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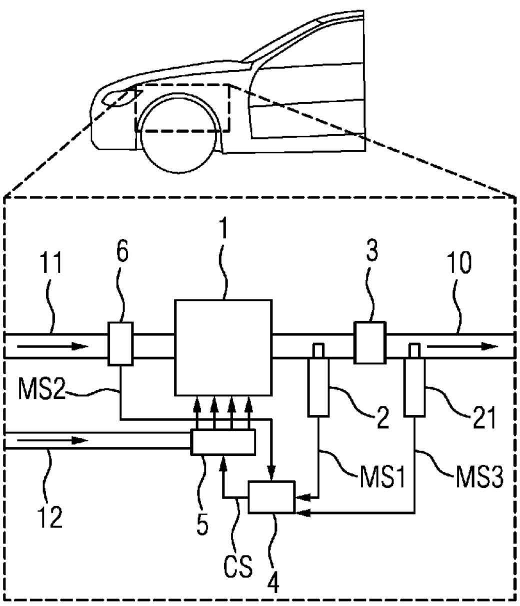
(54) Title: METHOD FOR OPERATING AN INTERNAL COMBUSTION ENGINE

FIG 1



(57) Abstract: In the method for operating an internal combustion engine (1), the internal combustion engine is connected to an exhaust gas tract (10) having an exhaust gas sensor (2) and a catalyst (3). The exhaust gas sensor is arranged upstream of the catalyst in the exhaust gas tract. A first measurement signal (MS1) of the exhaust gas sensor is characteristic of the residual oxygen content of the exhaust gas flowing past it. The method comprises a step A), in which a wanted air-fuel equivalence ratio (λ_wan) upstream of the catalyst is set and a control signal (CS) is generated and output for correspondingly controlling an actuator (5). The method comprises a step B), in which an oxygen storage state (Φ) of the catalyst is calculated using a nonlinear catalyst model taking as inputs a measured air-fuel equivalence ratio upstream (λ_{up}) of the catalyst extracted from the first

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[Continued on next page]

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measurement signal and an air mass flow ($\dot{m}_a$) through the catalyst. Furthermore, the method comprises a step C), in which the setting of the wanted air-fuel equivalence ratio and the control signal are adapted depending on the calculated oxygen storage state.

Description

Method for operating an internal combustion engine

A method for operating an internal combustion engine is specified. Furthermore, an apparatus for operating an internal combustion engine, a motor vehicle, a computer program and a computer-readable medium are specified.

One task to be solved is to specify a method for operating an internal combustion engine which allows to more accurately control the air-fuel equivalence ratio of an internal combustion engine. Further tasks to be solved are to specify an apparatus, a motor vehicle, a computer program and a computer-readable medium for performing such a method.

These objects are solved, inter alia, by the subject-matters of claims 1, 7, 8, 9 and 10. Advantageous embodiments and further developments are subject of the further dependent claims and can be further extracted from the following description and the Figures.

First, the method for operating an internal combustion engine is specified. The internal combustion engine is connected to an exhaust gas tract having an exhaust gas sensor (also called lambda sensor) and a catalyst. The exhaust gas sensor is arranged upstream of the catalyst in the exhaust gas tract. A first measurement signal of the exhaust gas sensor is characteristic of the residual oxygen content of the exhaust gas flowing past it.

The method comprises a step A), in which a wanted air-fuel equivalence ratio (also called Lambda) upstream of the catalyst is set and a control signal is generated and output for correspondingly controlling an actuator which is configured for influencing an air-fuel mixture supplied to the internal combustion engine. The method comprises a step B), in which an oxygen storage state of the catalyst is calculated using a nonlinear catalyst model taking as an input a measured air-fuel equivalence ratio upstream of the catalyst determined or extracted from the first measurement signal and as a further input an air mass flow through the catalyst. Furthermore, the method comprises a step C), in which the setting of the wanted air-fuel equivalence ratio and the control signal are adapted depending on the calculated oxygen storage state.

The steps A) to C) are preferably performed in the stated order. Particularly, the step B) is performed at a sufficient timely distance to step A) so that the setting of the wanted air-fuel equivalence ratio upstream of the catalyst from step A) is reflected in the measurement signal. The air mass flow through the catalyst is preferably also extracted or determined from one or more measurement signals, for example provided by an air mass flow sensor.

The invention is particularly based on the recognition that Lambda controllers (also called control units) control the air-fuel ratio supplied to the internal combustion engine to maintain the exhaust feed-gas in a window around stoichiometric Lambda. Conventional Lambda controllers do not use the catalyst dynamics which is dominated by the oxygen storage/release phenomenon and hence the emission control action is only possible after breakthrough is observed. Accurate residual oxygen content downstream of the catalyst is required for an effective emission control. However, usually an exhaust gas sensor downstream of the catalyst is too slow for its measurements to be used in the fast control of Lambda by the Lambda controller.

The present invention makes use of the idea that the Lambda controller performance can be improved by considering the amount of oxygen storage in the catalyst as a variable for control. In this invention, the oxygen storage state is predicted with the help of a nonlinear model. The Lambda controller can therefore implement a correction to the air-fuel ratio before the catalyst breakthrough. The catalyst can be controlled in a partly empty/filled state which compensates the future lean/rich pre-catalyst Lambda deviations, promoting effective emission reduction over a cycle. Indeed, the RDE (real drive emission) test, with the increasing complexity of the exhaust line with multiple components, requires an accurate downstream lambda prediction to monitor Lambda at various nodes for better emission control.

The method specified herein is particularly useful for a three-way catalyst (TWC). The method steps A) to C) can in particular be performed by a computer. Thus, the method is particularly a computer-implemented method.

When the method is performed, for example in a motor vehicle, a control signal is generated and output. The control signal is generated depending on the setting of the wanted air-fuel equivalence ratio. After the control signal is output, an actuator, particularly a fuel injector, is controlled with this control signal. On the basis of the control signal, the actuator influences the air-fuel mixture supplied to the internal combustion engine in order to fulfill the setting of the wanted air-fuel equivalence ratio. At the same time or afterwards, the residual oxygen content of the exhaust gas flowing through the exhaust gas sensor upstream of the catalyst is measured and a corresponding measurement signal is generated. This measurement signal, together with information about the air mass flow through the catalyst, is then used to calculate the oxygen storage state of the catalyst. With the information about the calculated oxygen storage state, the setting of the wanted air-fuel equivalence ratio and the control signal are adapted/corrected.

The wanted air-fuel equivalence ratio can be subjected to a preset forced excitation so that the internal combustion engine is operated alternatingly with a rich or lean air-fuel mixture.

According to at least one embodiment, the oxygen storage state of the catalyst is calculated from the oxygen storage state equation, which reads as follows:

$$\phi = \int_{T1}^{T2} 0.23\dot{m}_a\,\eta\big(\lambda_{up} - \lambda_{down}\big)dt.$$

In this equation, ϕ is the oxygen storage state of the catalyst, $T1$ and $T2$ are the borders of the integral. These borders are chosen such that the finite maximum and minimum storage capacities of the catalyst are taken into account. The value of 0.23 is the mass fraction of oxygen in air. $\dot{m}_a$ is the air mass flow through the catalyst. This value can be extracted from measurements. η is the efficiency of the catalyst. λ_{up} is the air-fuel equivalence ratio upstream of the catalyst. λ_{down} is the air-fuel equivalence ratio downstream of the catalyst.

In this equation, finite oxygen storage and release capacities of the catalyst are considered and hence the integral steps include the effect of the free space available in the catalyst. The limited integral is based on the principle of mass balance of oxygen in the exhaust feed-gas entering and leaving the catalyst. For solving the equation, λ_{up} determined from the measurement signal is used as an input.

According to at least one embodiment, λ_{down} is set to $N(\phi) + 1$. $N(\phi)$ is preferably set as an odd polynomial. Thus, $N(\phi)$ has the following formula:

$$N(\phi) = a_0\phi + a_1\phi^3 + a_3\phi^5 + +a_4\phi^7 \ldots,$$

wherein a_i are free parameters which can be chosen freely.
According to at least one embodiment, the parameterization of the polynomial is selected depending on whether the internal combustion engine is operated with a rich or lean air-fuel mixture. Thus, the parameters a_i are chosen differently for lean and rich phases. In other words, the asymmetry in oxygen storage and release phenomenon is accounted for by considering different set of parameters a_i and capacities for storage and release during lean and rich phases.

According to at least one embodiment, the oxygen storage equation is solved by using the explicit Euler integration method, also called explicit Euler method. Indeed, since λ_{down} is usually set to $N(\phi) + 1$, the oxygen storage equation is a differential equation, which can be rewritten to:

$$\phi(t_{n+1}) = \phi(t_n) + \int_{t_n}^{t_{n+1}} 0.23\dot{m}_a\, \eta \left(\lambda_{up} - 1 - N(\phi(t))\right) dt$$

The Euler integration method calculates:

$\phi_{n+1} = \phi_n + f(t_n, \phi_n)\Delta t$, wherein for the integration the integrand is constant.

The integral step in the oxygen storage state calculation represents the amount of oxygen stored in or released from the catalyst during the sample time step Δt. The oxygen storage state of the catalyst is estimated by adding the integral step to the previous value of the state in the time sequence.

According to at least one embodiment, for calculating the oxygen storage state the catalyst is subdivided into several sections, the sections being arranged one after the other along the streaming direction of the gas flow. The oxygen storage state is calculated from the oxygen storage state equation for each section separately, and from the obtained oxygen storage state an air-fuel equivalence ratio downstream of the section is calculated. Particularly, the air-fuel equivalence ratio downstream of a section is set to $N(\phi) + 1$, where ϕ is the oxygen storage state of that section.

According to at least one embodiment, the calculated air-fuel equivalence ratio downstream of a section is used as the air-fuel equivalence ratio upstream of the next section for calculating the oxygen storage state of the next section. In other words, the output of the calculation for one section is used as the input for the next section. For the first section, which is located most upstream, the air-fuel equivalence ratio upstream of the catalyst, which is extracted from the measurement signal of the exhaust gas sensor, is used. The output of the calculation for the last section is the final predicted oxygen storage state and the final predicted air-fuel equivalence ratio of the entire catalyst.

In other words, the oxygen storage state ϕ_i of a section i, wherein $i \geq 1$ is determined as follows:

$\phi_i = \int_{T1,i}^{T2,i} 0.23\dot{m}_a \eta(\lambda_{down,i-1} - \lambda_{down,i})dt$, wherein

$\lambda_{down,0} = \lambda_{up}$ and λ_{up} is the air-fuel equivalence ratio upstream of the catalyst, which is extracted from the measurement signal of the exhaust gas sensor.

For example, the catalyst is subdivided into two or more, preferably into three or more, sections. By this subdivision, the inhomogeneity and the spatial distribution of oxygen within the catalyst is considered, which makes the calculation more realistic and thus allows an even more efficient operation of the internal combustion engine.

For each section, the equation is preferably solved as mentioned above, using the explicit Euler integration method with feedback setting of $\lambda_{down,i}$.

Next, an apparatus for operating an internal combustion engine is specified. The apparatus is configured to perform the method for operating the internal combustion engine. The apparatus may comprise a processor for setting the wanted air-fuel equivalence ration, for calculating the oxygen storage state and for correspondingly generating the control signal. The apparatus may further comprise interfaces for outputting and receiving signals. The apparatus may be a control unit, also called Lambda controller.

Next, the motor vehicle is specified. The motor vehicle comprises an apparatus as specified herein. Furthermore, the motor vehicle comprises an internal combustion engine, an exhaust gas tract having an exhaust gas sensor and a catalyst arranged downstream of the exhaust gas sensor. The exhaust gas tract is connected to the internal combustion engine. The motor vehicle further comprises an actuator configured for influencing an air-fuel mixture supplied to the internal combustion engine. The motor vehicle is configured to perform the method specified herein.

Next, the computer program is specified. The computer program comprises instructions to cause the apparatus to execute the steps of the method specified herein.

Next, the computer-readable medium is specified. The computer-readable medium has the computer program specified herein stored thereon.

Further preferred embodiments and developments of the method for operating an internal combustion engine, of the apparatus, of the motor vehicle, of the computer program and of the computer-readable medium result from the exemplary embodiments described in the following in connection with the Figures. Equal or similar elements as well as elements of equal function are designated with the same reference signs in the Figures. The Figures and the proportions of the elements shown in the Figures are not regarded as being shown to scale. Rather, single elements can be shown exaggerated in magnitude for the sake of better presentation and/or better understanding.

In the figures:

Figure 1 shows an exemplary embodiment of a motor vehicle and, in an enlarged view, the internal combustion engine of the motor vehicle,

Figure 2 shows a flowchart of an exemplary embodiment of the method for operating an internal combustion engine,

Figures 3 and 4 show block diagrams of the nonlinear catalyst model used for the method for operating an internal combustion engine,

Figures 5 to 7 show diagrams comparing the model predictions with measured values.

In Figure 1 an exemplary embodiment of a motor vehicle is shown. The motor vehicle is an automobile. In an enlarged view, the internal combustion engine 1 of the motor vehicle is shown. The internal combustion engine 1 is connected to an air supply tract 11 and a fuel supply tract 12 through which, during operation of the motor vehicle, air and fuel are supplied to the internal combustion engine 1. Inside the air supply tract 11, an air mass flow sensor 6 is located. The amount of fuel injected into the internal combustion engine 1 is influenced and controlled by an actuator 4 in the form of a fuel injector.

The internal combustion engine 1 is further connected to an exhaust gas tract 10 through which the exhaust gas is lead away. The exhaust gas tract 10 comprises a catalyst 3, an exhaust gas sensor 2 upstream of the catalyst 3 and a further exhaust gas sensor 21 downstream of the catalyst 3. The exhaust gas sensors 2, 21 are signally connected to an apparatus 4, which is a control unit or a lambda controller. The exhaust gas sensors 2, 21 measure the residual oxygen content of the exhaust gas flowing past them. Then they generate corresponding measurement signals MS1, MS3 and send them to the apparatus 4.

The apparatus 4 is also signally connected to the air mass flow sensor 6 and during operation receives a measurement signal MS2 from the air mass flow sensor 6, which is characteristic of the air mass flow measured with the help of the air mass flow sensor 6.

Furthermore, the apparatus 4 is signally connected to the actuator 5. In operation, the apparatus 4 generates control signals CS and outputs these control signals CS to the actuator 5. On the basis of these control signals CS, the actuator 5 influences the air-fuel mixture supplied to the internal combustion engine 1.

In the present exemplary embodiment, the apparatus 4 is configured such that it generates and outputs control signal CS on the basis of a setting of a wanted air-fuel equivalence ratio λ_wan upstream of the catalyst 3. Furthermore, the apparatus 4 is configured for calculating an oxygen storage state ϕ of the catalyst 3 using a nonlinear catalyst model. Inputs for this model are the air-fuel equivalence ratio λ_{up} upstream of the catalyst 3 determined from the measurement signal MS1 of the exhaust gas sensor 2 upstream of the catalyst 3 and the air mass flow $\dot{m}_a$ through the catalyst 3 which, in the present exemplary embodiment, is extracted from the measurement signal MS3 of the air mass flow sensor 6. Depending on the calculated oxygen storage state ϕ, the apparatus 4 adapts or corrects the setting of the wanted air-fuel equivalence ratio λ_wan and correspondingly adapts or corrects the control signal CS.

Figure 2 shows a flowchart of an exemplary embodiment of the method. In a first step A), a wanted air-fuel equivalence ratio λ_wan upstream of the catalyst is set and a control signal CS is generated and output for correspondingly controlling an actuator 5 configured for influencing an air-fuel mixture supplied to the internal combustion engine 1. In a step B), and oxygen storage state ϕ of the catalyst 3 is calculated using a nonlinear catalyst model taking as inputs an air-fuel equivalence ratio λ_{up} upstream of the catalyst 3 extracted from the measurement signal MS1 and the air mass flow $\dot{m}_a$ through the catalyst 3. Then, in a step C), depending on the calculated oxygen storage state ϕ, the setting of the wanted air-fuel equivalence ratio λ_wan is adapted and correspondingly the control signal CS is adapted.

Figure 3 shows a basic block diagram of the nonlinear catalyst model. In this catalyst model, the oxygen storage state ϕ is calculated with the following oxygen storage state equation:

$$\phi = \int_{T1}^{T2} 0.23\dot{m}_a\,\eta\big(\lambda_{up} - \lambda_{down}\big)dt$$

The formula is solved with the explicit Euler integration method. The block diagram shows that input values for solving the oxygen storage state equation are the air-fuel equivalence ratio λ_{up}, also called lambda value, upstream of the catalyst 3. This value is extracted from the measurement signal MS1. Furthermore, an input value for solving the equation is the air mass flow $\dot{m}_a$ through the catalyst, which is, for example, extracted from the measurement signal MS2.The step of calculating ϕ is indicated by the first block on the left side of Figure 3.

In the next step of the nonlinear catalyst model, indicated by the middle block of Figure 3, $N(\phi)$ is calculated. $N(\phi)$ is set as a polynomial.

Finally, in a third step, indicated by the right block, λ_{down} is calculated to be $N(\phi) + 1$. This value is then used as an input to start calculation of ϕ for the next time step.

Figure 4 shows a further block diagram of the nonlinear catalyst model. This model is based on the model of Figure 3. However, in this model, the catalyst 3 is subdivided into three sections 31, 32, 33. For each section 31, 32, 33, the oxygen start state ϕ is calculated separately using the above-mentioned oxygen storage state equation. For the first section 31, the value of $\lambda_{up,31}$ is extracted from the measurement signal MS1. $\lambda_{down,31}$ is set as $\lambda_{down,31}$ from the previous time step (feedback). The output of the first section 31 is the air-fuel equivalence ratio $\lambda_{down,31}$ downstream of the first section 31. This value is used as the input value for $\lambda_{up,32}$ for the second section 32. The output value $\lambda_{down,32}$ is then used as the value for $\lambda_{up,33}$

of the third section 33. The output value $\lambda_{down,33}$ of the third section 33 is the air-fuel equivalence ratio λ_{down} of the catalyst 3.

By subdividing the catalyst 3 into three sections 31, 32, 33, the spatial distribution of oxygen within the catalyst 3 is considered so that the prediction of the model is more accurate.

As can be further seen in the upper part of Figure 4, the block diagram has a branch. In this branch, it is distinguished whether the internal combustion engine 1 is operated in a rich or lean phase. Depending on whether the internal combustion engine is operated in a rich or lean phase, the polynomial of $N(\phi) + 1$ is chosen differently. In this way, the asymmetry in oxygen storage and release is captured.

In Figure 5 the predicted oxygen storage state ϕ and the voltage measured by an exhaust gas sensor downstream of the catalyst (see exhaust gas sensor 21 in Figure 1) are compared. On the x-axis the time in seconds is shown whereas on the y-axis arbitrary units are shown.

The dashed curve with the reference sign K1 shows the value of $\lambda_{up} - 1$ extracted from the measurement signal MS1 of the exhaust gas sensor 2 upstream of the catalyst 3. From the dashed curve it can be seen that the air-fuel equivalence ratio λ_{up} upstream of the catalyst 3 is subjected to a preset forced excitation so that the internal combustion engine 1 is alternatingly operated in a rich and a lean phase. The curves with the reference signs K31, K32 and K33 show the predicted oxygen storage state ϕ obtained from the nonlinear catalyst model described above. The line with reference sign K31 shows the predicted value of ϕ for the first section 31 of the catalyst 3, the curve with the reference sign K32 shows the predicted value of ϕ for the second section 32 and the curve with the reference sign K33 shows the predicted value of ϕ for the last section 33. It can be clearly seen that the prediction of ϕ of the last section 33 is in good correlation with the curve with the reference sign K0, which is the voltage of the exhaust gas sensor downstream of the catalyst 3.

In Figure 6 the predicted values for λ_{down} obtained with the model are compared with the voltage values of the exhaust gas sensor downstream of the catalyst. The dashed curve with the reference sign S1 is λ_{up} extracted from the measurement signal MS1. The curves with the reference signs S31, S32, S33 are the predicted values for $\lambda_{down,31,32,33}$ for each section 31, 32, 33. The curve with the reference sign S0 is the measured voltage of the exhaust gas sensor downstream of the catalyst 3. Again, on the x-axis the time in seconds is shown whereas on the y-axis arbitrary units are shown.

Figure 7 shows the values for λ_{down} predicted by the nonlinear model (curve indicated by the reference signs A31, A32) compared to the values for λ_{up} determined from the measurement signal of the exhaust gas sensor upstream of the catalyst (curve indicated by reference sign A1) and the measured value of λ_{down}, measured with an exhaust gas sensor downstream of the catalyst (curve indicated by the references sign A0). In this case, the catalyst 3 was subdivided into two sections only, wherein the result of $\lambda_{down,31}$ of the first section 31 located more upstream is indicated with the curve with the reference sign A31 and the result of $\lambda_{down,32}$ of the second section located more downstream is indicated with the curve with the reference sign A32. It can be seen that the model prediction of the catalyst (curve with reference sign A32) is generally in good agreement with the curve for the measured λ_{down} (curve with reference sign A0). The large dip in curve A0 appearing in the rich phases has to do with an error in the measurement of the exhaust gas sensor downstream of the catalyst 3. The nonlinear model does not and is not foreseen to take this error into account.

The invention is not limited to the description of the exemplary embodiments. Rather, the invention comprises each new feature as well as each combination of features, particularly each combination of features of the claims, even if the feature or the combination of features itself is not explicitly given in the claims or exemplary embodiments.

Patent claims

1. Method for operating an internal combustion engine (1), wherein
- the internal combustion engine (1) is connected to an exhaust gas tract (10) having an exhaust gas sensor (2) and a catalyst (3),
- the exhaust gas sensor (2) is arranged upstream of the catalyst (3) in the exhaust gas tract (10),
- a measurement signal (MS1) of the exhaust gas sensor (2) is characteristic of the residual oxygen content of the exhaust gas flowing past it, wherein the method comprises the steps:
A) setting a wanted air-fuel equivalence ratio (λ_wan) upstream of the catalyst (3) and generating and outputting a control signal (CS) for correspondingly controlling an actuator (5) which is configured for influencing an air-fuel mixture supplied to the internal combustion engine (1),
B) calculating an oxygen storage state (ϕ) of the catalyst (3) using a nonlinear catalyst model taking as an input an air-fuel equivalence ratio (λ_{up}) upstream of the catalyst (3) determined from the measurement signal (MS1) and as a further input the air mass flow ($\dot{m}_a$) through the catalyst (3),
C) adapting the setting of the wanted air-fuel equivalence ratio (λ_wan) and adapting the control signal (CS) depending on the calculated oxygen storage state (ϕ).

2. Method according to claim 1, wherein
- the oxygen storage state (ϕ) of the catalyst (3) is calculated from the oxygen storage state equation reading as

$$\phi = \int_{T1}^{T2} 0.23\dot{m}_a \, \eta\big(\lambda_{up} - \lambda_{down}\big)dt,$$

- ϕ is the oxygen storage state,
- $T1$ and $T2$ are the borders of the integral,
- 0.23 is the mass fraction of oxygen in air,
- $\dot{m}_a$ is the air mass flow through the catalyst,
- η is the efficiency of the catalyst (3),
- λ_{up} is the measured air-fuel equivalence ratio upstream of the catalyst (3),
- λ_{down} is the air-fuel equivalence ratio downstream of the catalyst (3).

3. Method according to claim 2, wherein
- λ_{down} is set to $N(\phi) + 1$,

- $N(\phi)$ is set as an odd polynomial.

4. Method according to claim 3, wherein the parameterization of the polynomial is selected depending on whether the internal combustion engine (1) is operated with a rich or lean air-fuel mixture.

5. Method according to any of the claims 2 to 4, wherein
the oxygen storage state equation is solved by using the Euler integration method.

6. Method according to any of the claims 2 to 5, wherein,
- for calculating the oxygen storage state (ϕ), the catalyst (3) is subdivided into several sections (31, 32, 33), the sections (31, 32, 33) being arranged one after the other along the streaming direction of the gas flow,
- the oxygen storage state (ϕ) is calculated from the oxygen storage state equation separately for each section (31, 32, 33), and from the obtained oxygen storage state (ϕ) an air-fuel equivalence ratio ($\lambda_{down,31,32,33}$) downstream of the section (31, 32, 33) is calculated,
- the calculated air-fuel equivalence ratio ($\lambda_{down,31,32}$) downstream of a section (31, 32) is used as the air-fuel equivalence ratio ($\lambda_{up,32,33}$) upstream of the next section (32, 33) for calculating the oxygen storage state (ϕ) of this next section (32, 33).

7. Apparatus (4) for operating an internal combustion engine, wherein the apparatus is configured to perform the method according to one of the preceding claims.

8. Motor vehicle comprising
- an apparatus (4) according to claim 7,
- an internal combustion engine (1),
- an exhaust gas tract (10) having an exhaust gas sensor (2) and a catalyst (3) arranged downstream of the exhaust gas sensor (2), the exhaust gas tract (10) being connected to the internal combustion engine (1),
- an actuator (5) configured for influencing an air-fuel mixture supplied to the internal combustion engine (1), wherein
- the motor vehicle is configured to perform the method according to one of the claims 1 to 6.

9. A computer program comprising instructions to cause the apparatus (4) of claim 7 to execute the steps of the method of any of the claims 1 to 6.

10. A computer-readable medium having the computer program of claim 9 stored thereon.

FIG 1

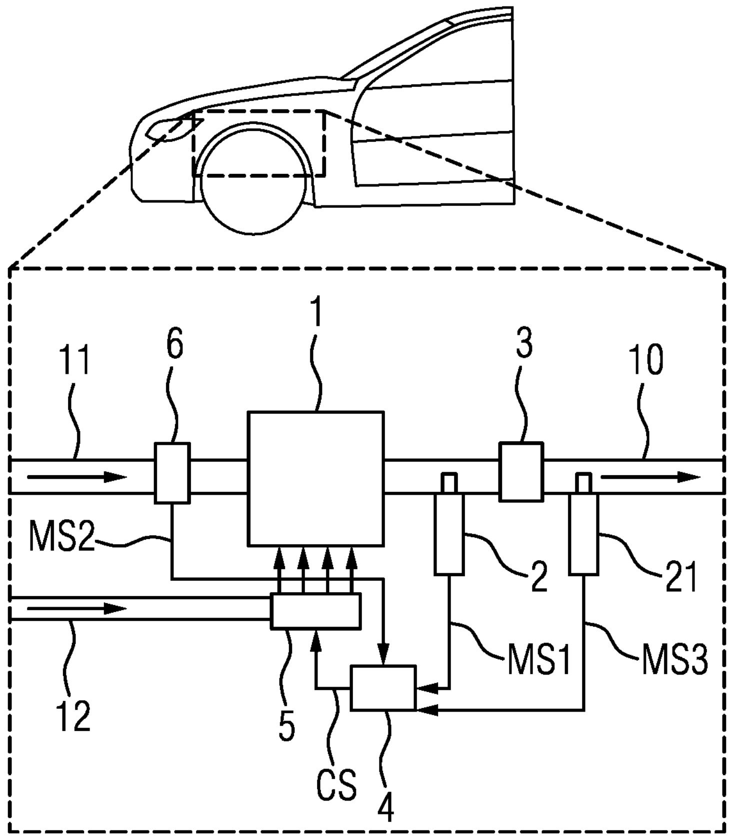


FIG 2

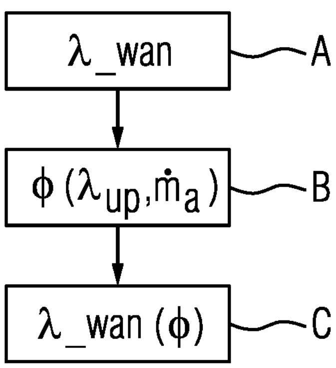


FIG 3

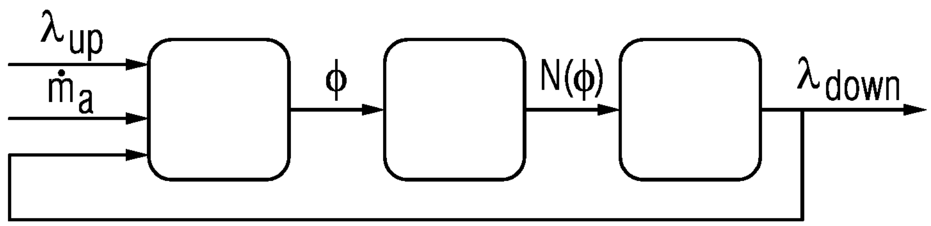

λ_{up}
$\dot{m}_a$
ϕ
$N(\phi)$
λ_{down}

FIG 4

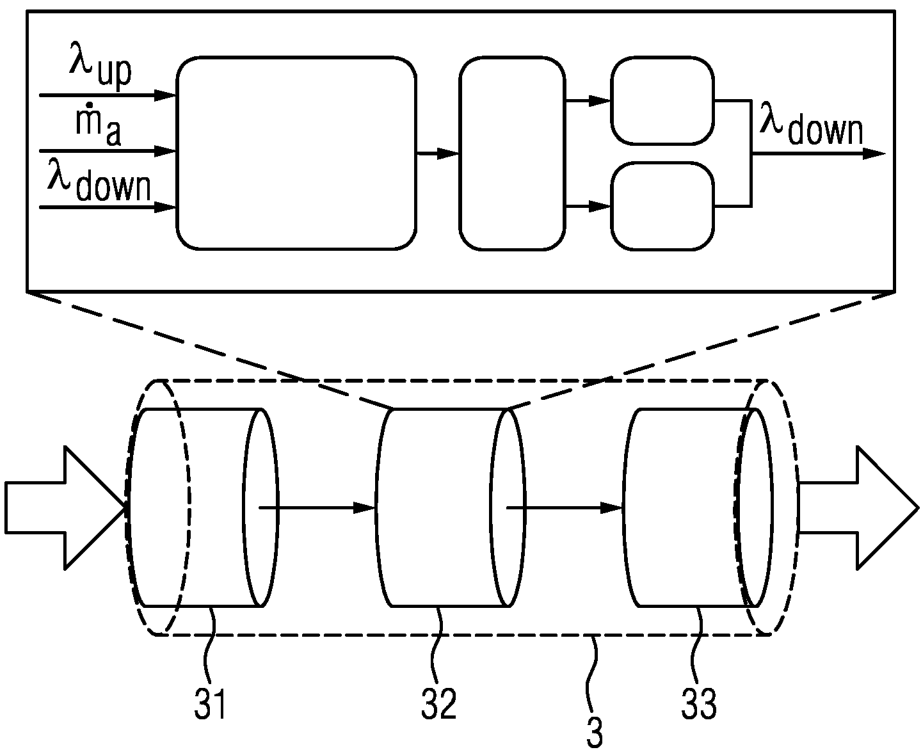
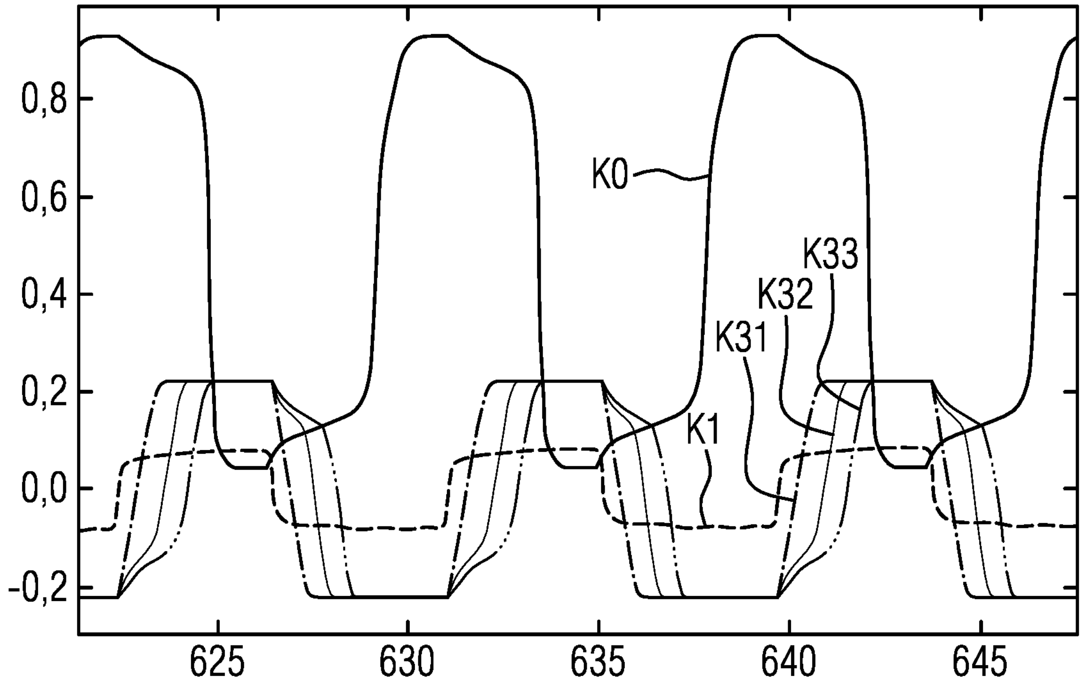

λ_{up}
$\dot{m}_a$
λ_{down}
λ_{down}
31
32
3
33

FIG 5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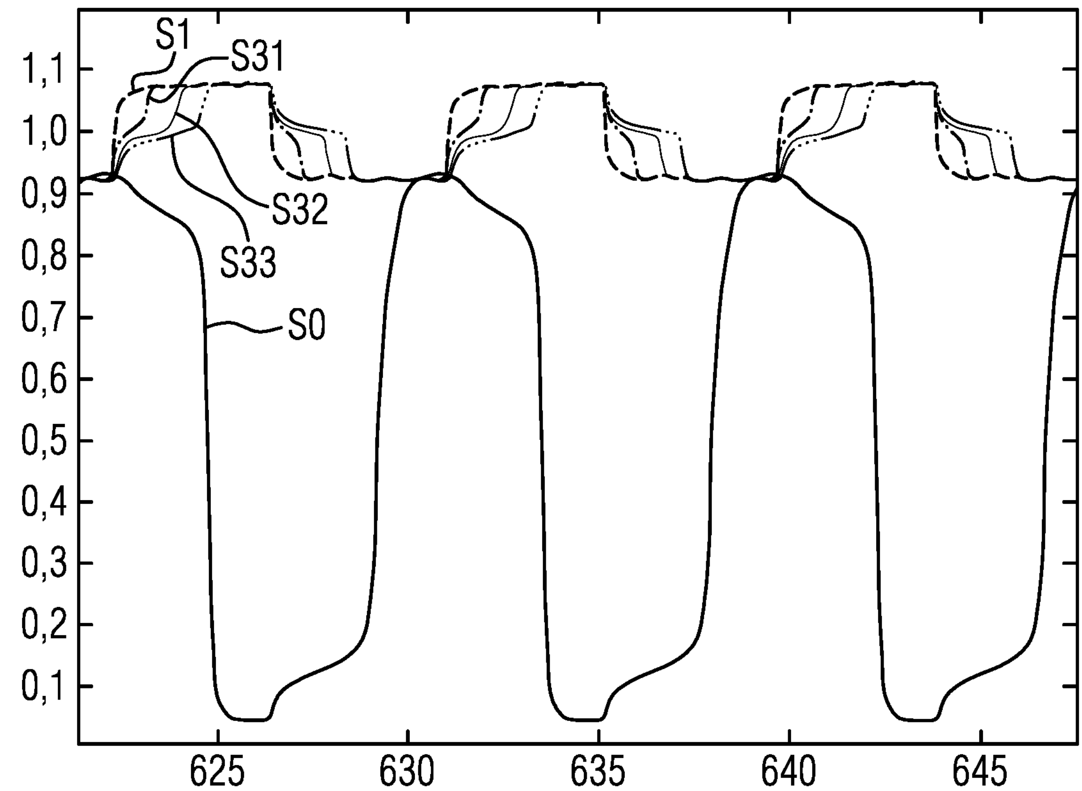
625
630
635
640
645
K0
K33
K32
K31
K1

FIG 6


1,1
1,0
0,9
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0,6
0,5
0,4
0,3
0,2
0,1
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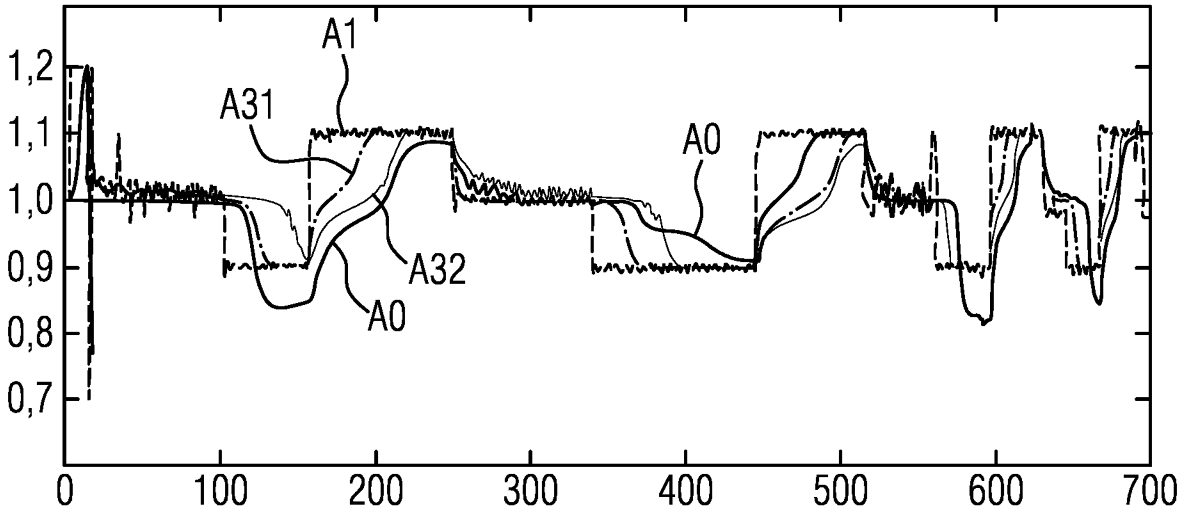
630
635
640
645
S1
S31
S32
S33
S0

FIG 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/066282

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02D41/02 F02D41/14
ADD.

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)
F02D F01N

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 10 2018 251719 A1 (BOSCH GMBH ROBERT [DE]) 2 July 2020 (2020-07-02) paragraphs [0011], [0036], [0039] - [0043], [0059], [0060]; claims 1-14; figures	1-10
X	EP 3 032 079 A2 (GEN ELECTRIC [US]) 15 June 2016 (2016-06-15) columns 24,29,33; claims 1-15; figures 1-3	1,7-10
X	US 2002/078683 A1 (KATAYAMA AKIHIRO [JP] ET AL) 27 June 2002 (2002-06-27) paragraphs [0043] - [0048], [0052], [0053], [0056], [0057], [0062], [0063], [0077], [0092]; claims 1-25; figures 2-12,13B	1,7-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 August 2021	07/09/2021

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Boye, Michael

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2021/066282

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