111), the result of the operation is depicted in Fig. 6.

The sensor signal can be compared for different operating points to verify if the same appearance could be seen in all modes.

Model development

The process in obtaining an estimated pressure model can comprise at least one of the steps of: filtering out high frequency noise, adjusting phase shifts, scaling and replacing noisy parts of the signal with known physical models or assumptions. The model can be based on a high resolution Crank Angle Degree (CAD) signal of for example 0.1 degrees. Also other resolution can be used such as 6 degrees resolution. Values in between the acquired data samples can be modelled. The modelled values can for example be generated by a virtual sensor.

To address robustness different models can be used. The models can be combined. Here two models are described. A first model with light signal processing to minimize the model dependencies and focus on achieving a low average offset of the maximum pressure amplitude relatively to the measurement data. A second more advanced model will have heavier signal processing including phase alignment, post power stroke modelling, high engine load dependencies and more focus on achieving full pressure signal correlation. The two models can also be combined.

Compression Model

A compression model can be used for scaling purposes. In accordance with some exemplary embodiments the compression model is based on the ideal adiabatic equations for compression of a gas to compensate for engine/load variance as well as possible non-linear Heat transfer losses. For example a Heat transfer model based on Woschni/Hohenberger model can be used. The heat transfer model can for example be multiplied by a coefficient of in the range of 1 – 10 such as in the range of 1 – 5 in order to compensate for all modelled losses and the wall temperature coefficient can be adjusted depending on engine speed and load to obtain a proper exponential increase during the compression stroke. These variables can be tested during the tolerance analysis in order to investigate the affect these decisions has on the model.

In accordance with one embodiment each step of the process is iteratively calculated based on the thermodynamic first law, where first the number of moles are calculated using the inlet manifold pressure and inlet manifold temperature as initial values for the model as well as the cylinder volume calculation at CAD -180 degrees, i.e. Bottom Dead Centre BDC prior to Top Dead

Centre for combustion. A first estimate of the index, in particular an adiabatic index, is then calculated using an index function. In case the model is adiabatic the index will be an adiabatic index. The main dependency of this function can be the current temperature and lambda. Heat loss from the heat transfer is calculated, which then provides the information needed to calculate the pressure derivate, the heat transfer is primarily used to compensate for the heating loss/gain due to the temperature in the cylinder wall. Temperature, (adiabatic) index and the cylinder pressure can be iteratively calculated up to CAD 160 in order to obtain the full cycle.

Below two models (Light and Advanced) are further exemplified for a typical test implementation.

Pressure model Light

filtering

The pressure related signal content of the signal from the vibration sensor is of relatively low frequency content compared to the whole frequency spectrum, the high frequency noise is reduced by applying a low-pass digital filter to the signal. The magnitude spectrum of the relevant frequency range can be seen in Fig. 7 which depicts the sensed signal (knock signal) with a measured cylinder pressure (pressure reference).

Different real-time filters such as Butterworth, Elliptic, Cheby1 and Cheby2 can be used. Typically there will be a trade-off between filtering too much information near the start of combustion and obtaining a relatively (depending on the operating point) clear signal peak. In accordance with some embodiments minimizing roll-off effects by the real-time filters can be performed with a Fourier Transform filter. In accordance with some embodiments a 10th order Butterworth filter with a normalized cut-off frequency of about 0.04 can be used. Phase-shift can in some embodiments be avoided by applying zero-phase filtering (forward and reverse filtering), hence the signal is then filtered e.g. with two consecutive 10th order Butterworth filters.

scaling

The obtained sensor signal can be received in any amplitude. In accordance with some embodiments data can be received in order of 1-10 V but it could be in other amplitude ranges depending on the amplifier and settings used as well as the engine speed and load. A pressure model, in particular an adiabatic pressure model, can be used to adjust the scaling to the correct level independent of amplifier, settings and the current operating point.

A proper scaling can in accordance with some embodiments be achieved by minimizing the average difference between the filtered sensor signal and the pressure model. The minimization can for example be performed between two CADs with negative values such as -28 CAD and -3 CAD, i.e. during the compression phase. Here all operating points approximately have the same appearance (but not necessarily the same amplitude, hence individual scaling factors are used for each operating point).

pre-compression model

The earlier stage of the compression stroke is cluttered and distorted by various noises, to reduce the amount of filtering needed and since the beginning of the compression stroke can be idealized as a compression the model can be replaced between some negative values such as starting in the range of -150 to -110 CAD and ending in the range of – 30 to – 5 CAD. For example -130 CAD to -15 CAD can be used with the scaling model above. This is done on the assumption that the state of the signal in this region coincides with the model used.

inlet-exhaust model

The opening of the inlet valve will level the cylinder pressure at approximately manifold pressure, hence the inlet stroke of the signal can be replaced with an averaged value of the manifold pressure for the specific operating point to minimize signal filtering and smoothing, to reduce the number of needed parameters the exhaust stroke has been set to the same level. For example based on measurements from an experimental campaign, it is true that the average inlet manifold pressure and exhaust manifold pressure are approximately the same, but with available sensors this assumption can be replaced by the actual exhaust manifold pressure if required. The replaced inlet region is between some negative CAD values, for example -360 CAD to -130 CAD can be used and the replaced exhaust region is between some positive CAD values, for example 190 CAD to 360 CAD can be used.

smoothing

The sensor is typically consistently registering somewhat higher peaks than the measured pressure curve. In order to get a smoother peak and minimise the discontinuities between the replaced pre-compression model and inlet/outlet model the signal can be smoothed. This can in accordance with some embodiments be performed using a filter for example using a first order Savitzky-Golay smoothing filter (for all operating points). Preservation of the content surrounding the Start of Combustion (SOC) is significant, hence a second signal can be smoothed with a smaller frame size. A smooth transition can in some embodiments be obtained by iteratively comparing the two smoothed signals and choosing the lower value of them for the region around 0 CAD for example between -5 CAD to +5 CAD or some other range around 0 CAD.

Pressure model Advanced

phase alignment

The low pass filtered signal can be phase shifted before scaling in order to raise the power stroke of the signal to the correct level. In accordance with some embodiments the phase shift model used can be a lag compensator, e.g. a second order lag compensator. In an exemplary embodiment the position of the pole is p = 1e-12 for all operating points and the position of the zero is varied ranging from z = 4.25e-04 to z = 3e-04 or some other suitable values with increasing speed and cylinder used. The value can be optimized by comparing measured pressure curve and phase shifted model.

The phase lag compensator will typically only minimize a certain amount of phase indifferences between the signal and the reference pressure signal. In some examples minimizing further phase differences can be done using higher orders of models. However a simple second order model typically works with reasonable results for all operating points without adjusting its parameters too much.

scaling

The filtered sensor signal can be scaled with the same adiabatic compression model as used for the light model above.

post-power model

The phase adjustment typically does not correct for all irregularities in the power stroke, hence a region during valve opening can be replaced with a similar model that was used to scale the signal. The region can be around 80 CAD such as between CAD 20 to CAD 135. The required initial temperature can be obtained through the thermodynamic first law with total amount of moles obtained from the estimated value in the scaling model, initial pressure and volume taken at around CAD 20 or some CAD value in that region such as in the range of CAD 10 - 30. Instead of compensating for heat transfer losses with a model a simple offset based on measurement can be used, the offset can be based on a sensor measuring the amount of fuel injected and optimized by comparing the amount injected to the current relative load (from measurements). The offset for 75% relative load and above is in accordance with some examples 0.10, 0.07 for 50%, 0.03 for 25% and 0 for 0% relative load and motored cycles. A linear interpolation can be done between the last value, for example at CAD 135, to the replaced manifold pressure value, for example at CAD 200.

smoothing

The signal can be smoothed to adjust scaling issues. This will remove irregularities in the crossovers between models and assumptions. For example a 1th Savitzky-Golay smoothing filter with a frame size of 111 can be used.

Combined model

A combined model can be developed to obtain better correlation in the power stroke and around the pressure peak. For example the light pressure model developed can be used as base with the advanced pressure model replacing the light model between some positive CAD values. The range can start at about 0 – 5 CAD and end at about 180 – 200 CAD. For example from CAD 2.5 to CAD 195. Hereby a smooth transition is obtained by choosing the higher value between the two models in the above stated region.

smoothing

The signal can be smoothed a final time to remove irregularities in the crossovers between models. In accordance with one exemplary embodiment a first order Savitzky-Golay smoothing filter with a frame size of 35 can be used based on measurements for non-motored cycles and frame size of 51 for motored cycles. The motored cycles can be indicated by the available sensor measuring injected fuel.

Test Results

Adiabatic pressure model

The final result of a typical adiabatic compression curve can be seen in Fig. 8 and Fig. 9, where Fig. 9 shows a detail of Fig. 8. In

Figs. 8 and 9 the model curve (Adiabatic model) is compared to the measured pressure (reference pressure).

The adiabatic scaling model can advantageously be individually calculated for each operating point prior to scaling to get correct pressure levels from the current sensor readings.

filtering

The filtered signal can be seen in Fig. 10. The high frequency noise is removed from the sensor signal and the remaining oscillations are related to lower frequency readings. Fig. 10 depicts the filtered and scaled sensor signal (Filtered and Scaled). The signal in Fig. 10 is also scaled using scaling model (here an adiabatic scaling model).

pre-compression model

The result of the replaced pre-compression content is clearly seen to smooth the curve during the start of compression as seen in Fig. 11 for the pressure model (Pre-compression model).

inlet-exhaust model

The curve in Fig. 11 is the replaced inlet and exhaust content which is very accurately following the measured pressure, the curve (inlet exhaust model) shows the noise replaced.

smoothing

The smoothed curve and the final results of the Pressure model light is seen in Fig. 12, which shows the model (Pressure – model light) compared with the cylinder pressure (Pressure Reference). From the start of the combustion cycle up to near pressure peak the model accurately follows the measured pressure.

Pressure model Advanced

phase alignment

The results of adding phase compensation to the signal is seen in Fig. 13, which shows the model (Pressure – model phase compensated and scaled) compared with the cylinder pressure (Pressure Reference). The signal has now better correlation with the measured cylinder pressure during the power and exhaust stroke.

scaling

The model is scaled in the same way as the light model using the same adiabatic scaling model. The results can be seen in Fig. 13.

post-power model

The replaced curve is less noisy and much smoother. The pressure peak can in accordance with some embodiments be lifted for most operating points. Smoothing the curve with a larger frame results in that the increase in peak amplitude is slightly lowered and yields better correlation with the measured pressure trace, the results is seen in Fig. 14, which shows a smoothened curve for the model curve (Pressure – model postpower and smoothed) compared with the cylinder pressure (Pressure Reference).

Advanced model

smoothing

A last smoothing can be performed to remove any discontinuities in the advanced model. Hence motored cycles can be smoothed. In accordance with some embodiments a first order Savitzky-Golay smoothing filter with a frame size of 51 and non-motored cycles are using a frame size of 25 are used. The final result can be seen in Fig 15, which shows a resulting model curve (Pressure – model Advanced) compared with the cylinder pressure (Pressure Reference).

The processing of a vibration signal from a sensor outside a cylinder of a combustion engine to generate an in-cylinder pressure curve is performed using a model. The overall model can involve several steps but is nonetheless simple. The filtering can be performed with simple real-time Butter-worth filters and performed using only a single cut-off frequency for all studied operating points, fuels and cylinders. The intake-exhaust model shows minimal difference between the measured pressure at the inlet manifold pressure for the measurements compared herein. In accordance with some embodiments individual exhaust sensor readings can be added. The smoothing steps are mainly to minimize discontinues between the different models applied and performed with relatively few frames. The smoothing performed with the larger frame is performed mainly to minimize the peak of certain pressure peaks. This can be performed to counter that the sensor signal registers higher peaks than measured with the pressure sensor. The phase alignment is giving an increase in pressure correlation for all operating points in various degrees.

Claims

1. A method of processing a signal generated by a sensor (7) adapted to sense pressure variations generated in a cylinder (61-66) of a combustion engine (1) and where the sensor is mounted on the combustion engine outside the cylinder, characterized by:
- low-pass filtering (201) the signal from the sensor forming at least a part of an in-cylinder pressure curve, and
- scaling (203) the in-cylinder pressure curve using a model of the compression in the cylinder forming a scaled pressure curve of the at least a part of the in-cylinder pressure curve.

2. The method according to claim 1, wherein the entire in-cylinder pressure curve of a complete working cycle of a cylinder is formed.

3. The method according to any of claims 1 or 2, wherein the formed in-cylinder pressure curve is phase aligned.

4. The method according to any of claims 1 – 3, wherein a part or parts of the formed in-cylinder pressure curve is replaced by pressure values determined from a model.

5. The method according to claim 4, wherein the part or parts being replaced correspond to parts of the in-cylinder curve that are determined to comprise noise above a predetermined threshold level.

6. The method according to any of claims 4 – 5 wherein the formed in-cylinder curve is smoothened to generate a curve that can be differentiated in each point of the in-cylinder curve.

7. The method according to any of claims 1 – 6, wherein the sensor senses signals on the long side of the engine.

8. The method according to any of claims 1 – 7, wherein the compression model is an adiabatic compression model.

9. The method according to any of claims 1 – 8, wherein the sensor senses a vibration or a displacement in the engine.

10. A device (3) for processing a signal generated by a sensor adapted to sense pressure changes generated in a cylinder of a combustion engine and where the sensor is mounted on the engine outside the cylinder, characterized by:
- a low pass filter adapted to low-pass filter the signal from the sensor and adapted to output at least a part of an in-cylinder pressure curve, and
- a scaling module adapted to scale the in-cylinder pressure curve using a model of the compression in the cylinder and adapted to form a scaled pressure curve of the at least a part of the in-cylinder pressure curve.

11. A combustion engine (1), characterised in that it comprises a device according to claim 10.

12. A computer program downloadable into an internal memory of a computer, which computer program comprises a computer program code adapted to make the computer control the steps according to any of claims 1 – 9 when said computer program is executed in the computer.

13. A computer program product comprising a non-transitory data storage medium, which is readable by a computer, and having the computer program code according to claim 12 stored thereon.

14. Motor vehicle (2), characterised in that it comprises a combustion engine (1) according to claim 11.

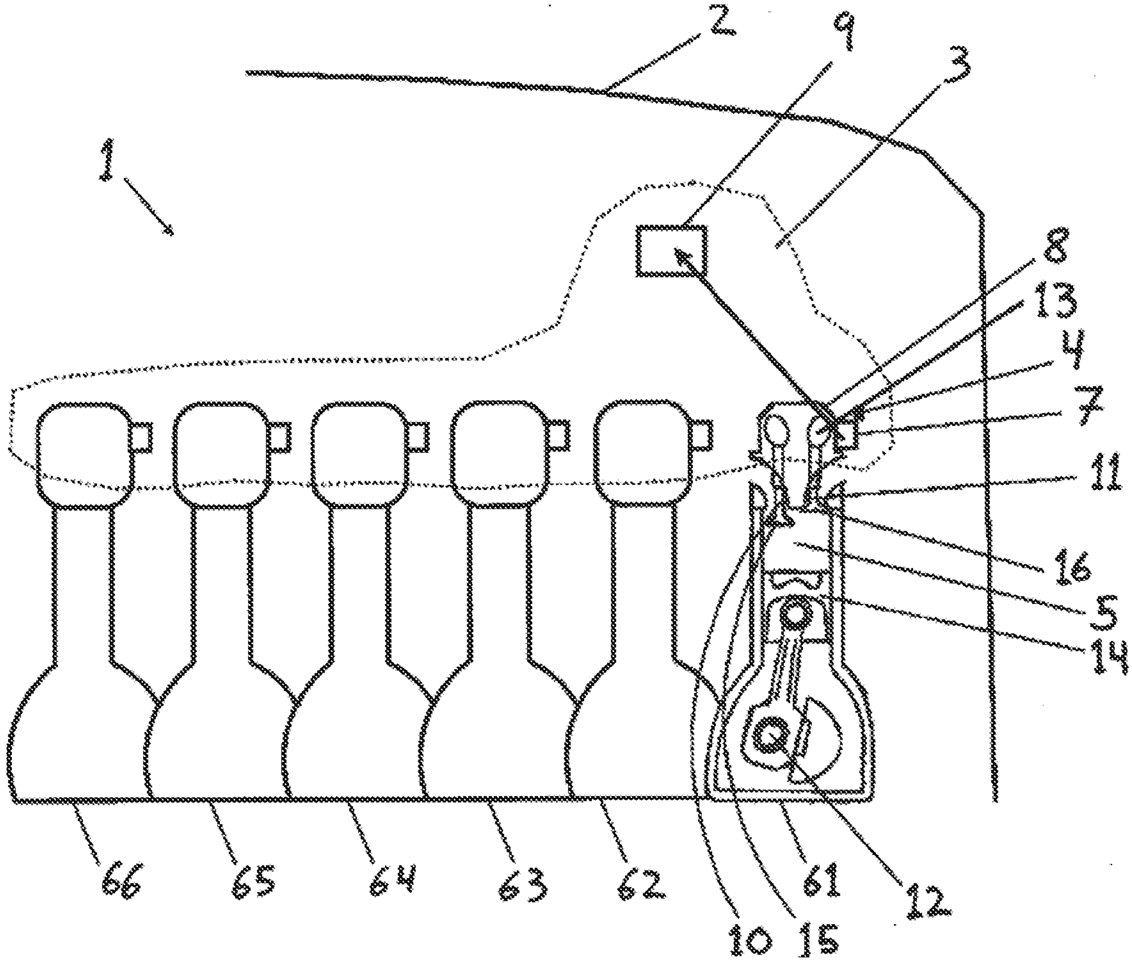

Fig. 1

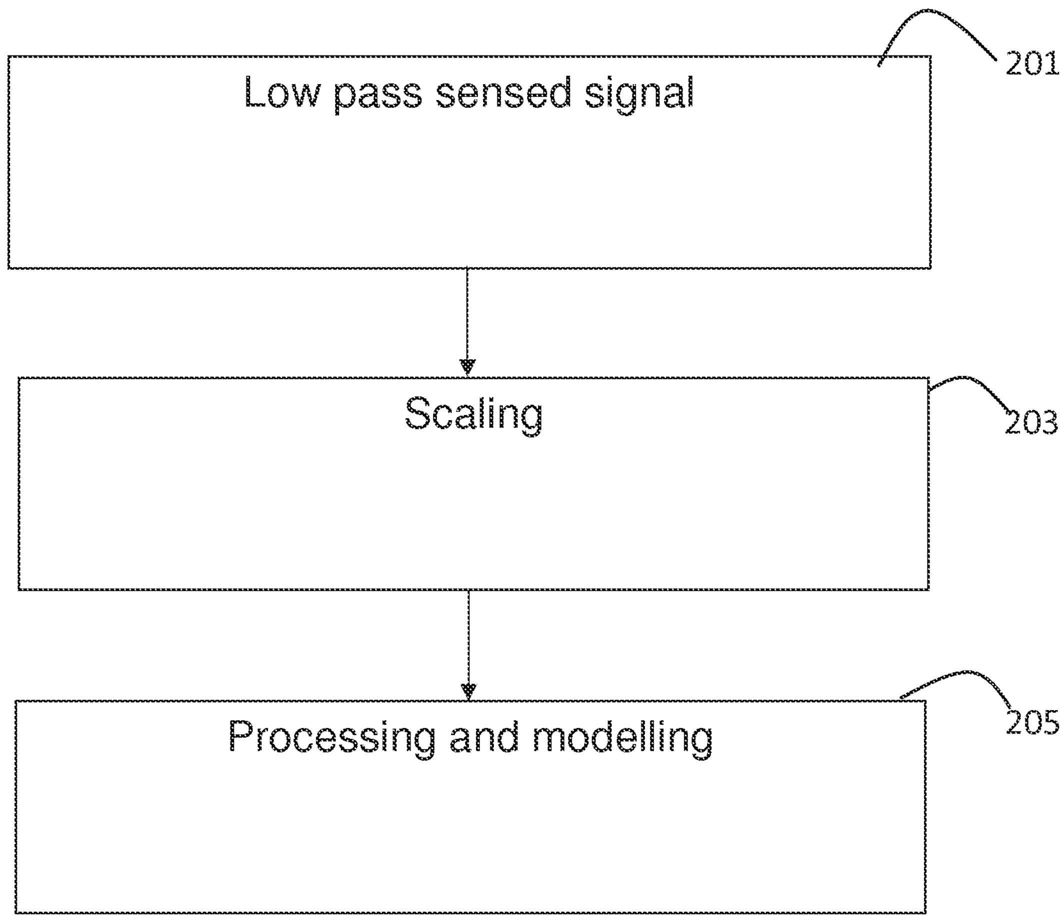
Low pass sensed signal
201
Scaling
203
Processing and modelling
205

Fig. 2

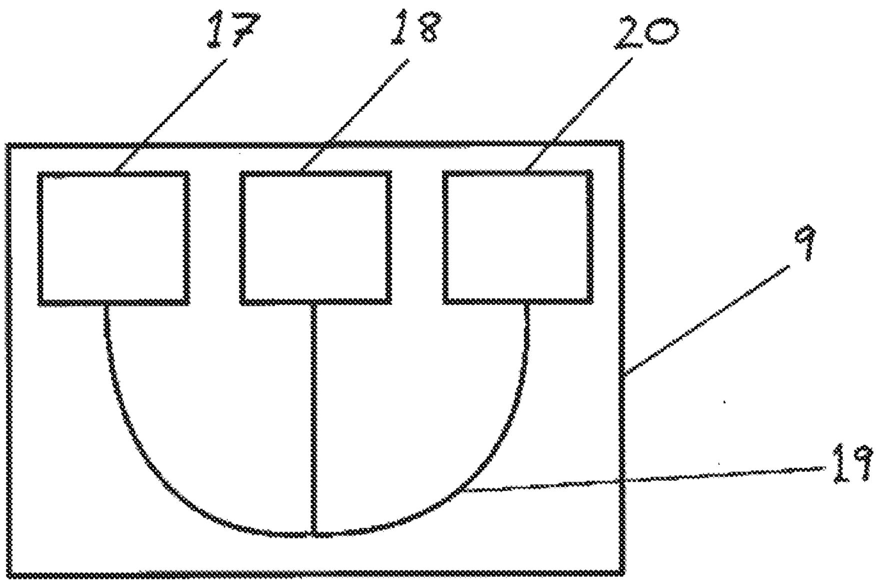

Fig. 3

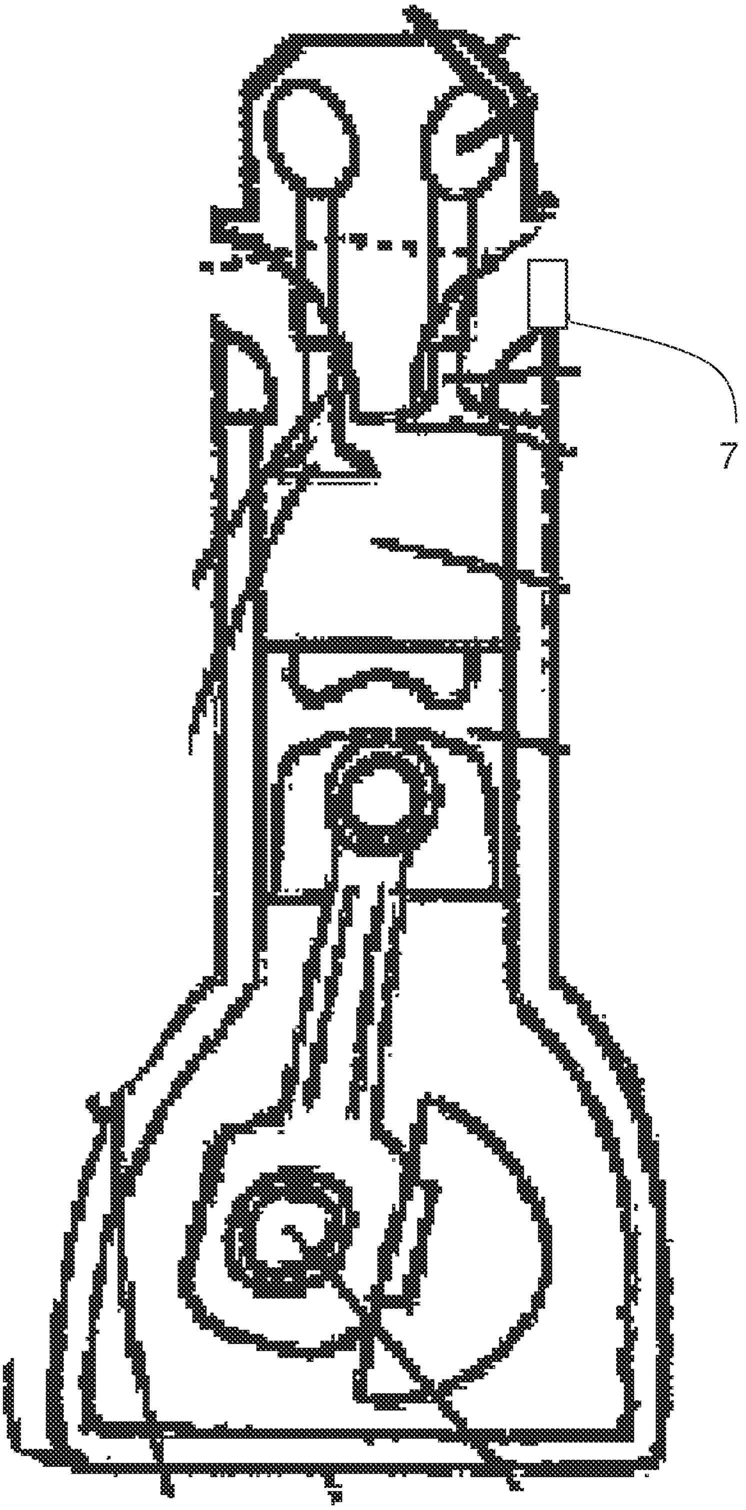

Fig. 4

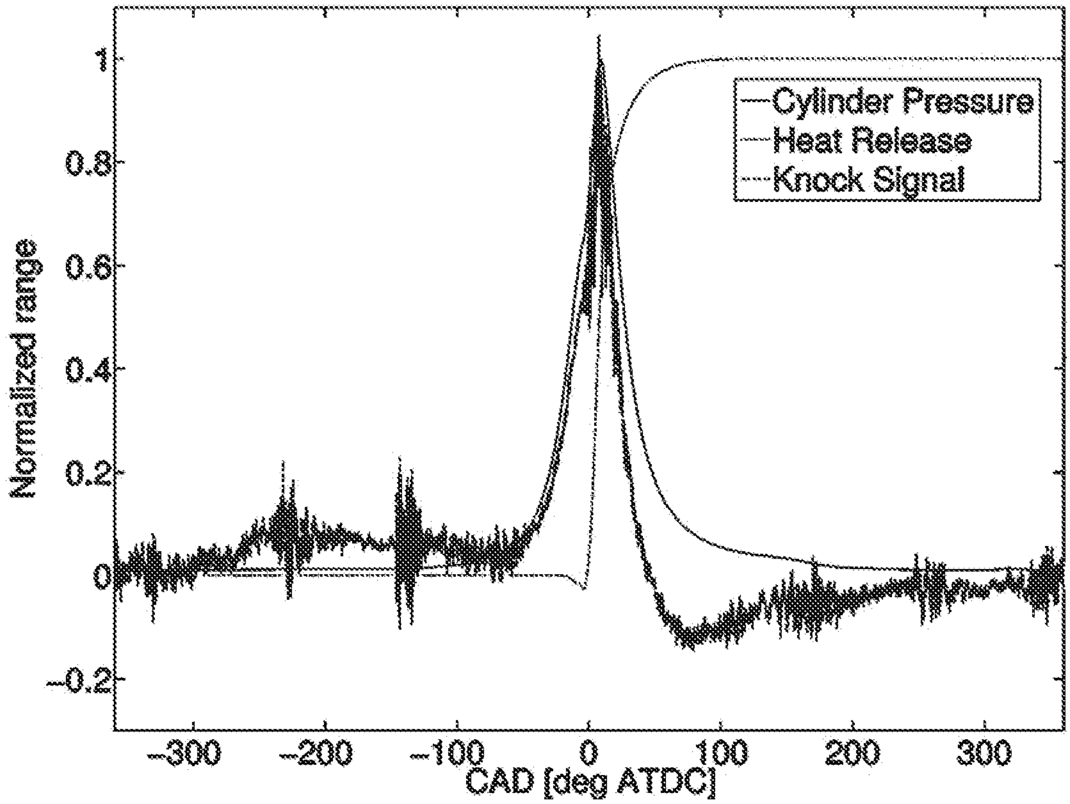
Cylinder Pressure
Heat Release
Knock Signal
Normalized range
CAD [deg ATDC]
1
0.8
0.6
0.4
0.2
0
−0.2
−300
−200
−100
0
100
200
300

Fig. 5

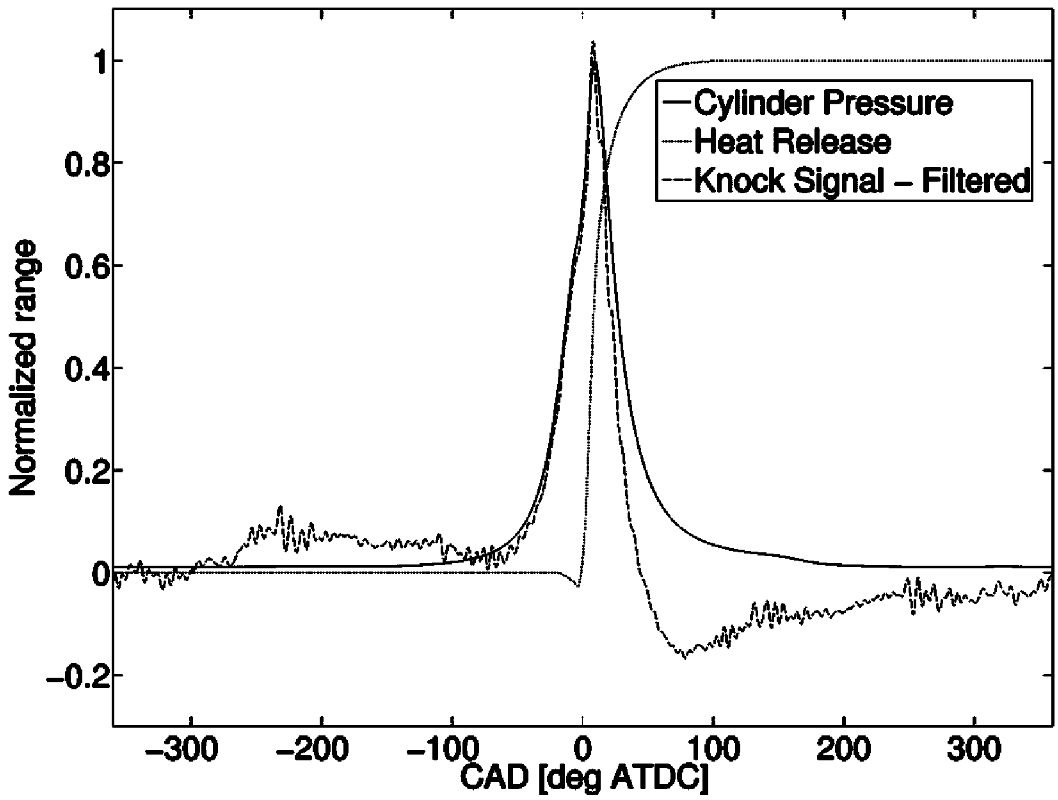
Cylinder Pressure
Heat Release
Knock Signal – Filtered
Normalized range
CAD [deg ATDC]
1
0.8
0.6
0.4
0.2
0
−0.2
−300
−200
−100
0
100
200
300

Fig. 6

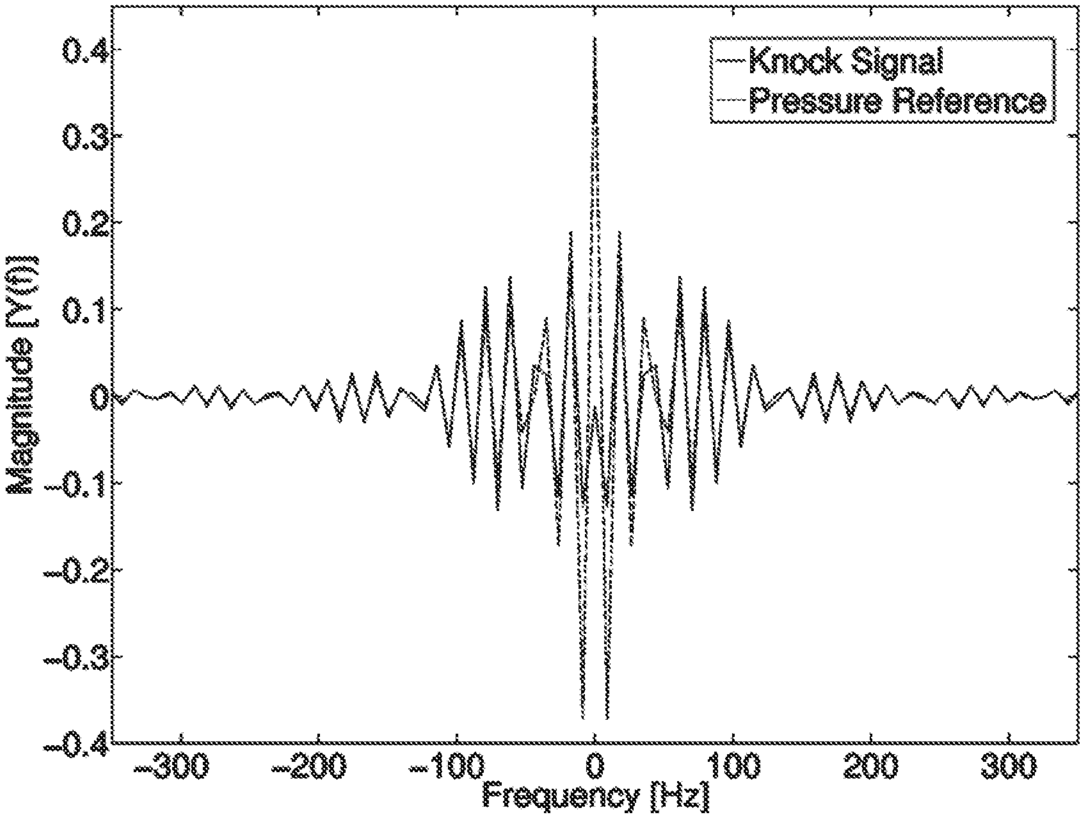
Knock Signal
Pressure Reference
Magnitude [Y(f)]
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−300
−200
−100
0
100
200
300
Frequency [Hz]

Fig. 7

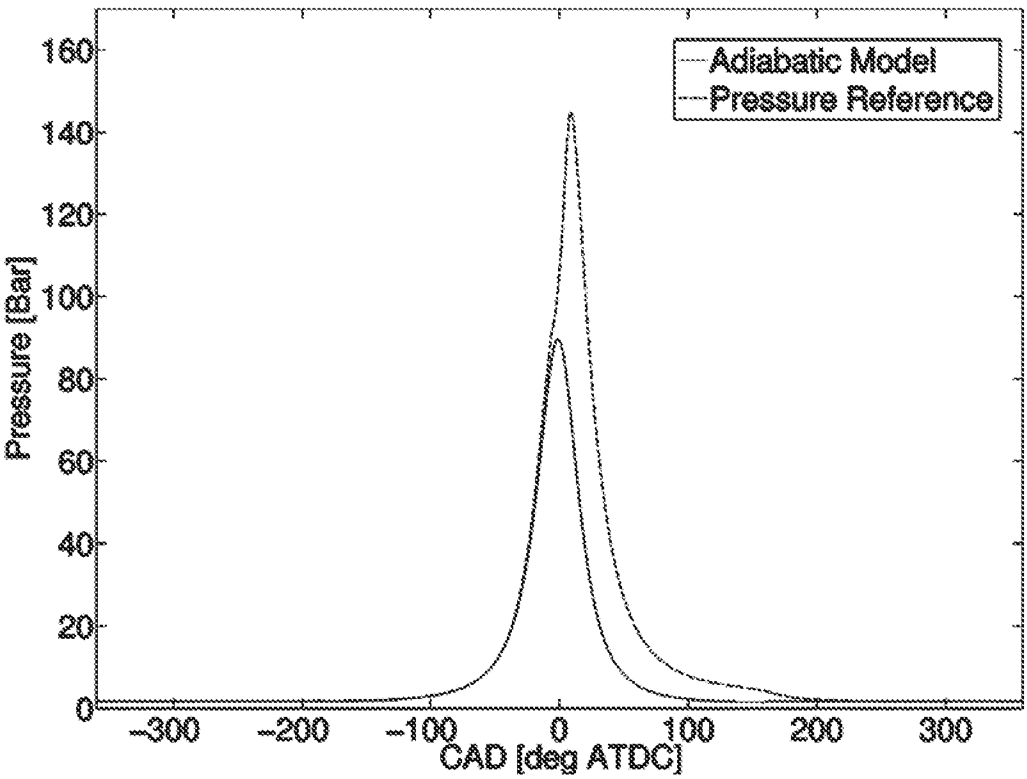
Adiabatic Model
Pressure Reference
Pressure [Bar]
160
140
120
100
80
60
40
20
0
−300
−200
−100
0
100
200
300
CAD [deg ATDC]

Fig. 8

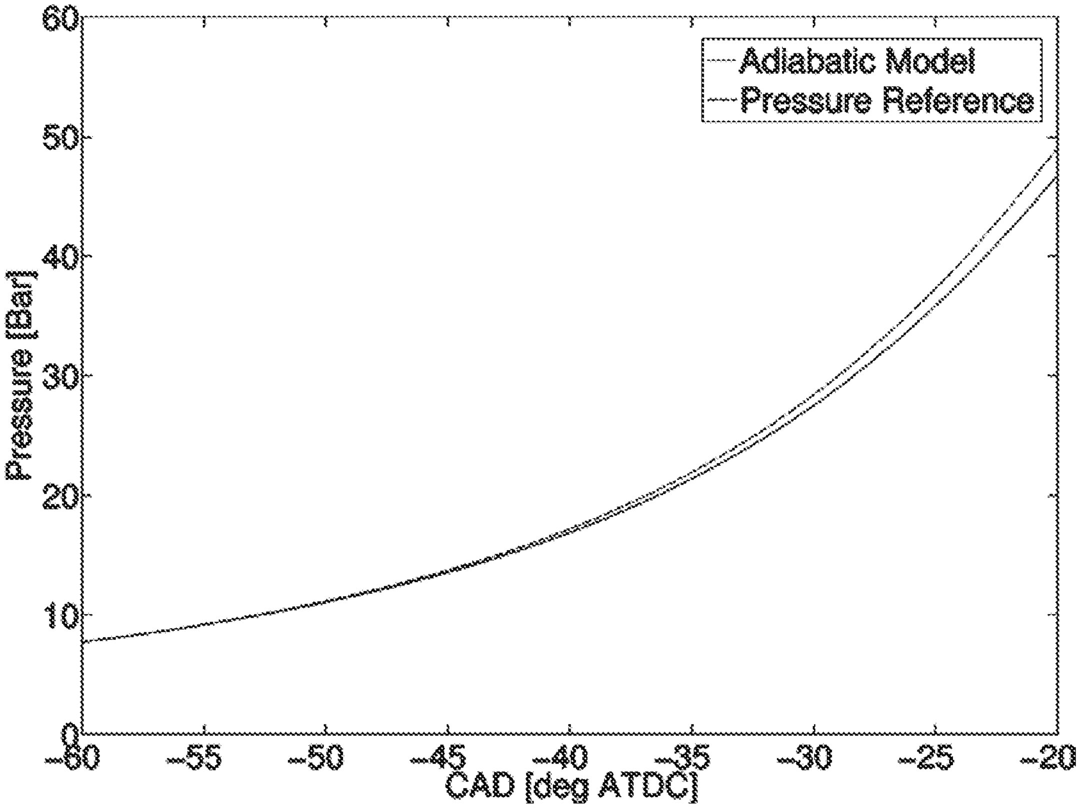
Adiabatic Model
Pressure Reference
Pressure [Bar]
CAD [deg ATDC]
60
50
40
30
20
10
0
-60
-55
-50
-45
-40
-35
-30
-25
-20

Fig. 9

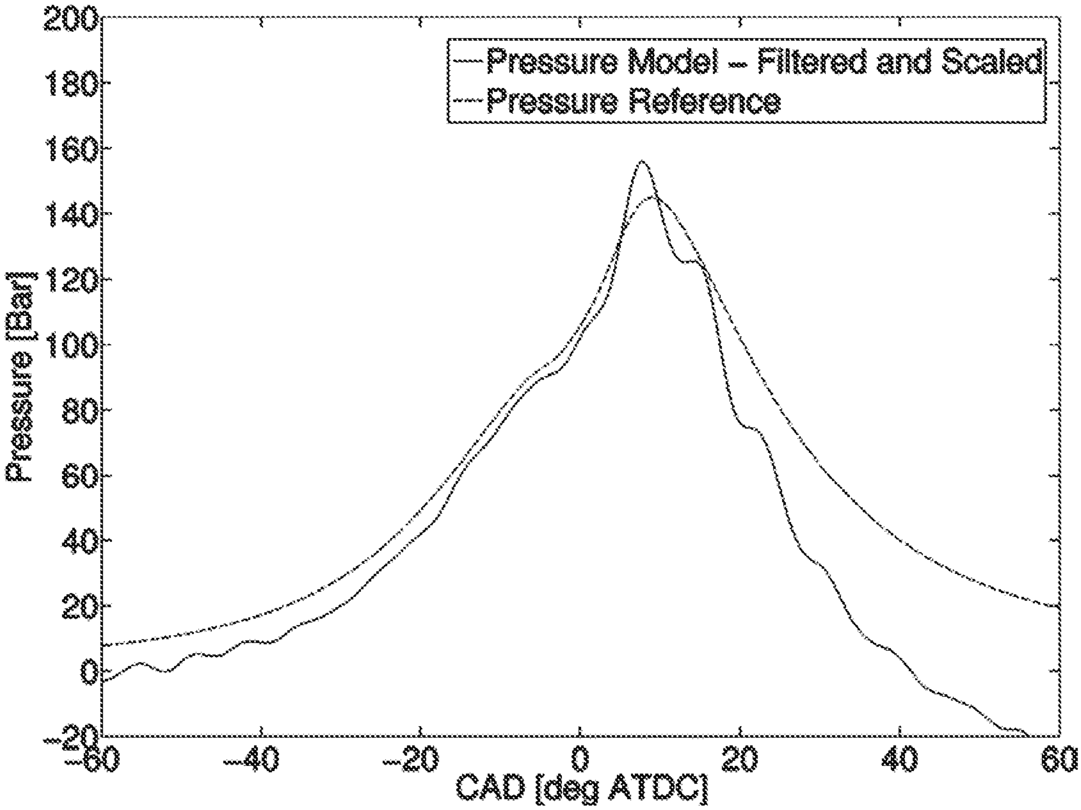
Pressure Model – Filtered and Scaled
Pressure Reference
Pressure [Bar]
CAD [deg ATDC]
200
180
160
140
120
100
80
60
40
20
0
-20
-60
-40
-20
0
20
40
60

Fig. 10

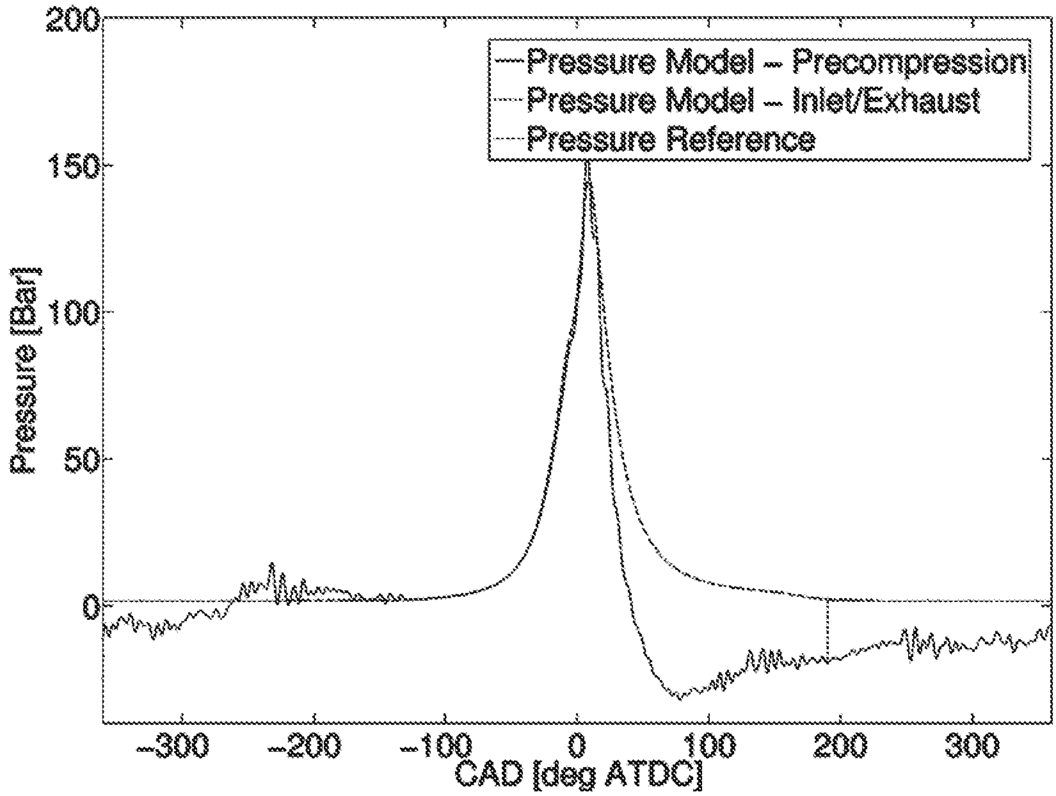
200
150
100
50
0
Pressure [Bar]
-300
-200
-100
0
100
200
300
CAD [deg ATDC]
Pressure Model – Precompression
Pressure Model – Inlet/Exhaust
Pressure Reference

Fig. 11

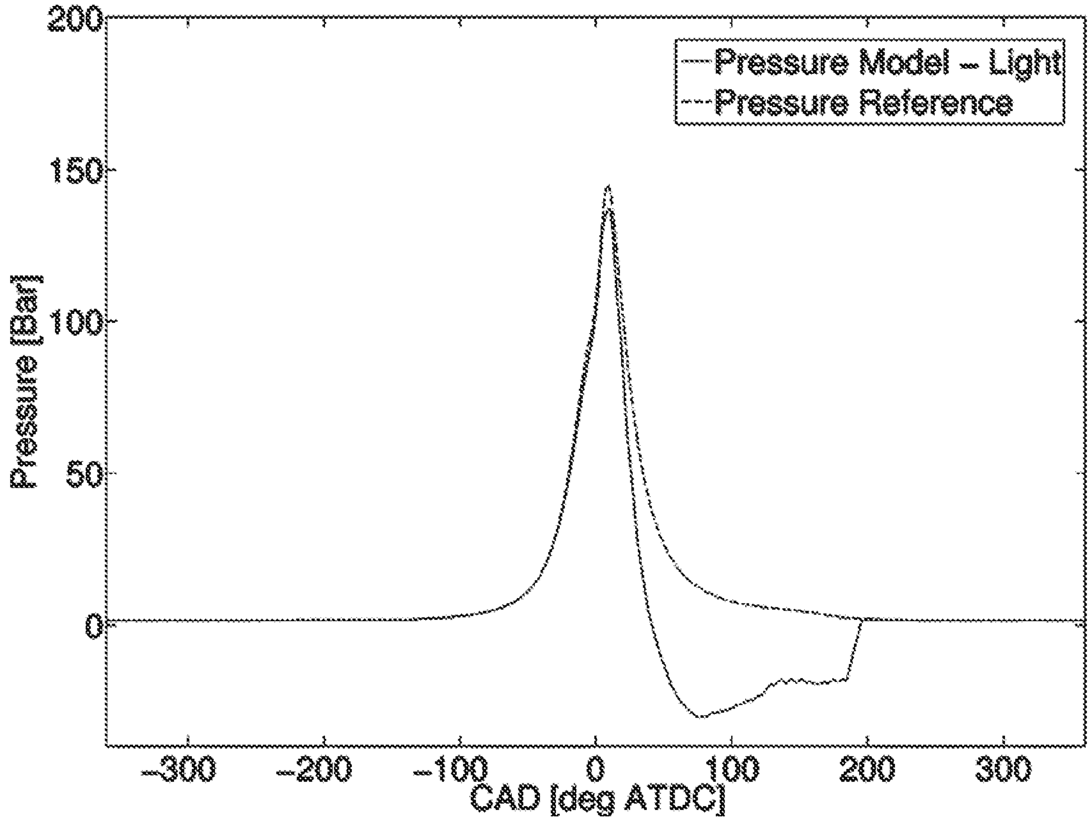
200
150
100
50
0
Pressure [Bar]
-300
-200
-100
0
100
200
300
CAD [deg ATDC]
Pressure Model – Light
Pressure Reference

Fig. 12

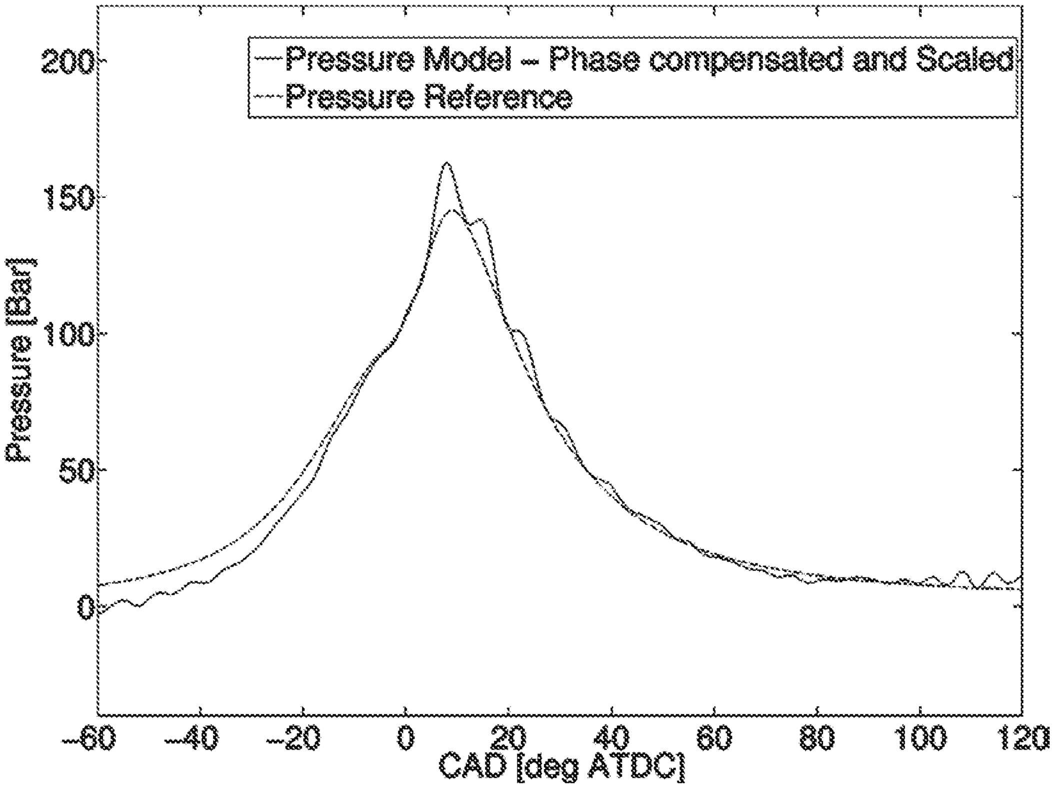
Pressure Model – Phase compensated and Scaled
Pressure Reference
Pressure [Bar]
CAD [deg ATDC]
200
150
100
50
0
-60
-40
-20
0
20
40
60
80
100
120

Fig. 13

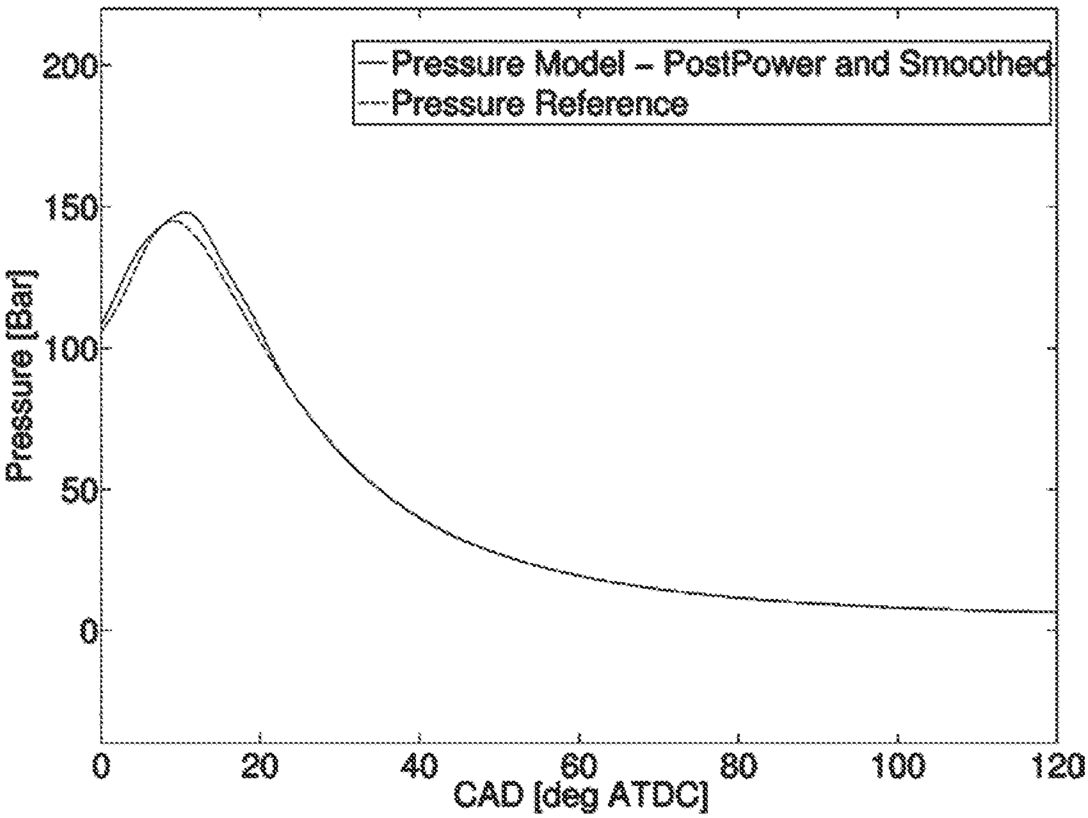
Pressure Model – PostPower and Smoothed
Pressure Reference
Pressure [Bar]
CAD [deg ATDC]
200
150
100
50
0
0
20
40
60
80
100
120

Fig. 14

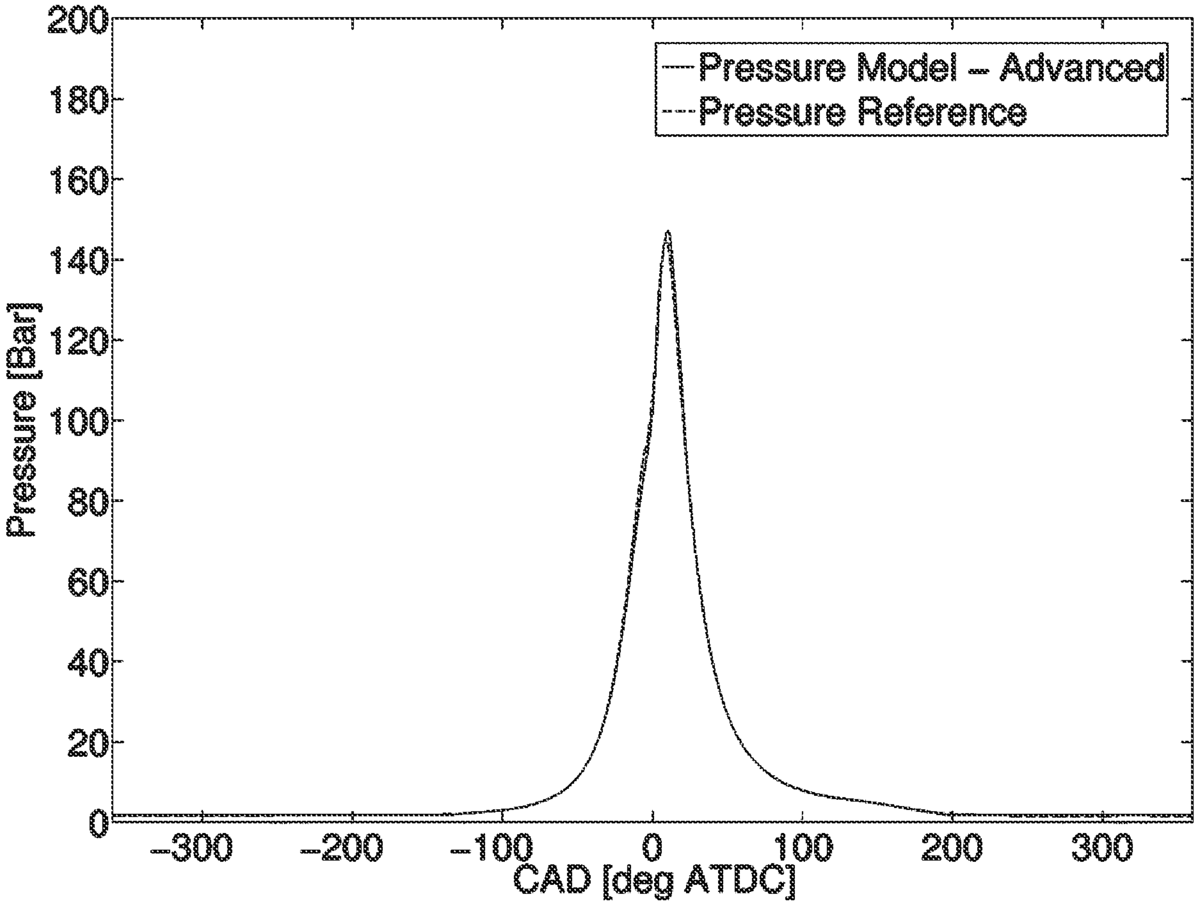
Pressure Model – Advanced
Pressure Reference
Pressure [Bar]
200
180
160
140
120
100
80
60
40
20
0
–300
–200
–100
0
100
200
300
CAD [deg ATDC]

Fig. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2016/051132

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: F02D, G01L

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6840218 B2 (SCHOLL DAVID JAMES ET AL), 7 August 2003 (2003-08-07); column 6, line 1 - line 15 --	1-14
A	US 20090301435 A1 (WEISSENBORN ERIK ET AL), 10 December 2009 (2009-12-10); abstract; paragraph [0059]; figure 1 --	1-14
A	US 8396649 B2 (HUANG JIAN), 14 June 2012 (2012-06-14); abstract; figure 1; claim 24 --	1-14
A	US 20090030593 A1 (CHAUVIN JONATHAN ET AL), 29 January 2009 (2009-01-29); abstract; figures 1,3 --	1-14

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20-01-2017	23-01-2017

Name and mailing address of the ISA/SE	Authorized officer
Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Lars Jakobsson Telephone No. + 46 8 782 28 00

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	WO 2015195032 A1 (SCANIA CV AB), 23 December 2015 (2015-12-23); page 2, line 7 - line 23; page 13, line 9 - line 22; figures 1a, 1b, 2a ,3 -- --------	1-14

International application No.
PCT/SE2016/051132

Continuation of: second sheet

International Patent Classification (IPC)

G01L 23/32 (2006.01)
F02D 35/00 (2006.01)
F02D 41/00 (2006.01)

US	6840218	B2	07/08/2003	EP	1321655 A1	25/06/2003
				US	20030145829 A1	07/08/2003
US	20090301435	A1	10/12/2009	CN	101598070 A	09/12/2009
				DE	102008002261 A1	10/12/2009
				US	7870846 B2	18/01/2011
US	8396649	B2	14/06/2012	AU	2010278627 B2	10/07/2014
				CA	2673216 C	03/05/2011
				CN	102498378 B	11/03/2015
				EP	2459980 A4	15/10/2014
				IN	1579DEN2012 A	05/06/2015
				US	20120150414 A1	14/06/2012
				WO	2011011868 A1	03/02/2011
US	20090030593	A1	29/01/2009	DE	602007002061 D1	01/10/2009
				EP	1994390 A1	26/11/2008
				FR	2898411 A1	14/09/2007
				JP	4871962 B2	08/02/2012
				JP	2009529115 A	13/08/2009
				US	7747380 B2	29/06/2010
				WO	2007101946 A1	13/09/2007
WO	2015195032	A1	23/12/2015	NONE		